3D cine Atherosclerotic Plaque Images using 3D Stack of Stars Trajectory Acquisition and ciné Reconstruction Method using Retrospective Ordering and Compressed Sensing (ciné-ROCS)

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Introduction: Clinical studies using high-resolution MRI have demonstrated that carotid plaque inflammation, intraplaque hemorrhage and fibrous cap disruption are associated with an increased stroke risk (1,2). Although promising, the accuracy of these studies is limited by the small size of plaque components, patient motion, and signal to noise ratio (SNR) resulting in many nondiagnostic scans discarded as 'uninterpretable'. Cardiac induced pulsations of the carotid wall can be as great as 1mm, causing blurring of the wall morphology (3) and may cause internal stresses on plaque that contribute to plaque instability. ECG-gated acquisition, especially during diastole, can compensate for cardiac cycle induced carotid wall motion (4) but increases scan time and results in image degradation due to non-constant TR (5). To acquire data for fully sampled "Ciné" 4D images with prospective ECG-gated acquisition would substantially lengthen the scan time of already long 3D sequences. To overcome these problems due to wall and unsuppressed blood pulsation, we have developed a cardiac or respiratory ciné reconstruction method using retrospective ordering and compressed sensing (ciné-ROCS) to minimize, characterize, and eliminate these artifacts (6,7). There are other complex neck motions, however, that challenge Cartesian techniques. We hypothesize that moving to a radial based k-space trajectory (8) such as the "stack of stars" will offer reduced motion sensitivity, reduced artifacts and more robust ciné-ROCS reconstructions due to its inherent oversampling of central k-space. Therefore the goal in this study was to incorporate ciné-ROCS into a 3D Stack of Stars (SoS) sequence to demonstrate improvements in the fine detail of the T1w 3D images for reliable plaque imaging and individual plaque component identification. This new technique was compared to the 3D Cartesian ciné-ROCS method.

Methods: IRB approval was obtained and three stroke patients with symptomatic plaque were enrolled and underwent informed consent prior to imaging on a 3T MRI (Tim Trio, Siemens AG, DE). Using a T1w 3D turbo FLASH sequence capable of both Cartesian and SoS trajectories, blood suppression was realized by executing an MSDE preparation before each TFL readout train. Following the MSDE prep and a fat saturation pulse, the same radial or k_y line for all partitions was acquired with a centric k-space ordering in the slice direction in SoS or Cartesian, respectively. A custom 16-channel carotid coil was used. Measurement parameters were matched for both SoS and Cartesian acquisitions. The parameters for each trajectory were: coronal, FOV=140x140 mm^2, isotropic voxel dimension=0.73 mm^3, TE/TR=2.5/8.0 ms, 64 slices per slab, effective first moment of MSDE=1523 $mTms^2/m$. Scan time was 5 minutes with two averages. Static images were reconstructed using standard reconstruction methods. Retrospective cardiac cycle gated ciné-ROCS image reconstruction was performed using data from the standard 3D Cartesian and 3D SoS acquisitions, which were obtained in conjunction with a cardiac signal (peripheral pulse). Each data line was sorted into eight phases of the cardiac cycle. The resulting sequence of undersampled images was then reconstructed using sliding window to complete the measurement data of each bin.

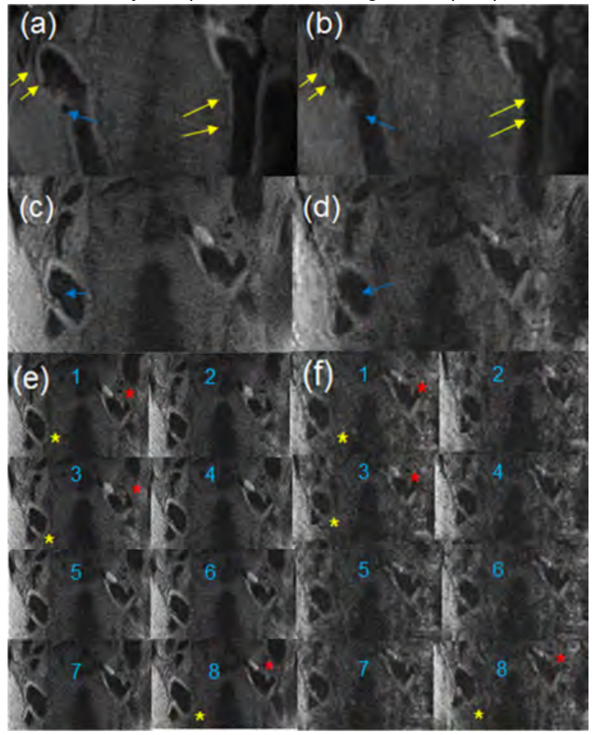

Figure1. MPR from 3D coronal volumes obtained from SoS(a) and Cartesian(b) trajectories. Corresponding coronal slice from same 3D volume as acquired with SoS(c) and Cartesian(d) trajectories and the corresponding ciné-ROCS images((e), (f)), respectively. Images were obtained from a stroke patient with intraplaque hemorrhage (image left).

Results: Figure 1 shows MPR (Multi-planar reformat) of 3D volumes acquired using the SoS (a) and Cartesian (b) trajectories for one of the subjects. A corresponding coronal slice from each 3D volume is shown in the figures (c) and (d). The wall delineation (yellow arrows) and calcification (blue arrows) were more clearly shown in the SoS acquisition than in the Cartesian. In (e) and (f), eight cardiac phases of ciné-ROCS images were reconstructed from the SoS (e) and Cartesian (f) acquisitions at the same slice location shown in (c) and (d). The ciné-ROCS reconstruction from the SoS acquisition demonstrates both improved SNR and clear plaque (red asterisks) or vessel wall movement (yellow asterisks) due to cardiac motion relative to Cartesian acquisition. As opposed to circumferential radial expansion/contraction, the SoS ciné-ROCS images show shearing plaque movements (shown in red asterisks in (e)).

Discussion: The radial trajectory yielded sharper image features with less motion sensitivity as expected. The radial k-space sampling employed with the SoS trajectory improves the performance of undersampled data reconstruction algorithms such as sliding window or compressed sensing (CS) where each sample line captures high signal energy in the k-space center and undersampling occurs in more than one direction. In this study the sliding window algorithm was used to estimate the missing data; other reconstruction algorithms such as Temporally Constrained Reconstruction (TCR)(6) or Robust Principal Analysis(9) will be evaluated. Future work will demonstrate the clinical importance of cardiac induced plaque movement and its relation to the development of symptomatic plaque.

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