4D Radial Coronary Artery Imaging at 3T within a Single Breath-hold Using Contrast Agent

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Introduction: Coronary MRA (magnetic resonance angiography) data is usually acquired during mid-diastolic period of each cardiac cycle to minimize cardiac motion related artifacts. Only a small fraction of time is utilized for data acquisition in each heartbeat (typically < 100ms). A proper trigger delay time needs to be determined to achieve optimal image quality, which varies widely among patients. Real-time imaging techniques acquire data continuously and have the potential to alleviate this problem. Previous real-time coronary MRA studies (1, 2) acquired 2D images which had limitations in delineating coronary arteries that were either torturous or moving through a 2D image plane. In this study, we used a 4D (3D cine) coronary artery imaging technique to acquire real-time image sets with 3D coverage in space within a single breath-hold. Relatively high temporal resolution and spatial resolution were achieved simultaneously with radial sampling, parallel data acquisition, and administration of an extravascular, paramagnetic contrast agent.

Method: Sequence structure: A radial sampling cine FLASH (fast low angle shot) sequence was used for this study. As shown in Figure 1, stacked 3D k-space was continuously acquired in various cardiac cine phases. The radial k-space was highly under-sampled at each phase to ensure a high temporal resolution. Complete k-space data sets were derived at each cine phase using a factor of three interleaved view-sharing scheme to achieve a high spatial resolution.

Coronary artery imaging: Volunteer studies (n = 5) were conducted using a 3.0T (Trio) Siemens whole-body scanner. Two 4-element cardiac phased array coils were used for data collection under breath-hold. Continuous dummy pulses were played out in the first heartbeat to establish a steady state. Contrast enhanced images were acquired during the first pass of contrast agent administration (Magnevist, Berlex Laboratories) with a time delay determined using a small test bolus (2 ml of contrast agent chased by 10 ml of saline solution at 2 ml/s). 30 ml of contrast agent was injected intravenously using a Medrad power injector at the same rate for contrast-enhanced 4D imaging. Imaging parameters included: TR/TE/flip angle = 4.6/2.3/21°; FOV = 200 mm; number of views per cine phase per heartbeat = 8, heartbeats per partition = 4, radial views per cine phase = 32, matrix size = 96×192 with a factor of three interleaved view sharing, number of cardiac phases = 16 - 24, number of partitions = 6 (interpolated to 12), slice thickness = 3 mm (interpolated to 1.5 mm), in-plane resolution and temporal resolution = 1.0×1.0 mm^2 and 37 ms.

Image reconstruction and reformatting: Images were reconstructed on a personal computer using Matlab (Mathworks, Natic, MA). Sensitivity encoding (SENSE) with rescaled matrix was used with sliding window reconstruction (3). The conjugate-gradient (CG) was modified to incorporate a rescaled matrix method to accelerate the computational speed as well as to reduce noise amplification. 3D maximum-intensity-projection (MIP) was performed in each phase to depict the dynamic motion of coronary arteries from systole to diastole. Multiple MIP images from mid-diastolic period were averaged to improve the signal-to-noise ratio (SNR) of coronary arteries.

Results: Coronary artery images were successfully acquired from all subjects without complications. Figure 2 demonstrates the capability of this technique in depicting coronary arteries throughout all cardiac phases. The left anterior descending artery (LAD) image from this subject shows that the LAD is moving in-and-out of the 6th slice in different phases of the cardiac cycle (upper row). By performing 3D MIP, the artery is visible in each phase (lower row) but the depiction is best in phases 16 to 19. Images in Figure 3 from another subject demonstrate that, by averaging multiple MIP images, the signal-to-noise ratio (SNR) is substantially improved as compared to single phase image.

Discussion: The proposed 4D coronary MRA technique with contrast agent administration is capable of imaging coronary arteries through the cardiac cycle, thus eliminating the need for accurate determination of trigger delay time and data acquisition duration. 4D images can be examined retrospectively and those acquired during mid-diastolic period can be merged to improve SNR. Radial sampling, parallel imaging, and sliding window reconstruction allow high temporal resolution. Contrast media improves SNR and eliminates the need for fat suppression using pre-pulses because the myocardium and fat are effectively suppressed using high flip-angle FLASH acquisition. This approach provides extensive flexibility in coronary imaging and warrants further investigation.

References:

1. Hardy CJ. et. al. MRM 44: 940-946 2. Nayak KS. et. al. MRM 46: 430-435 3. Oesterle C. et. al. JMRI 10 : 84 - 92

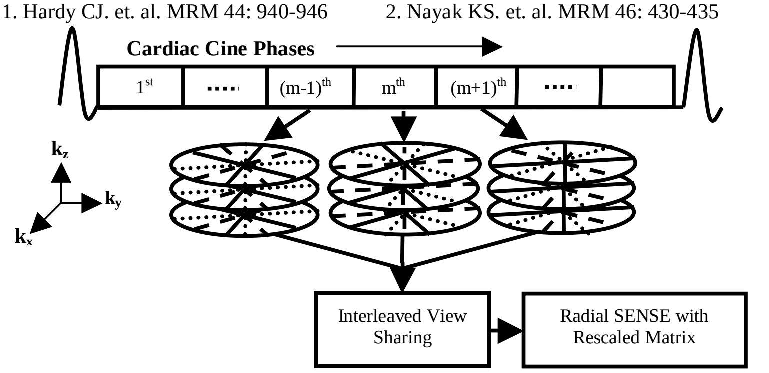

Figure 1. Schematic of the 4D radial k-space acquisition and image reconstruction using a factor of three interleaved view sharing and radial SENSE with rescaled matrix.

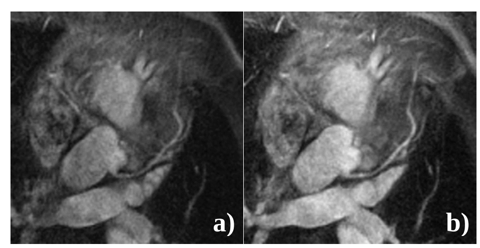

Figure 3. SNR is improved by averaging multiple MIP images of mid-diastolic region: a). MIP image from the 14th phase. b). Average of the MIP images from the 14th phase to the 17th phase.

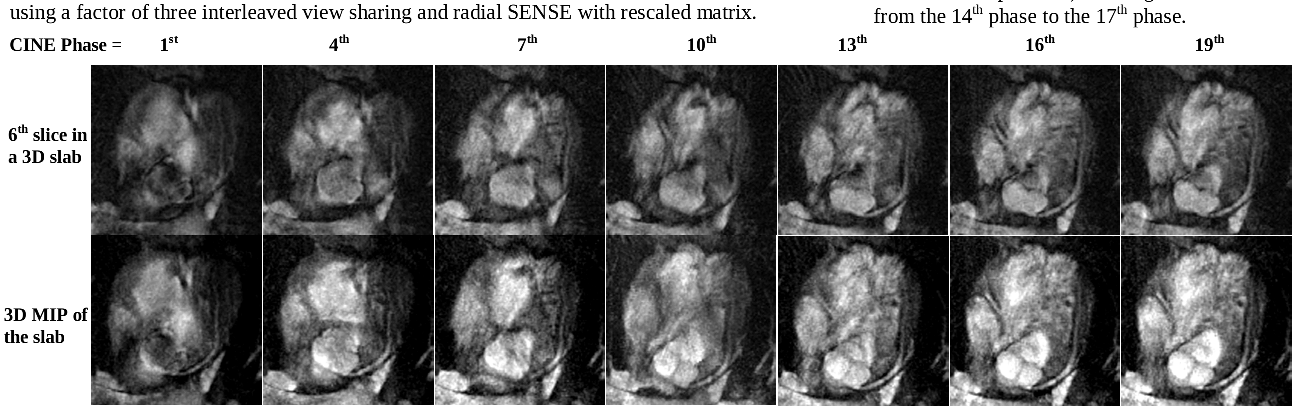

Figure 2. Depiction of the LAD in different cardiac phases: images in the upper row show the 6th slice of a 3D slab; corresponding 3D MIP image of each slab is illustrated in the lower row. Note the LAD is visible in all MIP phases but the depiction is best in phases 16 to 19.