4D Radial Coronary Artery Imaging Within a Single Breath-hold: Cine Angiography with Phase Sensitive Fat Suppression (CAPS)

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Introduction: Coronary artery data acquisition using steady state free precession (SSFP) is typically performed in a single frame during cardiac mid-diastole. To avoid cardiac motion, trigger delay and data acquisition window need to be determined accurately. In addition, data is acquired while signal approaches steady state, yielding artifacts from SSFP transient response. Continuous data acquisition and time-resolved image reconstruction during the cardiac cycle may alleviate these problems. In this work, we propose a four-dimensional (4D) coronary artery imaging technique, cine angiography with phase sensitive fat suppression (CAPS). Parallel imaging will be used to improve temporal and spatial resolution

Theory and Methods: A schematic of the CAPS technique is depicted in Fig. 1. In-plane k-space, k_x-k_y, is acquired using radial sampling, while k_z is acquired using conventional Fourier phase encoding. To increase temporal resolution, radial k-space is highly under-sampled at each cine phase, and then combined using a factor of two interleaved view sharing with a sliding window. The interleaved k-space undergoes the following two processes: 1) self-calibrating radial sensitivity encoded (SENSE) reconstruction with rescaled matrix to reduce streak artifact and noise from under-sampling radial k-space, and 2) conventional gridding reconstruction (1) to generate a water mask image (composed of ones for water voxel and zeros for fat voxel) using the phase image based on the fact that water and fat are out-of-phase in SSFP within a specific range of TR (>2.5ms and <7.1ms) (2). The image reconstructed by SENSE is multiplied by water mask, yielding a final fat suppressed image.

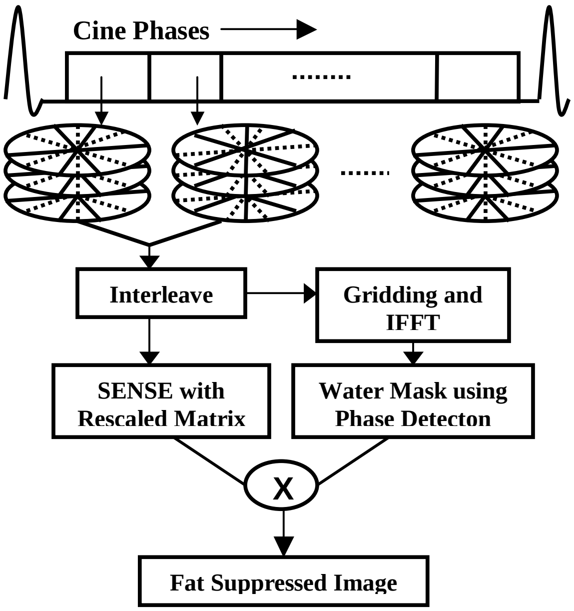

Fig.1. A schematic of the CAPS data acquisition and image reconstruction

Conventional radial SENSE reconstruction (3) employs gridding with conjugate-gradient (CG) iteration. However, forward and reverse gridding between Cartesian and radial k-spaces with iterations is computationally expensive. In this work, we use a rescaled matrix method (4) instead of gridding. All operations are performed in a rescaled rectilinear grid (rescaling factor=4), speeding up image reconstruction. In generating a water mask after gridding reconstruction, it is necessary to select a particular coil image where a region-of-interest (ROI) has relatively uniform intensity as well as slow phase variation. A phase correction (2) is applied, and then water and fat mask are reconstructed based on the sign of the real part of image.

To investigate the feasibility of the CAPS technique, left anterior descending (LAD) artery data were acquired in three volunteers, using the proposed data acquisition scheme in a single breath-hold. No spectrally selective fat saturation pulse was applied. Acquisitions were preceded by α/2 radio frequency (RF) preparation pulse (α=RF flip angle for data acquisition) and dummy pulses in the 1st heartbeat (HB) to establish steady state. The imaging parameters were: TR/TE/α=4.0ms/2.0ms/50°, FOV=200x200mm^2, slice thickness=3.0mm (interpolated to be 1.5mm), 12 views/cine phase/ HB, 17 cine phases, 6 partitions (interpolated to be 12), and 4 HB/partition.

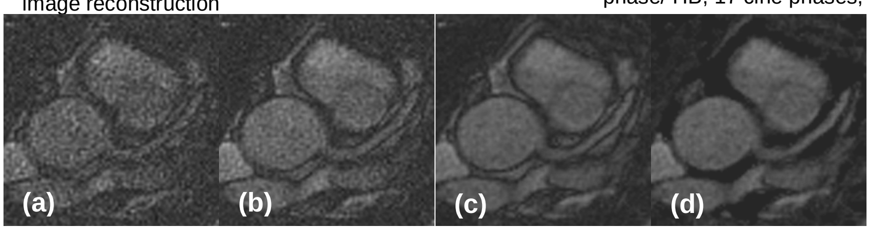

Fig. 2. LAD images generated by: (a) gridding reconstruction using one phase data (matrix=48x192), (b) girding reconstruction using an interleaved data (matrix=96x192), (c) SENSE with rescaled matrix after four iterations using the interleaved data, (d) SENSE with rescaled matrix and fat suppression with phase detection.

Result: Conventional gridding reconstruction using highly under-sampled data in a cine phase yields severe streak artifacts and noise (Fig. 1a). Interleaving with a factor of two reduces the artifacts, but noise still impedes vessel depiction (Fig. 2b). SENSE with rescaled matrix yields the image free of artifact and amplified noise (Fig. 2c). Fat signal is completely suppressed using the phase detection (Fig. 2d). Coronary artery motion is demonstrated, using 2D images of a slice (Fig. 3a-e) and 3D maximum intensity projection (MIP) images (Fig. 3f-j) for comparison. Compared to 2D images in a slice, a large part of vessel is traced over the entire cardiac cycle using 3D MIP.

Cine Phase = 4th　　7th　　11th　　13th　　16th

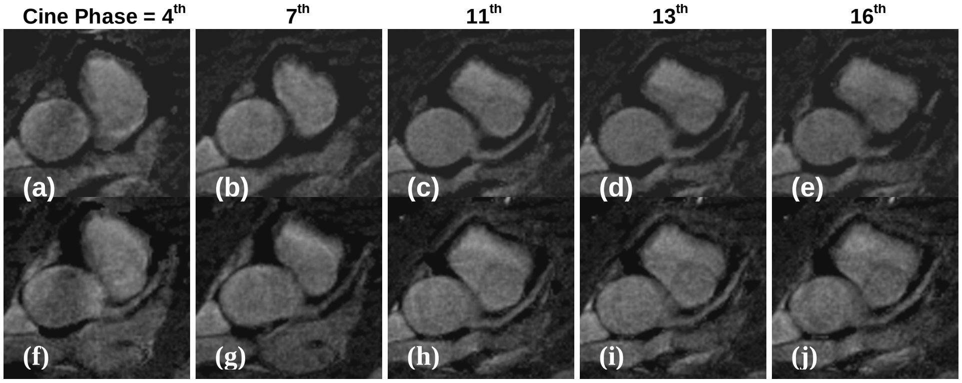

Fig. 3. LAD dynamic motion in cine phases (1.0x1.0mm^2 spatial resolution and 48ms temporal resolution) for: (a-e) a central slice in a 3D slab, and (f-j) 3D MIP images

Discussion: The proposed CAPS technique has been successfully performed with breath-hold, achieving high spatial and temporal resolution simultaneously. Compared to conventional single frame acquisition, it generates more T2-weighting, increasing the contrast between blood and myocardial tissue. It also provides the flexibility of choosing imaging frames that best delineate vessels, and allows signal enhancement by averaging. The technique warrants further technical improvements and evaluation

References: 1. Rasche V, et al. IEEE Trans. Med. Imaging, 1999, 18(5): 385-392, 2. Hargreaves BA, et al. MRM 2003, 50(1): 210-213, 3. Pruessmann KP, et al. MRM, 2001, 46(4): 638-651, 4. Oesterle C, et al. JMRI, 1999, 10(1): 84-92