Cardiac Phase Resolved 3D Coronary MRA using Balanced SSFP and a Spiral Trajectory

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INTRODUCTION

Acquiring data throughout the cardiac cycle for coronary MRA is highly desirable because the optimal rest period varies from patient to patient, and may vary within a patient from scan to scan with changes in heart rate. We achieve cardiac phase resolved 3D coronary imaging within a single breath hold by combining the high SNR efficiency of balanced-SSFP with the rapid acquisition of a spiral trajectory [1] and by employing intermittent fat saturation to suppress cardiac fat.

A sliding window reconstruction is used to produce images throughout the entire cardiac cycle, allowing retrospective selection of the optimal trigger delay [2]. Because a sliding window ideally requires that data from the center of k-space be acquired evenly throughout the entire cardiac cycle, we implement a shifting fat saturation scheme to allow the center of k-space to be consistently acquired shortly after fat saturation, while distributing the dead-time associated with the fat saturation pulses evenly throughout the cardiac cycle.

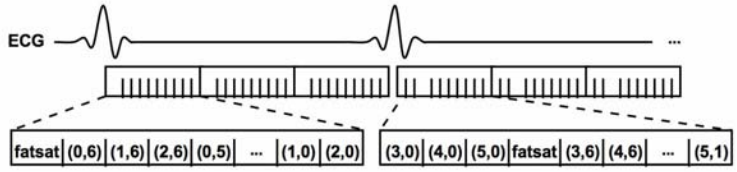

Fig 1. View ordering for a shifting fat sat coronary artery scan. Indices are (interleaf, kz).

METHODS

A variable density 3D stack of spirals trajectory [3][4] that oversamples the k-space origin by a factor of 3 to reduce susceptibility to motion artifacts while undersampling the periphery of k-space by a factor of 0.67 to reduce repetition time was developed. Fractional z phase encoding was performed, acquiring 7 out of 12 z phase encodes. Fat suppression was performed using an $\alpha/2$ tip-up pulse, a spectrally selective pulse followed by crushers, and an $\alpha/2$ restore pulse [5]. View ordering is illustrated in Fig 1. In all cardiac phases, the central z phase encode is acquired shortly after the fat saturation pulses are played out, and the fat sat timing was shifted from heartbeat to heartbeat. As a result, the central phase encode as well as all other phase encodes are acquired evenly throughout the cardiac cycle, and there are no points in the cardiac cycle during which data is completely absent. The distribution of k-space acquisition is shown in Fig 2.

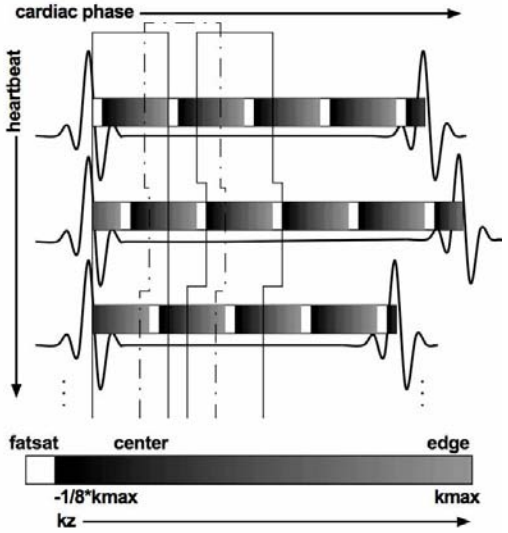

Fig 2. Distribution of data acquisition across heartbeats and sliding window reconstruction.

A standard regridding spiral reconstruction was performed in-plane. Homodyne processing using 5 iterations was performed along the z direction to reduce artifacts between slices [6]. A sliding window reconstruction yielded 16 cardiac phases and accounted for variations in heart rate in the following manner: data from each heartbeat were partitioned into 16 overlapping sets spaced evenly within that heartbeat, as illustrated in Fig 2. Data from within corresponding sets across heartbeats were combined to yield the k-space dataset for each cardiac phase.

Breath hold scans were performed on a GE Excite 11 1.5T scanner using a 4 channel cardiac coil, 26cm FOV, 192x192 matrix, maximum gradient strength 33mT/m, maximum slew rate 120T/m/sec. Sequence parameters were TR/TE/flip: 4.2-4.3ms/1ms/45°, 250KHz RBW, 72 spiral leaves, 3 leaves per heartbeat, 1.7ms readout. Each breath hold was 25 heartbeats in duration: 1 heartbeat to establish steady state, and 24 heartbeats for data acquisition. Peripheral finger gating was used to monitor the heartbeat.

RESULTS

Coronary artery scans were performed on 8 healthy volunteers. In all exams, the RCA and LAD were successfully visualized. The coronary arteries are clearly visible in phases corresponding approximately to mid-diastole, and in volunteers with a low heart rate, are visible in other phases as well. Fig 3 shows a segment of the LAD throughout the cardiac cycle in a normal volunteer. The artery is clearly depicted in the diastolic images (t=50%), but suffers from blurring throughout the remainder of the cardiac cycle.

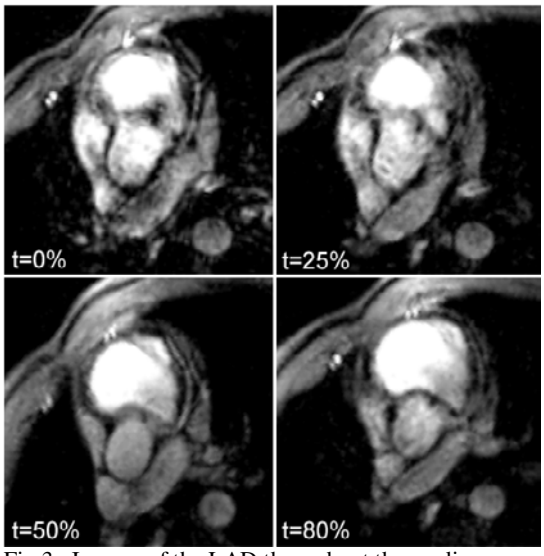

Fig 3. Images of the LAD throughout the cardiac cycle. Percentages are percentage of time from one peripheral trigger to the next.

DISCUSSION

The feasibility of a fat suppressed 3D spiral SSFP sequence for cardiac phase resolved coronary artery imaging was demonstrated. Future work will focus on parallel and temporal prior based acceleration techniques to improve temporal resolution and reduce motion artifacts during systole, enabling clearer visualization of the coronary arteries throughout the entire cardiac cycle.

REFERENCES

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