Compensating for Beat-to-Beat Variation in Coronary Motion Improves Image Quality in Coronary MR

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Introduction

Robust imaging of the coronary arteries is challenging due to the complex motion of these arteries induced by both cardiac and respiratory motion [1]. Many state of the art methods [2,3] work reasonably well in healthy volunteers, but there have been few techniques published that have been shown to work well in larger patient populations [4]. One factor may be that these approaches make a simple assumption that diaphragm motion and/or bulk cardiac motion is well correlated with the motion of the coronary arteries [5,6]. Recent efforts in making patient specific motion measurements as a prescan have improved image quality [7,8]. However, these approaches suffer from the disadvantage that the motion model built initially is not updated during the acquisition to take into account variability both in respiratory and cardiac cycles.

We propose a method to measure coronary motion directly on each heartbeat. We rely on *a priori* knowledge of the primary direction of motion of each of the 3 major coronary arteries with respect to the heart orientation. In this coordinate system, the proximal LAD moves primarily in plane in a short-axis view, while the LCX and RCA move in plane primarily in the x-y plane in a 4-chamber view [9]. The z-motion of the LAD can also be used to correct bulk heart motion derived from the 4-chamber view. Figure 1 shows the approach--the motion of the coronary arteries can be tracked using real-time imaging (image-based navigators) in specific orientations (short axis and 4-chamber views) which can then be used to predict the acquisition window and coronary location for high resolution imaging with slice correction.

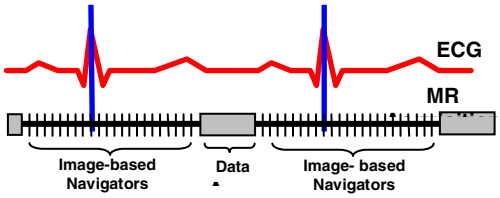


Figure 1: *Basic sequence-timing diagram involving Image-based navigators to track the motion of the coronary arteries*

As a step towards this goal of comprehensive real-time beat-by-beat motion correction, our aim in this study was to determine the impact of cardiac motion variability on coronary imaging. Our approach was to use actual coronary motion extracted from human images as input to an MR simulation of synthetic coronary arteries to test the effect of acquisition methods on image quality. With respiratory motion removed, we hypothesized that adaptive acquisition window selection for each heartbeat would provide better cardiac motion compensation than a fixed trigger delay.

Methods

***MR Acquisition*:** We acquired real time TrueFISP images in the short axis and 4-chamber views as well as coronal views in 5 volunteers with the following parameters: TR/TE/FL=1.7-2.7/0.85-1.35/50-55, GRAPPA accel=2, in plane resolution=1.5-2.4mm, slice thickness=6-10mm, 15-20 frames/sec for a total of 128-640 frames during free breathing on a 1.5T scanner (Espree, Siemens).

***Tracking and Extraction of Coronary Motion*:** In the real-time images, the fat filled grooves where the coronary arteries sit are used as tracking targets for the coronary arteries (Figure 2). The tracking algorithm we developed uses a variation of normalized cross-correlaton with multiple templates and weighted template updating. The tracked motion data is then filtered using Savitzky-Golay and Gaussian filters to remove noise. This can be done in real-time by integrating estimation filters to the output of the tracking algorithm. The tracking algorithm has accuracy of one pixel, and has been validated against manual tracking.

Figure 2: These images show the tracked LAD and LCX grooves respectively in RT images

MR Simulation: A 2D segmented gradient echo imaging sequence was simulated (MATLAB) with 1mm in plane resolution (assuming T1 fat 260ms,blood 100ms (in-flow), myocardium 870ms, TE/TR/FL 8/15/20). The synthetic image contained a representative coronary artery (4 mm diameter). Respiratory motion was first removed from the coronary trajectories by filtering out the low frequency respiratory component of the motion to reduce the analysis to cardiac motion only. For each of the 5 subjects, the coronary motion data obtained from the tracking algorithm was fed into the simulation and the acquisition was adjusted for the determined position of the coronary artery. A fixed trigger delay, determined from locating the minimal velocity timepoint in diastole was used to approximate the standard approach to coronary imaging. To test the hypothesis that variable delays improve image quality, we also tested use of adaptive trigger delays by determining the period of minimum velocity in each heartbeat. Acquisition window widths of 65ms, 100ms, 150ms and 200ms were tested for each subject in each of the coronal, short axis and four-chamber views. CNR of the coronary compared to background 'myocardium', and SNR of the coronary were computed in each case.

Results

An example of the results for the fixed delay and adaptive delay is shown in Figure 3. The ghosting due to motion is reduced in the adaptive delay as compared to the fixed delay, especially for longer acquisition windows. Over all subjects, both CNR and SNR were greater in the adaptive delay case than in the fixed delay cases (Figure 4a and 4b).

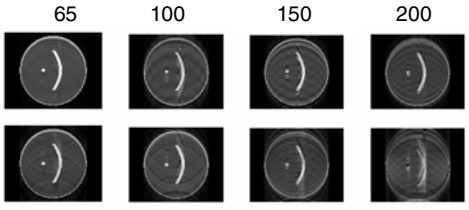
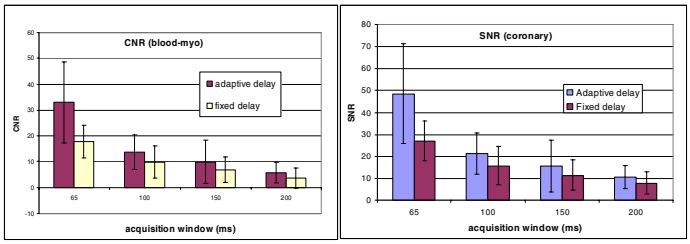


Figure 3. Comparison of adaptive (top) and fixed (bottom) delays as function of acquisition window.



Figures 4a (left) and 4b (right). CNR/SNR adaptive and fixed delays.

Discussion and Conclusions

The results of this simulation study using human coronary motion data, indicate that adaptive trigger delays for each heartbeat may improve overall motion compensation over fixed delays especially in cases where heart rate variability is high. Future work will be to integrate real time coronary tracking into the acquisition to further evaluate this approach.

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