Direct Respiratory Tracking and Motion Correction for Free-Breathing Whole-Heart Coronary Angiography

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Introduction Free-breathing MR Coronary Angiography sequences must handle the respiratory motion in order to prevent artifacts and blurring. Typical approaches include estimating respiratory motion using pencil-beam navigators, and then gating by only accepting the acquisitions whose navigators fall within a prescribed respiratory window. Residual motion can be mitigated by using experimentally determined correction factors [1] or by creating patient-specific models [2]. However, the success of such schemes rely heavily on the placement of the 1D pencil-beams. Very accurate direct measurements of the location of the heart would allow better correction, and allow the use of larger respiratory windows, increasing the acquisition duty cycle. This has the potential to reduce scan times, increase resolution, and increase SNR.

Methods We have developed a pulse sequence which acquires a low-resolution (3 mm x 3 mm) sagittal image covering the left ventricle once per heartbeat. This image is acquired with 11 spiral interleaves (readout time = 3 ms, TR = 4.8 ms). As shown in Fig. 1, once the cardiac trigger is observed, we catalyze the desired sagittal slice into a balanced SSFP steady-state with a 12-TR raised-cosine flip angle ramp up to 60°. We acquire several passes of the image, and reconstruct with a sliding window. We then select the image with the minimum amount of motion between frames, which corresponds to the systolic rest period. Catalyzing out of the steady state with another 12-TR raised-cosine flip angle ramp down returns the magnetization almost perfectly to the longitudinal axis so that there is minimal effect on the 3D imaging sequence.

A cross-correlation algorithm over a region of interest, followed by an interpolating peak-finding technique is used to determine the S-I and A-P displacements with sub-millimeter accuracy. The displacements are then temporally interpolated between heartbeats in order to determine the position of the heart corresponding to each 3D readout location.

A 3D Cones [3] trajectory with a resolution of 1.1 x 1.1 x 1.5 mm^3 is used in an Alternating-TR (ATR) fat suppressed balanced SSFP pulse sequence [4] to acquire the 3D dataset. Every acquired interleaf was corrected by applying linear phase in the S-I and A-P directions corresponding to the estimated displacement. No gating was performed (that is, data from all heartbeats were used.) A total of 480 heartbeats were required to obtain a temporal resolution of 100 ms.

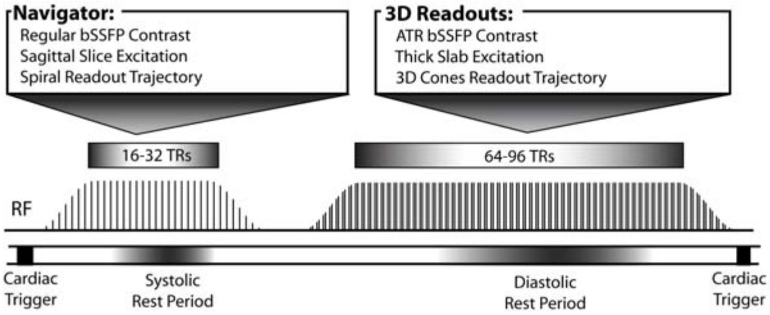

Fig. 1: *Two different steady states are entered and exited during each heartbeat. A thin slice is excited during the systolic rest period and a thick slab is excited during the diastolic rest period.*

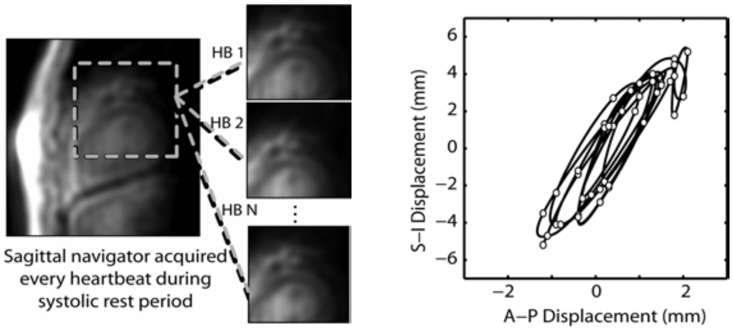

Fig. 2: *Detection of motion within a region of interest of the low-resolution navigator (left) can be performed using cross-correlation. Respiratory position in both the S-I and A-P directions (right) can be determined. Temporal interpolation between heartbeats gives an estimate of the position during each 3D readout.*

Results Figure 2 shows sample frames of the sagittal navigator as well as the estimated and interpolated displacements. Figure 3 shows the results of correcting for respiratory motion using this direct-measurement technique.

Discussion The method is very successful in correcting for respiratory motion in the proximal vessels. Objects which do not move in the same direction as the heart (such as the spinal cord and chest wall) are blurred but do not contribute significant ghosting artifact because of the properties of the 3D Cones trajectory. Using multiple regions of interest could be used in the future to support an affine motion model and might give a more complete model of the motion and improve the performance of the technique for the distal vessels. This technique does not account for motion in the L-R direction, however, this does not seem to adversely affect the image quality. As we progress to higher and higher resolutions for the 3D acquisitions, this technique may begin to break down, and some gating may become neccesary.

Conclusion By measuring the motion of the heart directly using a 2D image as a navigator, we are able to correct for substantial respiratory motion, and greatly increase the acquisition duty cycle.

Fig. 3: *Applying linear phase corresponding to the measured displacement for each 3D readout significantly increases the sharpness of the left (above) and right (below) coronary trees. No respiratory gating was performed in these examples.*

References [1] Spuentrup et al, Invest Radiol. 2002; 37(11):632-6. [2] Nehrke et al, MRM 2005; 54(5):1130-8. [3] Gurney et al, MRM 2006; 55(3):575-82. [4] Leupold et al, MRM 2006; 55(3):557-65.