Three-Dimensional Image-based Navigator for 3D MR Coronary Angiography

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Introduction: Many respiratory motion compensation techniques have been proposed to correct for the respiratory-induced heart motion in cardiac MRI [1]. A right-hemidiaphragmatic navigator (NAV) is the most commonly used method that monitors the respiratory motion of the right-diaphragm along the superior-inferior (SI) direction with acceptance during a narrow gating window [2]. Recently, a two-dimensional (2D) image-based NAV has been presented to compensate for the respiratory motion of the heart along the SI and right-left (RL) directions, and to increase the size of the gating window [3]. In addition to the SI and RL motions, respiratory motion may also occur along the anterior-posterior (AP) direction [4, 5, 6]. In this study, we sought to develop and evaluate a 3D image-based NAV (3D-NAV) to estimate the respiratory motion along the three-directions to increase gating efficiency and improve image quality. Experiments using phantom and human studies were performed to investigate the proposed method.

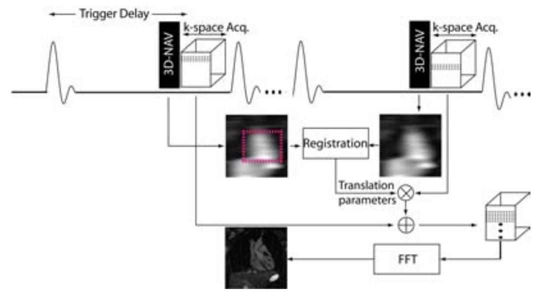

Fig.1: *Schematic diagram of the proposed motion compensation method (3D-NAV).*

Material and Method: A schematic diagram of the proposed method is shown in Fig. 1. Thirteen startup pulses of a balanced SSFP 3D MR coronary angiography sequence were modified to acquire a low resolution 3D-NAV at each cardiac cycle immediately before the acquisition of segmented *k*-space data. Gradients with a high to low profile-order were included in the startup pulse sequence to perform phase encoding in the slice and phase-encode directions. The 3D-NAV was then measured in the coronal orientation with frequency encoding in the SI direction. The spatial and temporal resolution of the 3D-NAV were approximately 1(SI)×56(RL)×18(AP) mm^3 and 60 ms, respectively. The 3D-NAVs were automatically segmented to extract the heart and registered to the first acquired 3D-NAV to estimate the relative bulk translational SI, AP, and RL motions. The estimated motions were used to retrospectively correct the phase of the subsequently acquired *k*-space data. To demonstrate the feasibility of the 3D-NAV, phantom and human studies were performed on a 1.5T CMR scanner (Philips Achieva) using the whole-heart 3D SSFP MR coronary angiography sequence with the following imaging parameters: FOV = 280×280×90 mm^3; voxel size = 1×1-2×1-2 mm^3; TR/TE/α = 4.6/2.3/70° and half-Fourier acquisition with a factor of 0.625. A body-coil and a 32 element cardiac coil array were used for the phantom and human studies, respectively. During the phantom experiment, scan was paused and the phantom was moved to create motion along three-directions. The motion was estimated using the 3D-NAV and corrected in the *k*-space data. The human study was performed on 5 healthy adult subjects (4 males, 30±7 years) using the same MR coronary angiography sequence. The 3D-NAV was again used to retrospectively correct the respiratory-induced heart motion. A conventional MR coronary angiography image dataset (reference) was also acquired by gating and tracking the respiratory motion using the right-hemidiaphragmatic NAV with a 7mm gating window and 0.6 tracking factor. The reference, motion-corrupted, and motion-corrected images were scored by two blinded expert readers (1-poor, 4-excellent). Normalized vessel sharpness was calculated using Soap-Bubble [7] and a signed-rank test was used for comparison.

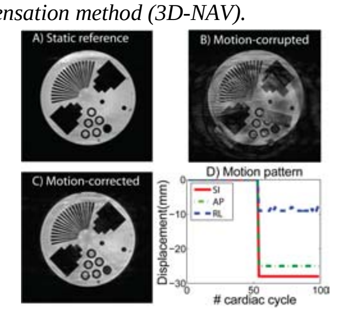

Fig.2: *Performance of the 3D-NAV on the estimation and correction of a 3D motion in the phantom study.*

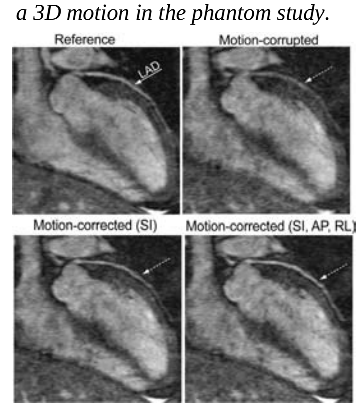

Fig.3: *Reformatted left coronary artery images acquired from a healthy female subject.*

Results and Discussion: Fig. 2 shows the performance of the 3D-NAV in estimating and correcting the 3D motion in the phantom study. As shown, the motion-corrected image is very similar to the reference image. Fig. 3 and 4 display the efficacy of the 3D-NAV in two healthy subjects. As shown, the quality of motion-corrected images is further improved by correcting the motion along the three directions. The vessel sharpness and image scores for the reference and motion-corrected images along the three-directions were similar (Table 1) but with improved respiratory gating efficiency for the 3D-NAV (100% *vs.* 57±13%). The mean magnitude of estimated motion along the SI, AP, and RL directions was 3.7±2.7, 2.3±1.9, and 1.9±0.8 mm.

Method	Vessel sharpness		Visual grading	
	RCA	LAD	RCA	LAD
Reference	0.46±0.09	0.50±0.07	3.60±0.52	3.60±0.52
3D-NAV	0.50±0.01	0.54±0.03	3.60±0.52	3.60±0.52
corrupted	0.39±0.24	0.33±0.19	3.10±0.57	2.80±0.79

Table1: *Normalized vessel sharpness and visual garading.*

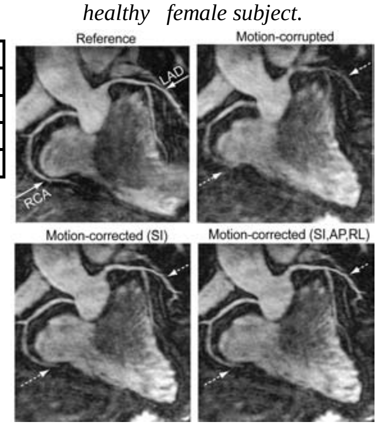

Fig.4: *Reformatted left and right coronary artery images acquired from a healthy male subject.*

Conclusions: A novel 3D-NAV for 3D MR coronary angiography is presented. This technique allows for the correction of respiratory-induced heart motion along the SI, AP, and RL directions, thereby facilitating reduced scan time without compromising image quality.

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References: [1] Scott, Radiology, 2009; [2] Wang, MRM,1995; [3] Henningsson, MRM, 2012; [4] Nehrke, MRM, 2003; [5] Keegan, JMRI, 2007; [6] Lai, MRM, 2009; [7] Etienne, MRM, 2002.