Respiratory Self-Gating with 3D-Translation Compensation for Whole-Heart Coronary MRA

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Introduction:

Whole-heart coronary MRA (CMRA) [1] has been gaining increasing acceptance with improved visible vessel length and ease-of-use. However, it necessitates free-breathing imaging and thereby accurate respiratory motion detection. Conventional diaphragmatic navigator (NAV) suffers from indirect measurement of heart position. A newly proposed respiratory self-gating (RSG) method [2,3] can improve the accuracy but is still limited to 1D translation detection. Inaccurate or incomplete motion detection prohibits wide respiratory gating windows (GW) and results in a long scan time, which increases both patient discomfort and the susceptibility to respiratory motion drifting. This study aimed to develop a new RSG technique capable of direct measurement of heart translation in 3D (3D RSG) and evaluate its effectiveness in free-breathing whole-heart CMRA.

Theory & Methods:

It has been demonstrated by dual-projection RSG (DP-RSG) that surrounding chest wall signals can be eliminated by averaging two superior-inferior (SI) projections with properly designed anterior-posterior (AP) dephasing [3]. An SI heart projection could be generated enabling accurate detection of SI heart motion. If an additional dephasing gradient is applied along a transverse axis for acquisition of this heart projection, heart translation along this direction induces a phase shift in the heart projection proportional to the amount of the corresponding translation. Therefore, it is feasible to detect transverse heart motion by adding motion-encoding (ME) gradients along AP and left-right (LR) directions.

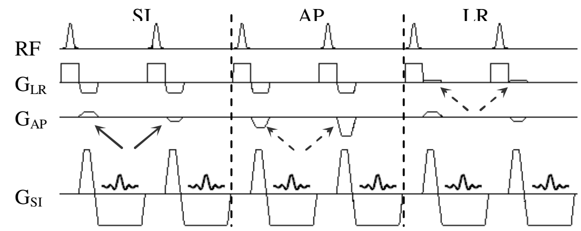

Fig. 1. Sequence diagram of 3D RSG. Solid arrows: AP dephasing for DP-RSG. Dashed arrows: ME gradients.

As illustrated in Fig. 1, 3D RSG acquisition is comprised of collection of 3 heart projections in 3 pairs of gradient echo RF cycles, corresponding to motion detection along SI, AP and LR. Acquisition of the first SI projection is identical to DP-RSG. The same acquisition was repeated with a nonzero ME gradient applied along AP for the 2nd projection and along LR for the 3rd projection. For motion detection, each pair of RSG signals is average to reconstruct a heart projection without chest wall contamination. Next, profile and phase shifts in the 1st projection with regard to a reference projection at end-expiration are detected, corresponding to SI heart translation and phase shift induced by background gradients (e.g. coil sensitivity). This background phase shift was then removed from the phase shifts calculated in the 2nd and 3rd projections to estimate phase shifts induced by AP and LR heart motion, respectively, which were divided by the strength of ME gradient to estimate transverse motion components.

3D RSG was implemented by inserting the acquisition described above after NAV echo in each heartbeat in a conventional 3D TrueFISP sequence with ECG-triggering and NAV-gating. 9 healthy volunteers were imaged using this new sequence on a 1.5T Siemens Avanto system. Typical parameters for coronary imaging included: 320×240 mm^2 FOV; 60 slices interpolated to 120 with 1.0 mm thickness; 1.0×1.1 mm^2 in-plane spatial resolution; 38 lines/segment; 90º flip angle; TE/TR = 1.87/3.74 ms. 3D RSG data were acquired from a sagittal whole-heart slice with 10º flip angle. Based on our simulations, a 5º/mm gradient was used for ME to achieve an optimal compromise between sensitivity to transverse motion and SNR. A GW of ±4.5 mm was used for NAV gating. Respiratory motion during the scan was compensated offline using 3 methods: 1D SI correction based on 1) NAV motion detection; 2) only the SI component of 3D RSG; 3) 3D correction based on 3D RSG motion detection. Qualitative comparison with regard to coronary artery delineation (0-4; 0:worst, 4:best) was performed to assess the effectiveness of different motion correction methods.

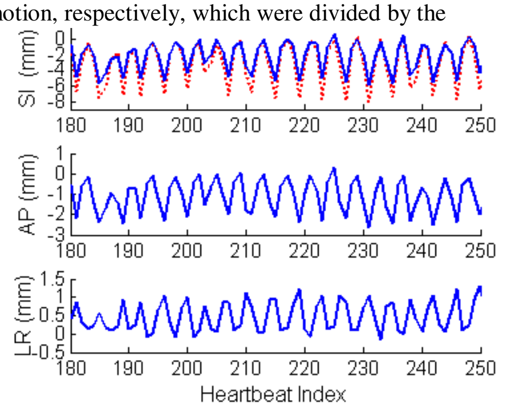

Fig. 2. Motion derived using NAV (red) & 3D RSG (blue)

Results:

Fig. 2 shows motion signals obtained from a subject using NAV and 3D RSG. SI motion signals derived using NAV and 3D RSG closely follow each other with noticeable deviation. For 3D RSG, the AP and LR motion components are synchronized with the SI component with substantially reduced magnitude. Fig. 3 shows the reformatted RCA images from the same subject. The NAV image suffers from significant motion blurring. RCA is better depicted in the 1D RSG image, whereas a medial segment remains undistinguishable. In comparison, 3D RSG provides sharp vessel delineation throughout the visible RCA segment. Table 1 shows the mean scores for different methods. Statistically, 1D RSG received higher scores than NAV ($p<0.05$) and 3D RSG further improves vessel delineation ($p<0.05$).

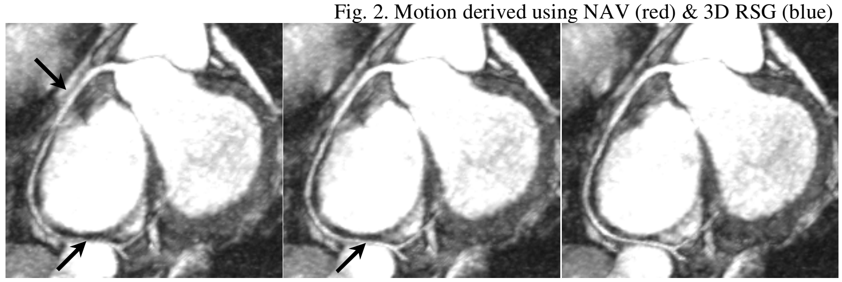

Fig. 3. Left to right: RCA images reconstructed using NAV, 1D RSG and 3D RSG.

Table 1. Mean scores for NAV, 1D RSG and 3D RSG.

	NAV	1D RSG	3D RSG
LAD	2.57±0.35	2.89±0.15	2.97±0.20
RCA	2.57±0.41	2.82±0.21	3.19±0.21

Discussion:

This work demonstrated a new RSG method enabling real-time detection and correction of 3D respiratory motion with a minor acquisition overhead (~20 ms). RSG signals can be acquired during the dead time of a heartbeat, enabling flexible orientation selection for coronary imaging. With more accurate and complete motion compensation, 3D RSG can significantly reduce residual motion artifacts and improve coronary artery delineation. Furthermore, the proposed method maintains good image quality with a large GW and high acquisition efficiency (64.3±8.6% in this study), indicating its potential for improving the robustness of CMRA.

References: [1] Weber OM et al, MRM, 2003:50:1223; [2] Lai P et al, MRM, 2008:59:1378; [3] Lai P et al, JMRI, 2008:28:612;