3D Coronary MRA with 2D beat-to-beat translational and bin-to-bin affine respiratory motion correction using a golden radial image navigator

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Introduction: Respiratory motion remains a challenge in 3D coronary MR angiography (CMRA). Diaphragmatic navigators (1DNav) are commonly used to compensate for respiratory motion during free-breathing CMRA acquisitions, but these lead to prolonged scan times as only data acquired during a pre-defined gating window are used in the reconstruction (~20-60% efficiency). Furthermore, such techniques can only compensate for translational motion in one direction and may leave residual motion artefacts in the images. Image navigators can address these problems, as they can achieve 100% scan efficiency and can correct for more complex motion. Such methods typically follow one of two approaches. In the first, low resolution or undersampled 2D or 3D navigators (2D/3DNavs) are acquired in every RR-cycle and used to estimate beat-to-beat translational motion.[1-3] In the second, the image navigator is acquired over several RR-cycles to provide a navigator for several respiratory states (bins).[4-6] Such navigators enable higher signal-to-noise ratios and spatial resolutions than beat-to-beat navigators, allowing affine motion to be estimated and corrected for a bin-to-bin basis. In this work we propose a 2D golden radial navigator, which allows the two approaches to be combined to perform beat-to-beat 2D translational and bin-to-bin 2D affine motion correction with 100% scan efficiency.

Methods: A highly under-sampled (~7x) high-resolution golden radial 2DNav was acquired per heartbeat before each segment of a whole heart 3D CMRA scan (Fig 1.). Each 2DNav was reconstructed with iterative SENSE (1) and registered to a common position to estimate 2D translational beat-to-beat motion (2). Using the estimated foot-head translational motion and the flexibility of the golden radial acquisition, the 2DNavs were combined to obtain high-quality 'binned' 2DNavs (3). The quality of these images allowed registering the binned-2DNavs to obtain bin-to-bin affine motion parameters to correct for residual non-rigid motion. Using the estimated motion the 3D CMRA data was corrected directly in k-space for both 2D beat-to-beat translational (4) and 2D bin-to-bin affine motions (5). **In vivo experiments**: 3D Cartesian CMRA was performed in 4 healthy volunteers using a b-SSFP sequence (3T Philips, 1.4mm isotropic voxel size, 300x300x120 mm^3 FOV, TE/TE/angle = 2.1/4.1/70^o, 98-131 ms acquisition window, T_2 preparation (TE = 30 ms) and fat saturation pre-pulse). Parameters for the 2D acquisition include: TFE sequence, 1.5x1.5mm^2 pixel size, 20mm slice thickness, 300x300mm^2 field of view, 89 ms acquisition window, TE/TR/angle = 1.6/3.5/5^o. 10 Respiratory bins were used for the bin-to-bin motion correction with the proposed approach. Images were reconstructed with: a) no correction (I_{uncorr}) b) 2D translational beat-to-beat correction only (I_{trans}) and c) 2D translational beat-to-beat and 2D affine bin-to-bin correction (I_{affine}). A 1DNav gated acquisition (6mm window) was performed for comparison purposes, using the same scan parameters as the ungated 3D CMRA.

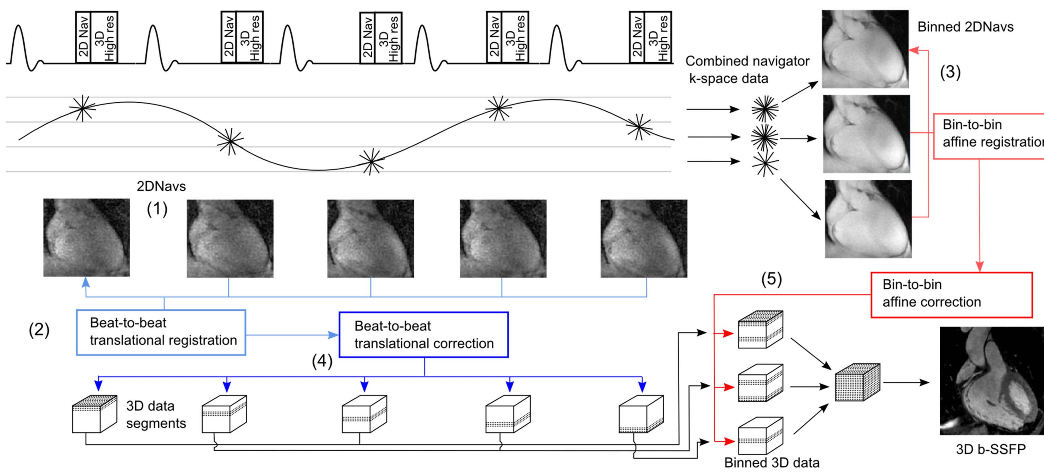

Figure 1 – Motion estimation and correction workflow. The flexibility of golden radial 2DNavs allows beat-to-beat translational and bin-to-bin affine motion correction.

Results Representative reformatted images of the right coronary artery (RCA) and left anterior descending artery (LAD) for two subjects are shown in Fig. 2. ***Subject 1:*** Visualization of the distal LAD is considerably improved in I_{trans} and I_{affine} compared to I_{gate} (yellow arrows). Sharpness of both proximal LAD and RCA further improves in I_{affine} compared to I_{trans} and I_{gate} (red arrows). However, the distal RCA can be visualized more clearly in I_{gate} than in I_{trans} or I_{affine}. ***Subject 2:*** Both I_{affine} and I_{trans} show similar image quality to I_{gate}. Artifacts in the distal RCA are seen in I_{uncorr} (green arrows), which are corrected for in I_{trans} and I_{affine}. The proximal RCA shows a slight improvement in sharpness in I_{affine} compared I_{trans} (blue arrows), although translational correction is generally sufficient in this case. Gating efficiencies for subjects 1 and 2 were 29% and 55%, respectively.

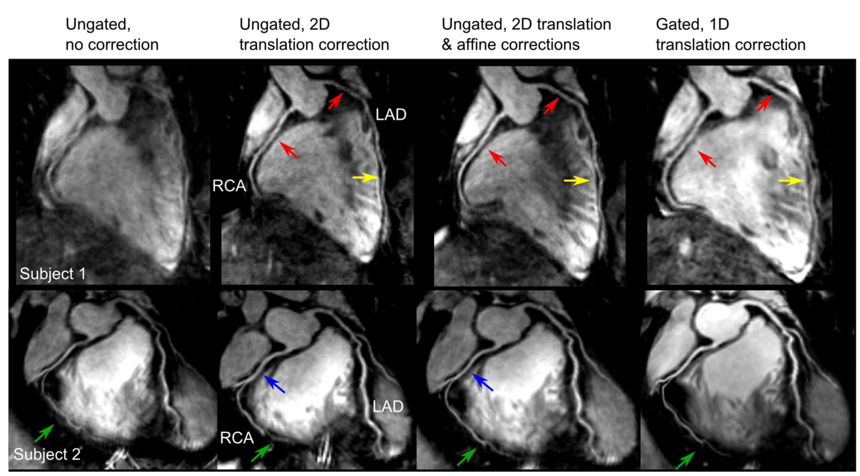

Figure 2 – Reformatted images showing the main coronary arteries of two subjects.
Subject 1: 2D Affine + translational motion correction gives superior image quality compared to both 2D translational correction and a gated scan (with ~3x reduction in scan time).
Subject 2: 2D motion correction gives similar image quality to the gated scan with ~2x reduction in scan time. Affine correction shows small improvements over 2D translation only.

Conclusions A 2D golden radial navigator is proposed, which allows both 2D beat-to-beat translational motion correction and 2D bin-to-bin affine motion correction to be performed without the need for respiratory gating, leading to a reduction in scan time (~2-3x) with comparable quality to a gated scan. In Subject 1 2D affine correction considerably improved visualization of the LAD compared to the reference gated scan. Affine correction may not be necessary in all cases, but the proposed method is flexible as it allows the choice of correction method to be made retrospectively from the same image navigator acquired data, allowing even non-rigid motion correction when required. Future work will focus on extending the navigator to 3D and applying the method to a greater number of subjects.

References [1] Henningsson et al. 2012 MRM 67:437-45 [2] Henningsson et al. 2013 MRM 69:486-94 [3] Wu et al. 2013 MRM 69:1083-93 [4] Bhat et al. 2011 MRM 65:1269-77 [5] Henningsson 2013 MRM (doi:10.1002/mrm.24652) [6] Pang et al. 2013 MRM (doi:10.1002/mrm.24628).