2D image-based respiratory motion estimation for free-breathing coronary MRA

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Introduction: Accurate correction for respiratory motion has been a major challenge in free-breathing whole-heart coronary MRA. Motion estimation directly from the heart is potentially superior to conventional diaphragmatic navigators, and several methods based on DC or 1D projection signals have been proposed [1-4]. We present a 2D image-based approach which allows accurate estimation of both SI and AP motion of the heart. Instead of acquiring 2D full-FOV images, aliased images are used to significantly reduce the navigator acquisition time. The preserved motion correlation between 2D aliased images allows motion estimation to be performed rapidly and reliably.

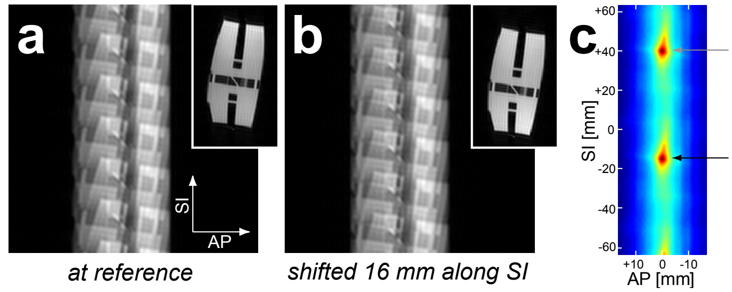

Figure 1. Illustration of the proposed 2D motion estimation.

Theory and Methods: The proposed motion estimation is illustrated in Fig. 1 which contains six-fold aliased sagittal images of a resolution phantom at a reference position (a) and shifted 16 mm along the SI direction (b). Correlation between the two images is calculated in 2D search space (c) and the maximum value indicates the true displacement (black arrow). Since all aliased replicas exhibit the same translational motion, spurious solutions are also found at increments of (n·FOV/R) (gray arrow) away from the true solution, where n = integer and R = undersampling rate. To avoid this ambiguity, R must be chosen such that the expected range of true displacement is less than (FOV/R). Estimation error was investigated by acquiring sagittal images of the phantom at 9 SI positions with 4 mm increments by moving the scanner table (S16, S12, … , I12, I16 mm). R was varied from 1 (full sampling) to 8. Free-breathing coronary MRA was performed in healthy volunteers with a 3DFT SSFP readout, FOV = 26×26×16 cm^3, resolution = 1.4×1.4×1.6 mm^3, 30 lines/segment, FA = 90º, TR = 4.2 ms. Sagittal navigator images were acquired immediately after the coronary acquisition using a 2DFT GRE readout, FOV= 32×(32/R) cm^2 with R = 6, resolution = 3.8×3.8mm^2, FA = 15º, slice thickness = 12 mm, TR = 2.8 ms, and acquisition time = 39.2 ms. A notched saturation pulse of 20 cm width was applied along the SI direction to suppress thoracic trunk signal outside the FOV [5]. The ROI for motion search was specified manually based on a full-FOV image that was acquired prior to the coronary scan. Motion was searched within [-19.0, 19.0] mm for SI and [-7.6 7.6] mm for AP with 0.475 mm step size (1/8 pixel).

R	1	2	4	6	8
Error [mm]	0.20 ±0.17	0.22 ±0.15	0.28 ±0.15	0.32 ±0.15	0.38 ±0.20

Table 1. Motion estimation errors in phantom test.

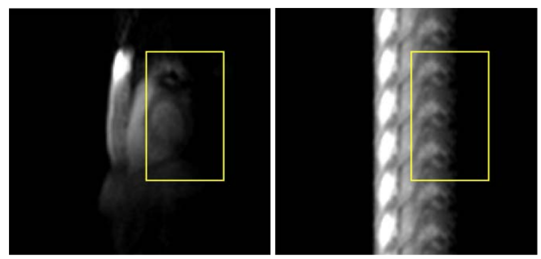

Figure 2. Full-FOV image used for ROI specification (yellow box), and 6-fold aliased navigator image acquired during an MRA scan.

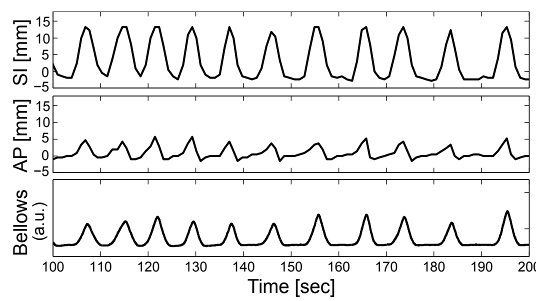

Figure 3. Estimated motion and bellows signal in a temporal segment.

Results: The result of the phantom experiment is summarized in Table 1. The absolute errors increase slightly with the undersampling rate, presumably due to decreasing SNR. Fig. 2 shows the full-FOV sagittal image used for ROI specification and an aliased image acquired during an MRA scan. Fig. 3 contains estimated breathing motion along SI and AP, temporally synchronized with the signal recorded from respiratory bellows. Fig. 4 shows reformatted images containing the LAD from the same subject. The depiction of the artery was significantly improved after 1D SI correction. 2D correction (SI and AP) further improved vessel delineation.

Discussion: We have proposed a 2D image-based motion estimation method which utilizes motion correlation between rapidly acquired aliased images, and have demonstrated its feasibility in free-breathing whole-heart coronary MRA. Higher undersampling rates can be used to further reduce the navigator acquisition time, possibly up to R=10 when the largest SI displacement is less than 3 cm.

Figure 4. Reformatted LAD images without motion correction (left), with SI motion correction (middle), and with 2D (SI+AP) motion correction (right). Vessel delineation progressively improves with 1D and 2D correction (arrows).

References: [1] K Nehrke et al, Radiology 220:810-815, 2001. [2] C Stehning et al, MRM 54:476-480,2005. [3] P Lai et al, JMRI 28:612-620, 2008. [4] P Lai et al, MRM 62:731-738, 2009. [5] CH Cunningham et al, ISMRM 2007:1709