The Next Step in Self-Navigated Coronary MRI: A Hybrid Approach for Affine Motion Correction

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INTRODUCTION

Compensation of respiratory motion is one of the major challenges for effective coronary MRI. Conventional navigator-gated techniques suffer from low scan-time efficiency, as only 40-50% of the acquired data is used for image reconstruction, and from errors due to the indirect estimation of the heart motion. A promising alternative has been introduced by self-navigation, which estimates the position of the heart directly from readouts oriented along the superior-inferior (SI) direction for subsequent 1D rigid motion compensation and achieves 100% scan efficiency [1] [2]. In contrast, an image-based approach for affine motion correction was recently proposed in [3]. In this approach, the information of a conventional navigator was used to cluster all acquired data in several bins, representing separate phases of the respiratory cycle. Low resolution images were reconstructed for each bin containing enough data and registered to the most populated bin in end expiration. In the present work, a hybrid method is presented, which combines both 1D self-navigation and image based affine motion compensation. This method exploits the intrinsic properties of the 3D spiral phyllotaxis trajectory [4] advantageously. The improvement in image quality was compared to a navigator-gated setup in 5 healthy volunteers.

METHODS

The 3D spiral phyllotaxis trajectory [4] intrinsically combines two essential features for 3D radial interleaved acquisitions: an overall uniform distribution of the readouts, and highly reduced eddy current effects. Moreover, SI self-navigation can be integrated without any effect on these properties. As shown in the upper half of the flow chart of Fig. 1, the 1D motion estimate resulting from the analysis of the intrinsic SI navigator was used to divide the respiratory cycle into several bins and, thus, to cluster all acquired readouts accordingly. In the highly interleaved setup required for coronary MRI, the phyllotaxis trajectory arranges the radial readouts in such a way that each new interleave is placed in the largest azimuthal gap left by the preceding set of interleaves and always divides the gap according to the golden ratio. As a consequence, basically any subset containing a sufficient number of interleaves (I_b) provides a reasonably uniform coverage of k-space. A pilot study was performed to determine the minimum number of interleaves (I_{min} = 30) allowing for a reliable and robust affine registration. As displayed in Fig. 1, all bins with a sufficient number of interleaves were registered to the reference bin in end expiration using a slightly modified variant of [5]. The resulting affine motion correction was applied for each bin directly in k-space. Bins that did not contain the minimum number of interleaves were not discarded, as in [3], but tagged and corrected in k-space for the preparatory 1D rigid motion estimate.

Whole-heart coronary MRI was performed in-vivo on 5 healthy volunteers, after written consent was obtained. A 3D radial, non-selective, T2-prepared, fat-saturated, balanced SSFP sequence with navigator-gating (acc. window: 5 mm) was compared to the proposed approach with the following parameters: TR/TE 3.0/1.51 ms, FOV $(220)mm^3$, matrix 192^3, voxel size $(1.15\ mm)^3$, flip angle 90° and receiver bandwidth 898 Hz/Px. A total of 377 heartbeats/interleaves of 31 radial readouts each were acquired for imaging, for an overall undersampling ratio of 20%. All experiments were performed on a 1.5 T clinical MRI scanner (MAGNETOM Avanto, Siemens AG, Healthcare Sector, Erlangen, Germany), with software release syngo MR B17. A total of 12 elements of a body matrix coil (anterior) and the spine matrix coil (posterior) were selected for signal reception. Image quality was assessed by visual inspection in all datasets for the two methods. The datasets were reformatted with CoronaViz (Work in Progress software, Siemens Corporate Research, Princeton, NJ, USA) to better visualize the coronary vessels. RCA and LAD were evaluated for vessel length, while vessel sharpness was computed as described in [6].

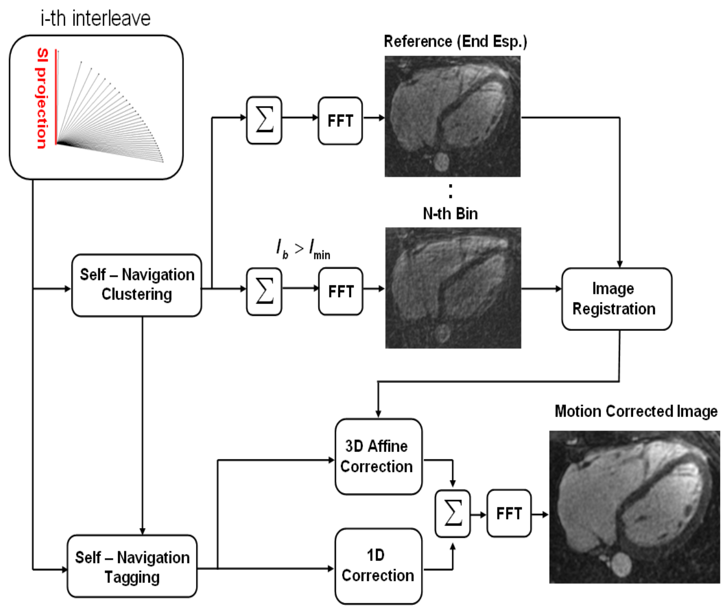

Figure 1: Schematic description of the hybrid motion correction technique

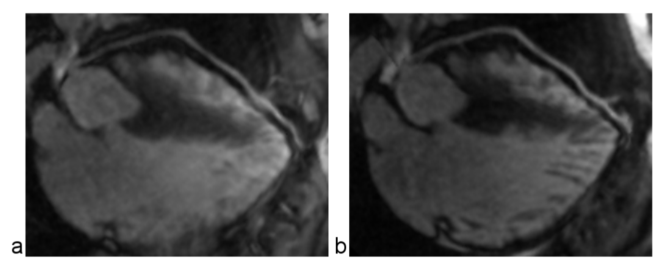

Figure 2: Reference images, acquired with the navigator-gated technique and reformatted to display the coronaries (here LAD), (a) were compared to acquisitions performed with the new hybrid method (b). In this case, the vessel sharpness resulted visibly improved in the central and distal parts of the LAD.

RESULTS

The total number of bins (*N*) containing at least I_{min} interleaves was always between 4 and 6 and an average of 11% of all readouts was corrected only for 1D rigid motion in the SI direction. The average acquisition time for the new method was 6.7±0.7 min compared to 18.8±7.3 min of the navigator-gated method. Visual inspection revealed that the overall image quality of the hybrid method was comparable to the navigator-gated reference. The RCA could be detected in all data sets with an average length of 111.73±22.44 mm for the navigator-gated approach and 123.16±20.88 mm for the presented method. The LAD was detected in 3 cases for both methods, with a mean length of 115.51±39.20 mm for the navigator-gating and 106.81±41.64 mm for the hybrid approach. In the 2 remaining cases, the LAD could be detected only with the hybrid approach. For the RCA, the vessel sharpness followed the same trend of the vessel length, with an average value of 0.88±0.14 for the navigator-gated and 1.01±0.15 for the new approach. For the LAD, the average sharpness was 0.96±0.11 for the navigator-gated approach (Fig. 2a), and 1.07±0.12 for the new approach (Fig. 2b).

DISCUSSION AND CONCLUSIONS

The presented hybrid approach extends the 1D approach to a more realistic estimation of the respiratory motion, while maintaining a true 100% scan efficiency. On the other hand, an extensive user-interaction is still required to achieve the final result. This new method might potentially be used for a full 3D validation of the respiratory motion in the coronaries in a number of subjects. An improved and more automated version of this approach will be the subject of further studies.

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