Robust and Fully Integrated One Dimensional Respiratory Self-Navigation for Whole-Heart Coronary MRI

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INTRODUCTION

Free-breathing coronary imaging is a very challenging topic in the field of cardiac MRI and the implementation of efficient and reliable methods to improve the current navigator-gated protocols is a most desirable goal. In the recent years, whole-heart self-navigating techniques for coronary MRI were introduced as a promising alternative to the conventional approaches, [1] [2]. These methods promise to increase the scan time efficiency up to 100%. Furthermore, temporal delays and hysteretic effects due to the use of a fixed correlation factor between the measured navigator position and the actual position of the heart [3] are significantly reduced. Recent self-navigating techniques are based on bright blood balanced SSFP sequences, which make the positional information of the heart directly assessable in readouts oriented along the superior-inferior (SI) direction. The greatest challenge of such procedures is to suppress signal that would render the detection of the position of the heart impossible, i.e. signal of the spine, chest wall, arms and liver. In the present work, an innovative method to efficiently suppress such unwanted signal is presented. This method was implemented for a 3D radial whole-heart coronary imaging sequence [4], adapted for self-navigation. Free-breathing whole-heart coronary MRI was successfully performed in 10 healthy volunteers and the new method was compared with navigator-gated acquisitions.

METHODS

The suppression of unwanted signal is essential for the reliability of the self-navigating information that is extracted from the SI projections. While signal of the posterior chest wall and the spine can be excluded from the data processing by not taking into account the receiver channels of the spine matrix coil, a regional saturation slab needs to be precisely placed to suppress the signal of the anterior chest wall.

The signal originating from lateral structures, nevertheless, is a more challenging issue, Fig. 1a. If this signal is not sufficiently suppressed, then the tracking of the heart will still not succeed, Fig. 1b. Therefore, the magnitude of the Fourier transformed signals of the primary mode (P) and the secondary mode (S) of a body matrix coil (Siemens AG, Healthcare Sector, Erlangen, Germany) placed on the anterior chest wall were advantageously combined (C) to remove the lateral structures, Fig. 1c. As a consequence, it was possible to segment the location of the heart automatically, Fig. 1d, thus eventually excluding also the signal of the liver. Although the current implementation utilizes the mode matrix technology (Siemens AG, Healthcare Sector, Erlangen, Germany) [5], the method can be generalized for other configurations of phased array surface coils with right (R), middle (M) and left (L) coil elements:

$$C = \left|FFT\{P\}\right| - \left|FFT\{S\}\right| = \left|FFT\{(R-L)/2 - j\cdot(M/\sqrt{2})\}\right| - \left|FFT\{(R+L)/\sqrt{2}\}\right|.$$

The coil combination and an automatic segmentation algorithm for the first SI projection were integrated into the image reconstruction software. The respiratory motion of the heart was estimated by maximizing the cross-correlation between the result of the segmentation and all successive SI projections. The calculated offsets were applied to the original readouts during image reconstruction by multiplication of a linear phase in k-space.

Free breathing whole-heart coronary MRI was performed in-vivo in 10 healthy volunteers, after written consent was obtained. A 3D radial, non-selective, T2-prepared, fat-saturated, balanced SSFP sequence with navigator-gating (acceptance window: 5 mm) was compared to self-navigation: TR/TE 3.0/1.51 ms, FOV $(220)\text{mm}^3$, matrix 1923, voxel size $(1.15\ \text{mm})^3$, flip angle 90° and receiver bandwidth 898 Hz/Px. A total of 11687 radial readouts were acquired in 377 heartbeats, with 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. For signal reception, a total of 12 elements of a body matrix coil (anterior) and the spine matrix coil (posterior) were selected. Images of the RCA and of the LAD were reformatted with CoronaViz (Work in Progress software, Siemens Corporate Research, Princeton, NJ, USA) and were evaluated for vessel length. Vessel sharpness was computed as described in [6].

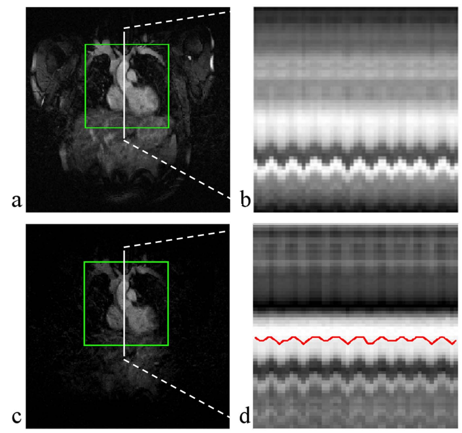

Figure 1: Coronal views before (a) and after (c) signal suppression. The green square and the white line represent the FOV of the whole-heart acquisition and the SI projection, respectively. A series of 50 SI-projections used for navigation before (b) and after (d) signal suppression is also shown. The first combined projection was automatically segmented and used as reference in the CC algorithm. The result is depicted in (d) as a red line.

RESULTS

Navigator-gated as well as self-navigated whole-heart coronary MRI was successful in all volunteers. The respiratory motion, displayed as a red line in Fig 1d, could always be reliably tracked with the new method. The acquisition time was reduced of more than 60%, with an average of 6.9±0.8 min for the self-navigated method compared to 18.5±6.1 min of the navigator-gated method. A visual inspection revealed that the image quality of the self-navigated datasets was comparable to the navigator-gated reference.

Quantitative analyses showed that the self-navigated approach provided an improved detection of the coronary vessels. While the RCA could be detected in all data sets for both methods, the LAD was detected in 9 of the 10 data sets acquired with the new method and only in 6 of those acquired with the navigator-gating. Moreover, the average length of the RCA increased from 96.88±23.24 mm, for the navigator-gated approach (Fig. 2a), to 108.90±28.36 mm, for the presented method (Fig. 2b). The average length of the LAD increased from 93.15±37.31 mm, for the navigator-gated approach, to 98.8±28.96 mm, for the self-navigating approach. The vessel sharpness followed the same trend of the vessel length, with average values of 0.92±0.17 (RCA) and 0.94±0.13 (LAD) for the navigator-gated and 1.05±0.19 (RCA) and 1.07±0.13 (LAD) for the new approach.

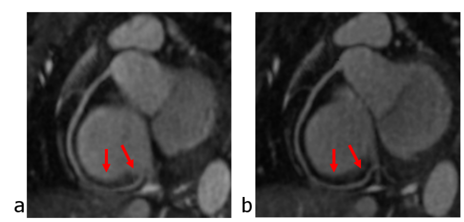

Figure 2: Reference images, acquired with the navigator-gated technique and reformatted to display the coronaries (here RCA), (a) were compared to acquisitions performed with the new method (b). The acquisition time was more than halved and the image quality was comparable to the reference. The red arrows highlight the improved vessel length.

DISCUSSION AND CONCLUSIONS

The acquisition time of the self-navigated approach only depends on the heart rate of the subject and can always be estimated in advance. Furthermore, the robustness of the self-navigation, shown here in a number of different subjects, and the full integration of the motion correction algorithm into the online reconstruction make the presented method appealing for clinical studies. Further improvements can be obtained by extending the motion correction to more complex transformations, such as rigid 3D or 3D affine. Furthermore, the combination of this method with parallel imaging and/or compressed sensing techniques will be subject of future investigations. The presented method can be a basis for the future development of a coronary imaging technique that meets the requirement of the clinical practice.

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