Fast Whole-Heart Coronary MRA Using 3D-radial SSFP With 32 Channel Parallel Acquisition and Self-Navigated Image Reconstruction

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Abstract

Recently, three-dimensional volumetric projection reconstruction (3D-PR) was successfully applied in coronary MRI, as it offers a high, isotropic resolution in a large field of view [1]. However, scan times in whole-heart imaging [2] are long and may vary greatly with the breathing pattern of the patient, especially if navigator gating is applied. To address these shortcomings, an accelerated 3D-radial SSFP sequence using a 32-element receive coil array and SNR-optimized image reconstruction was developed and implemented on a clinical 32-channel system. An acceleration factor of 25 was achieved in initial in-vivo experiments. Furthermore, respiratory navigator gating was replaced with a self-navigated image reconstruction. Respiratory motion was extracted directly from the echoes acquired for imaging and corrected in a post-processing step. Isotropic, high resolution whole-heart images were acquired in 2 minutes during free breathing.

Methods

Experiments were performed in phantoms and four healthy adult volunteers on a 1.5T clinical MR scanner (Achieva, Philips Medical Systems, Best, NL). A whole-body 32 channel array coil prototype was used for parallel signal reception. To optimize SNR and minimize aliasing artifacts, the magnitude images reconstructed from each individual coil were weighted with estimated coil sensitivity maps [3,4]. These measures ensure that each coil contributes a localized region with optimal SNR to the final image, and does not contaminate other parts of the imaged volume with streaking artifacts resulting from polar undersampling. The sensitivity maps were obtained from lowpass-filtered image data, and no additional scan was necessary. After the combination of all images, the resulting image was de-weighted with the sum of all sensitivity maps for a homogeneous presentation.

The acquisition was ECG-triggered with a cardiac acquisition window of T_{AQ} = 115ms. To cope with respiratory motion, a previously described [5] 3D-radial interleaved sampling scheme was slightly modified so that the first echo acquired in each RR interval is oriented in the superior-inferior direction, where respiratory-induced bulk cardiac motion exhibits its major component. Translational motion was extracted from the 1D-FT of this echo (Fig. 1a) using a first momentum ("center of mass") approach with sub-pixel resolution [6]. The subsequent echoes measured in the corresponding cardiac cycle were modulated according to the Fourier shift theorem using a linear phase depending on the calculated displacement and the azimuthal angle of the current readout. All acquired data were accepted for reconstruction after correction for respiratory motion. The following sequence parameters were used: matrix: 256^3; FOV: $(300\ mm)^3$; measured voxel size: $(1.17\ mm)^3$; TE/TR: 1.8/3.6ms; SSFP with flip angle 60°; receiver bandwidth 781Hz / pixel. 4,096 radial readouts out of $0.5 \cdot \pi \cdot 256^2 = 102{,}944$ necessary to fulfill the Nyquist limit were acquired, resulting in an acceleration factor of 25. The total scan time was approx. 2 minutes during free breathing. The isotropic whole-heart data set was reformatted to visualize the coronary vessels.

Results

Selected in-vivo results for a volunteer are shown in Fig. 1. The 1D-FT of the first echo acquired in each cardiac cycle is shown in (a) The corresponding center-of-mass position is plotted as a solid line. Three orthogonal views of the motion-corrected, volumetric data set are shown in (b-d). A long segment of the right coronary artery was visualized retrospectively from the isotropic data set (e).

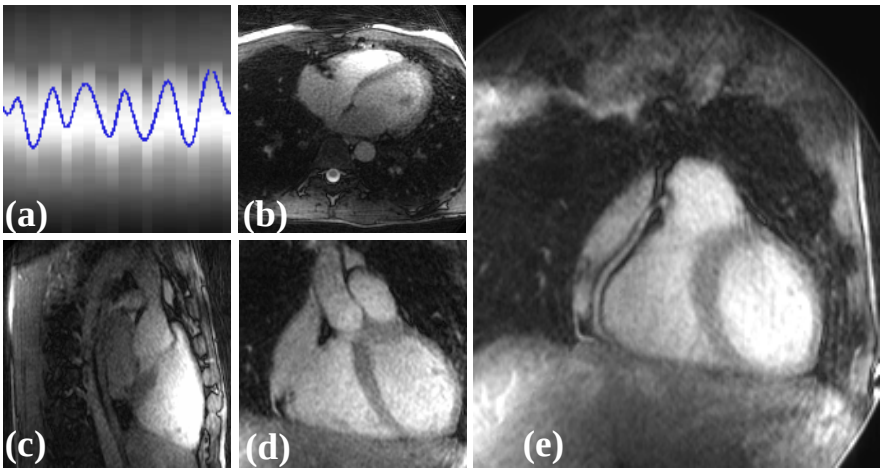

Fig 1: Sections of the 1D-FTs of the first echoes acquired in each cardiac cycle are shown in (a). Respiratory motion is measurable as a displacement of the center-of-mass (solid line). Three orthogonal views demonstrating the large volume coverage are shown in (b-d). A reformatted view of the right coronary artery (RCA) is shown in (e).

Discussion and Conclusion

The applied 3D-radial sampling in combination with the parallel acquisition has proven to provide a good image quality and low aliasing artifacts, and long segments of the coronary arteries were clearly depicted. Using a clinical 32-channel system, the whole-heart data set with high and isotropic resolution was acquired in 2 minutes during free breathing. Furthermore, the ease-of-use of coronary MRA was greatly improved due to the whole-heart approach with a simplified planning procedure, and no respiratory bellows or navigator pulses were necessary. The correction of respiratory motion was completely based on image data and thoroughly automated. Scan times were significantly shortened and independent of the subject's breathing pattern. Further experiments are necessary to validate the feasibility of the technique in patients.

References:

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