Improved Data Acquisition for Cardiac Fiber Detection based on 3D Phase Contrast Velocity Data

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Introduction

Established methods for quantification of myocardial wall motion are tagging and phase contrast (PC) velocity mapping and DENSE. Data acquisition with these methods is typically based on multiple breath-held (BH) 2D measurements. One major problem is related to limited spatial and temporal resolution due to the length of the breath-hold period. Navigator echoes (NE) provide an efficient method to overcome these limitations related to breath-holding. An improved navigator-guided technique for the acquisition of PC data during free-breathing (FB) was implemented [1]. This technique provides several benefits for a detailed analysis of the velocity or acceleration fields in order to derive surrogate parameters describing the fiber structure of the left ventricle [2]. In comparison to breath-held acquisition this method does not suffers from potential mismatch between adjacent slices and low spatial resolution in slice-direction and therefore partial volume effects that lead to an inadequately coverage of th apex. In order to maintain SNR while decreasing the slice thickness, the bandwidth has to be increased. The resulting longer TR can be tolerated due to the free-breathing acquisition.

Methods

Improved navigator gating was performed using two NE per cardiac cycle in combination with real-time acceptance criteria based on signal from successive navigator echo pairs, in the center and at the end of the cardiac cycle (Fig.1). Data acceptance or rejection was based on the combined information from both navigators for the two resulting data blocks which were treated independently. The total time for two NE including the evaluation following the second NE was 40 ms. Data was accepted when the current diaphragm position was inside a 5-mm acceptance window in end-expiration.

The measurements were performed on a 1.5 T Magnetom Sonata (Siemens Medical Solutions, Erlangen, Germany). PC images were acquired with a black blood k-space segmented gradient echo sequence (TR = 6.4 ms, flip angle = 15°, bandwidth = 320 Hz/pixel) with first-order flow compensation in all dimensions to minimize artifacts from flow or motion. The pixel size was 1.3 x 1.3 mm (96 x 256 matrix interpolated to 192 x 256). Velocity encoding was performed in an interleaved order with a *venc* of 20cm/s in-plane and 30cm/s through-plane according to typical velocity values occuring in the wall motion of the left ventricle. A temporal resolution of 64 ms was achieved by using view sharing technique. Full in-plane velocity information of the beating heart was obtained in 32 heartbeats assuming a scan efficiency 100%. The whole LV of two volunteers was covered with gapless slices of 5 mm thickness in short axix images from the basis to the apex. The mean scan efficiency over all sices was 35%. For comparison PC images were acquired during breath-hold period of 25 heartbeats with the same temporal resolution.

Data post processing was performed on a personal computer using customized software programmed in Matlab (The Mathworks). After contour segmentation and a correction for translational motion components of the LV, the resulting velocity vector was calculated as a vector sum of the measured x-,y- and z-velocity components. Acceleration fields (with slice interpolation) were calculated using the first two phases of the cardiac cycle since the wall motion experiences a reversal between these two phases due to a strong force which is mainly responsible for the isobar contraction (velocity twist). Subsequently, a tracking of the vectors was performed using an algorithm proposed by Mori et.al. [3]. The maximum difference of the tracking angle between adjacent voxels was set to 25° and the minimum number of passed voxels as a criteria for defining a velocity track was set to 20. The velocity vector tracking was then performed for different phases of the heart cycle. The tracks identified by the algorithm show a spiral pattern from the epi- to the endocardium derived from the radial component of the velocity vectors. In contrast, the anatomical fiber structure is described by tangential components only, whereas the geometrical contraction contains cross fiber terms for the wall thickening also. As presented earlier, tracks were also be generated from circumferential velocity components for a better description of the motion component parallel to the ventricular wall [2].

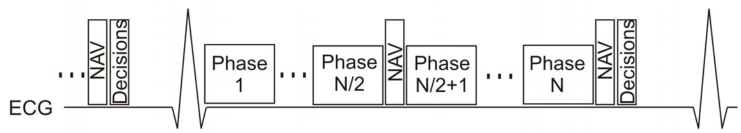

Fig.1: Acquisition strategy for the navigator-gated free-breathing measurements.

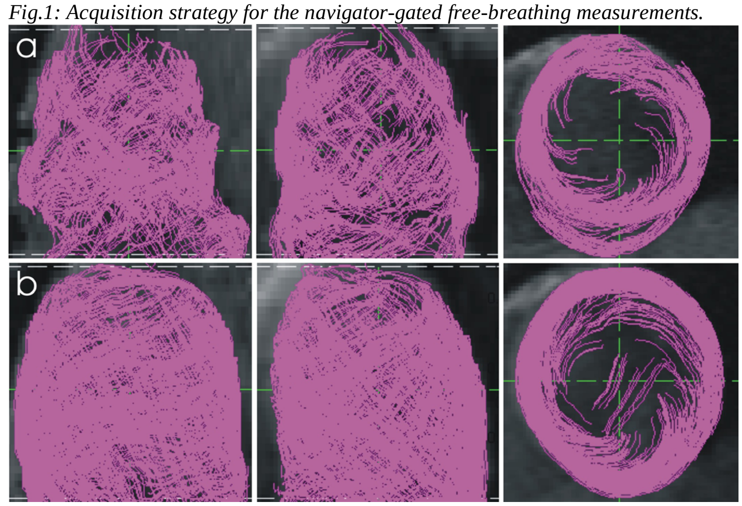

Fig.2: Projection of all identified tracks in x-,y- and z-direction with the data set acquired during breath-hold (a) and free breathing (b).

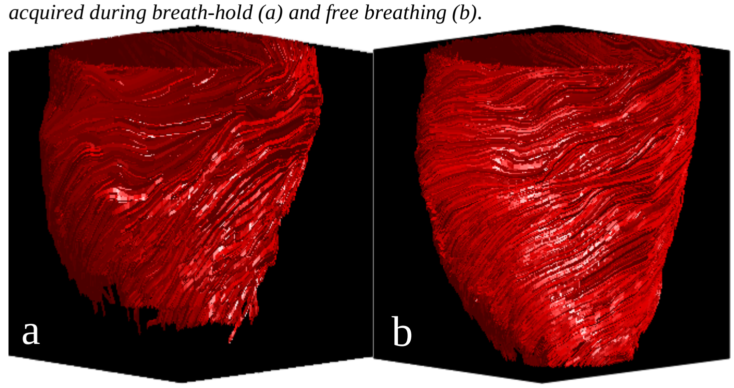

Fig.2: 3D-acceleration tracks with breath-hold (a) and free breathing (b) data set.

Results

Fig. 2 shows a projection of all identified tracks in x-,y- and z-direction of a volunteer (a:BH; b:FB) demonstrating the mismatch between adjacent slices. Fig. 3 shows the 3D-acceleration tracks of another volunteer (a:BH; b:FB) demonstrating the better coverage of the LV of the data set acquired with thinner slices during FB.

Discussion

In this study, an efficient strategy for the combination of NE based respiratory gating was introduced. The use of thinner slices and a lower bandwidth compared to the breath-hold acquisitions lead to better coverage of the left ventricle with the identified tracks. Further increase in scan efficiency could be achieved without adding significant motion artifacts by the use of a motion-adapted gating technique based on k-space weighting [4]. Additional scan time reduction while maintaining SNR might be feasible by the use of parallel imaging techniques at the higher field strength of 3T [5]. Future work will include the investigation whether these tracking data allow for the extraction of surrogate parameters which are characteristic for the anatomical structure of the fibers or for the function of the heart muscle, i.e. for surgical evaluation in patients with dilation of the heart.

References

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