Initial experience in cardiac fiber detection based on 3D phase contrast velocity data

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Introduction

Information on the structure and orientation of the muscle fibers in the human heart might provide significant information for surgical evaluation of patients with a dilation of the heart due to myocardial infarction who undergo a reduction of the dilated ventricle. However, no method exists to extract such information in-vivo. MR imaging with phase contrast (PC) velocity mapping and tagging are two methods to quantify myocardial wall motion. These methods can be used to extract parameters such as strain or radial and tangential velocity components but to date no attempts have been made derive information on the fiber structures of the left ventricle (LV) from the motion data. PC velocity mapping has proven to be an objective method for the quantification of segmental myocardial wall motion [1] and this work investigates the tracking of the resulting velocity vectors out of a time resolved PC data set of the whole LV with velocity encoding in all dimensions. The results are compared with the pathways of muscles fibers as known from in vitro specimens.

Methods

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 (TE/TR=4.5/6.2 ms, flip angle=15°) 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 (255 x 340 mm FOV, 96 x 256 matrix interpolated to 192 x 256). Velocity encoding was performed by adding a bipolar gradient in read, phase and slice direction after each RF pulse to the otherwise identical sequence (*venc in-plane*=20 cm/s, *venc through-plane*=30 cm/s). A temporal resolution of 62 ms was achieved by using a view sharing techniques [2]. Full in-plane velocity information of the beating heart was obtained in 25 heartbeats within a single breath-hold measurement. The whole LV of a volunteer was covered with gapless slices of 8 mm thickness in short axix images from the basis to the apex.

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. 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 15° and the minimum number of passed voxels as a criteria for defining a velocity track was set to 10. The velocity vector tracking was then performed for different phases of the heart cycle.

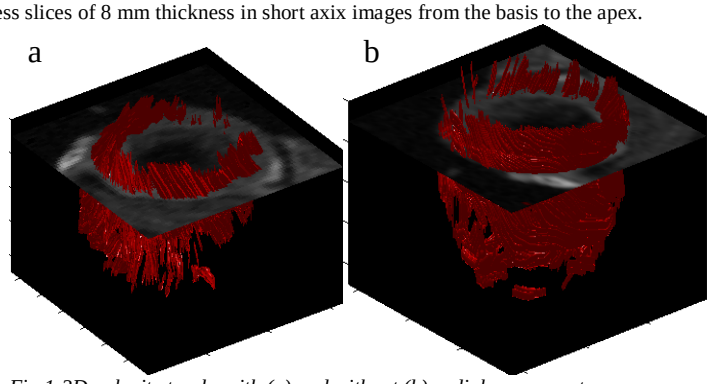

Fig.1:3D-velocity tracks with (a) and without (b) radial component.

Theoretical considerations

The underlying assumption of this evaluation is that if a force is exerted in a defined direction over a certain time period, then the motion will also adapt to this direction. In the heart this direction belongs to the long axis of the myocardial fibers. With this criteria we focused on the tracking performance of a time frame whithout positive accelerations during the isobar contraction. This is during the downslope close to the maximum of the systolic velocity pattern and corresponds to approximately the third phase of the ECG-cycle in our measurement.

There are two different kinds of fiber shortenings described in the literature: one in the longitudinal direction of the fibers and the cross fiber shortening which seems to be mainly responsible for the thickening of the subendocardial regions of the heart [4]. The anatomical fiber structure is described by tangential components only, whereas the geometrical contraction contains these cross fiber terms for the wall thickening also. For a better description of the motion component parallel to the ventricular wall, the radial velocity component was discarded by a projection of the velocity vector of each voxel onto the corresponding tangential plane, which was calculated by the splines of the segmentation.

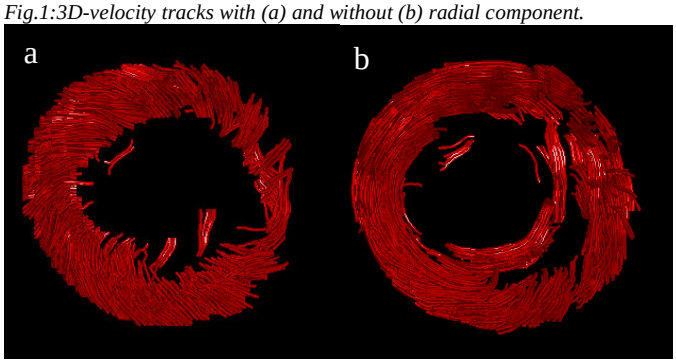

Fig.2:short axis projection of all 3D-velocity tracks with (a) and without (b) radial component.

Results

Fig.1a shows a three dimensional depiction of the calculated velocity tracks of the third phase of the heart cycle. Additional to the extension in the direction along the ventricular wall the velocity tracks extend from the epi- to the endo-cardium due to the radial velocity component describing the contraction. Fig.1b shows the calculated velocity tracks of the same phase with the projection of the velocity vectors into the heart intrinsic coordinate system. Fig.2a and 2b show the projection of all tracks from the short axis view for a better visualization of the differences between inclusion and exclusion of the radial component. The algorithm could find more and longer tracks within the second figure with otherwise identical tracking criteria.

The third phase is about 230 ms after the R-wave of the ECG-cycle and corresponds to the late-systole of the cardiac cycle. With a view from the apex looking up towards the base, the velocity vectors describe a clockwise spiral structure. This kind of pathways has been shown in investigations of postmortem human hearts in the subendocardial regions [5]. These results might indicate that subendocardial fibers dominate the main part of the isobar contraction in the later systole.

Discussion

We have introduced a new tool to visualize and process 3D velocity measurements of the LV. Further work includes a closer look at angles of the velocity tracks with respect to the circumferential plane, because there are different ranges of these angles described depending on epi- and endocardial regions and on different locations of long axis planes of the LV [6]. Future work for investigations of the acceleration fields are also planned since they might correspond closely to the development of force. In addition, a more detailed evaluation of different cardiac phases could give more information on subregions of the ventricular wall and may resolve structures of different muscle layers. An improved data acquisition could further reduce the slice thickness because the current 8 mm thick slices cause problems in performing a reasonable tracking of velocity vectors in the region of the apex due to partial volume effects (see Figures). For a reduction of the slice thickness without a loss of SNR a 3D measurement would be desirable but only practicable using with navigator technique. Also further investigations are necessary concerning the temporal resolution of the PC-data that is usable for performing velocity tracking.

References

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