Myocardial fiber tracking based on high temporal resolution tissue phase mapping data: principles and implications for cardiac fiber structures

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Introduction: The spatial arrangement of myocardial fiber structure affects the mechanical and electrical properties of the heart [1,2]. Therefore, information on the structure and dynamics of the orientation of the muscle fibers in the human heart might provide significant insight into principles of the mechanics of ventricular contraction and electrical propagation and may aid pre- and postsurgical evaluation of patients. Fiber orientation is inherently linked to cardiac wall motion, which can be measured with phase contrast MRI (Tissue Phase Mapping, TPM). Here, this technique was used to generate acceleration fields in order to derive surrogate parameters describing the fiber structure of the left ventricle [3]. High temporal resolution TPM measurements were performed during free-breathing [4]. Based on the assumption that the accelerations are related to the forces generated by the muscle fibers a tracking algorithm was applied to acceleration fields derived from the velocity data for different cardiac frames of left ventricular (LV) performance representing iso-volumetric contraction (IVC), mid-systole, iso-volumetric relaxation (IVR) and mid-diastole.

Methods: TPM measurements were performed in a healthy volunteer on a 3T system (Trio, Siemens, Germany) using a black blood k-space segmented gradient echo sequence (TR = 6.9 ms) with first-order flow compensation. The pixel size was 1.3 x 1.3 mm (96 x 256 matrix interpolated to 192 x 256). Velocity encoding was performed with a *venc* of 15 cm/s for in-plane and 25 cm/s for through-plane encoding. A temporal resolution of 13.8 ms was achieved by using an improved navigator gating with two navigator echoes per cardiac cycle [4] in combination with view sharing. The whole LV was covered with gapless slices of 8 mm thickness in short axis images from the base to the apex. The total acquisition duration was about 50 min.

Data postprocessing was performed using customized software programmed in Matlab (The Mathworks). After contour segmentation and a correction for translational motion components of the LV, the resulting velocity vectors were calculated from the measured x-,y- and z-velocity components. Subsequently, pixel-wise myocardial acceleration vectors were calculated from the time-resolved velocity data by calculating discrete temporal derivatives (with slice interpolation to 4 mm). Subsequently, a tracking of the vectors was performed using an algorithm proposed by Mori [5]. Tracks were terminated if the maximum angle deviation of the acceleration vectors between adjacent voxels exceeded 30°. In addition, a minimum length of 10 voxels along the track was required and tracks were generated from accleleration components parallel to the ventricular wall while radial acceleration components were ignored [3]. The global track angle with respect to the circumferential plane (see fig.2 left) for all identified tracks in each slice was calculated. Additional color coded 3D stream-line visualization of acceleration vector fields was performed (Ensight, CEI, USA). The resulting 3D images could be freely rotated in real-time and viewed from any user selected angle allowing for a fast qualitative investigation of the derived acceleration fields.

Results: Fig.1 shows pixelwise arrow plots of the in-plane velocity component in a basal short axis view during different cardiac frames (a-d). The dominant motion behaviour is illustrated by the time courses of global velocity components (e-g). Fig. 2 shows 3D stream-line visualization of the acceleration vector fields in cardiac frames during IVC and mid-diastole. Fig. 3 shows a 3D-depiction of acceleration tracks for four different cardiac frames viewed from the same direction compared to Fig.2. The tracks show a smooth coverage of the entire LV during IVC (a). During IVR a different tilt of the identified tracks in base and apex can cleary be identified (c). Due to the complex rotational motion behaviour of the LV (see also fig.1f) the tracks change their orientation dependent on the time point during the cardiac cycle (d). The definition for the track angle orientation is shown in the schematic diagram on the left. For illustration purposes only about 25 % (~2500) randomly chosen of all identified tracks are depicted.

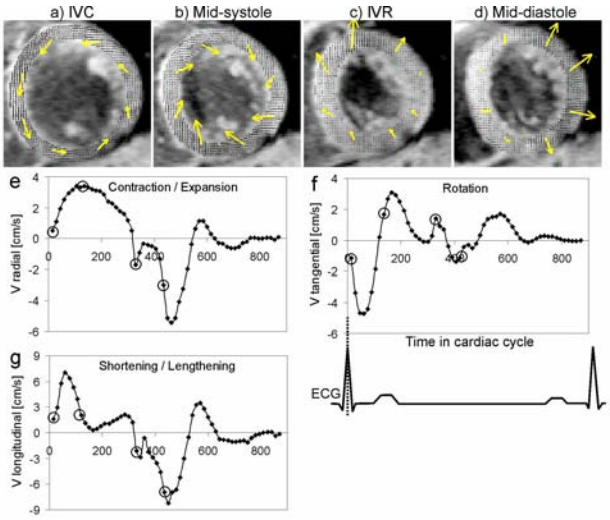

Fig.1:Pixelwise arrow plots of the in-plane velocity component: cardiac frames during a) IVC, b) mid-systole, c) IVR and d) mid-diastole. Global time courses of radial (e), tangential (f) and longitudinal (g) velocities illustrate the dominant motion behaviour. The small circles indicate the temporal location of the arrow plots in the cardiac cycle.

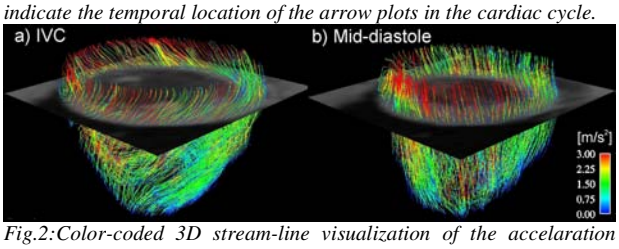

Fig.2:Color-coded 3D stream-line visualization of the accelaration vector fields: cardiac frames during a) IVC, b) mid-diastole.

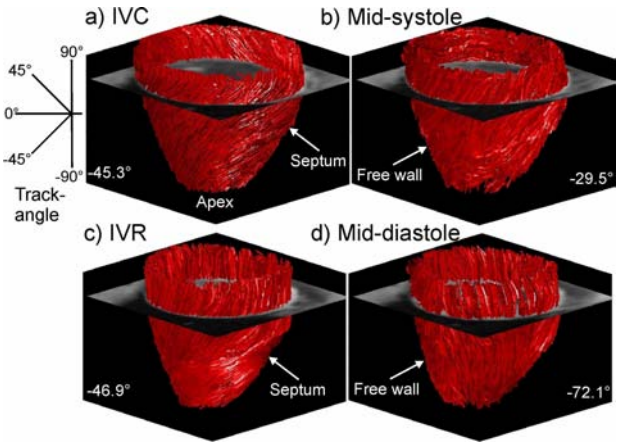

Fig.3. 3D-depiction of identified accelaration tracks: cardiac frames during a) IVC, b) mid-systole, c) IVR and d) mid-diastole. The definition of the track angle orientation is shown on the top left. The global track angle over the entire LV is given for each depicted cardiac frame.

Discussion: In order to investigate if relevant information characterizing myocardial fiber architecture could be extracted from functional MRI data, the idea of a tracking of acceleration fields of the LV based on TPM data was presented. The high temporal resolution data allows for a reasonable calculation of acceleration fields (see fig.1). Interactive 3D stream-line visualization can be used to determine characteristical cardiac frames with respect to a smooth and wide coverage of the LV or to high accelerations of e.g. rotational components. These frames may be promising in order to derive surrogate parameters (e.g. track angle) for the desription of cardiac fiber structure. For a flexible and quantitative analysis of acceleration fields the above mentioned matlab tools that provide more control over the tracking algorithm are necessary. Note that the identified tracks do not necessarely correspond to the direction of existing anatomical muscle fibers. The aim of this heuristic parametrization is not primary an exact biometric characterization of the structural fiber orientation, but rather the determination of surrogate parameters that are stable and reproducible. Although exact reconstruction of the myocardial fiber structure from velocity data requires mathematical modelling of spatiotemporal evolution of the velocity fields, it is demonstrated, that acceleration fibers may serve as useful surrogate parameter for clinical studies.

References: [1] Waldman et al. *Circ Res* 1988;63:550-562. [2] Chen et al. *Am J Physiol* 1993;264:H1760-1773. [3] Jung et al. *Proc ISMRM* 2004; p.648. [4] Jung et al. *Proc ISMRM* 2005; p.779. [5] Mori et.al. *Ann Neurol* 1999;45:265-269.