

Global Myocardial Fiber and Sheet Architecture in Diffusion Spectrum Imaging Tractography

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Abstract

Global pattern of myocardial fiber and sheet architecture was studied on a cow heart using diffusion spectrum imaging (DSI) tractography. Although fiber helical orientations were circularly symmetric, 3D fiber pathway was found to be asymmetric between the septum and free wall. The same asymmetry was also found in the sheet architecture. The findings supported the previous observations in histology. In conclusion, this technique has the potential to study fiber and sheet pathways nondestructively and provides a clearer view of the global myocardial architecture.

Introduction

Myocardial fibers course around the left ventricle (LV) in a unique spiral pattern. One resulting feature can be appreciated from a transmural block of the LV wall. Fibers change the pitch continuously with the wall depth, from the right-handed helix in the outer wall to the left-handed helix in the inner wall [1]. Reconstruction of 3D global fiber pathway resulting from this spiral pattern has been attempted by many anatomists, but no general agreement has been reached yet. From a higher level of scale, myocardial fiber architecture presents another sophisticated pattern; aggregates of fibers arrange themselves in layers. These myocardial sheets resemble the blades of a propeller, stacking on one another from apex to base. Although delicate histology sections disclosed the orientations of the sheets at each location, a global view of sheet architecture is not clear [2]. Recent advance in tractography based on diffusion spectrum imaging (DSI) has shown complex white matter tracts in the brain [3]. It is equally applicable to the heart, and should have the potential to show global fiber and sheet architecture nondestructively. In this abstract, we demonstrated the myocardial fiber tractography of a dissected cow heart acquired by DSI.

Materials and Methods

Images were acquired with a 1.5 T scanner (Avanto, Siemens, Erlangen, Germany). The pulse sequence was a multislice SE EPI, TR/TE = 4000/150 ms, incorporating a "balanced" double echo: two 180° radiofrequency pulses separated by TE/2, with diffusion gradients of alternating sign to maximize time efficiency and minimize eddy effects. DSI acquisitions sampled 515 q-values comprising a rectangular grid contained within a sphere, this of maximum radius corresponding to a $b_{max} = 8500 \text{ s cm}^{-2}$. Q-ball acquisitions used a spherical shell of 492 ($=10 \cdot 7^2 + 2$) samples comprising a 7-fold geodesated icosahedron, all at $b = 8500 \text{ s cm}^{-2}$. Data were acquired at isotropic resolutions of 4.0 mm. Following reconstruction of orientational spin displacement probability density functions $P(r)$ by integral transform at each voxel (3DFT for DSI, Funk-Radon transform for q-ball), data at each voxel were reduced to vectors V_i of local orientations of maximum diffusion and fiber tracts were reconstructed with a streamline algorithm. Specifically, tracts were extended (integrated) from one voxel to the next by selecting the vector of maximum diffusion closest in angle to the incoming orientation, halting when no such vector was found within a fixed tolerance angle, here 35°. Integration of cross-fiber directions used the same algorithm, only now applied to the vector fields $U_i = V_i \times W_i$ where V_i was the absolute maximum orientation vector of $P(r)$ and W_i were the orientation maxima of the raw signal $S(q)$. By this construction, W_i being the normals to discs of maximum diffusion, $U_i = V_i \times W_i$ indicated directions of maximum diffusion perpendicular to the principal orientation V_i .

Results

Although helical orientation of the myocardial fibers appeared circularly symmetric around the LV, 3D global fiber architecture presented an asymmetric pattern. Fibers with left-handed helix in the outer wall of the LV free wall coursed toward the vortex near the apex and turned upward along the inner wall of the septum and became right-handed helix (Fig. 1). These fibers constituted the main part of long-range fibers in the tractography. The counter part of the asymmetry, i.e., fibers in the outer wall of the LV septum and inner wall of the LV free wall, was less clear. They were formed by short-range fibers without apparent connection at the vortex. Similar to the fiber architecture, the sheet architecture also showed an asymmetry pattern between the septum and free wall. The sheet orientation in the outer wall of the LV free wall was in coherence with the orientation in the inner septum, whereas the sheet orientation in the inner wall of the free wall was in coherence with that in the outer septum (Fig. 2).

The asymmetric pattern of myocardial fiber architecture was a result of figure-eight fiber pathway described previously [4]. Our results further elucidated the close connection between left-handed helical fibers in the LV free wall and right-handed helical fibers in the septum. The asymmetric arrangement of myocardial sheets between free wall and septum was consistent with more recent findings by LeGrice et al. [5]. With 3D reconstruction of sheet pathways, two cylinders of sheet architecture off set laterally were revealed (Fig. 2). It is interesting to note that the same finding was also observed in the esophagus in which circular fibers formed two shifted cylinders in the esophageal wall [6].

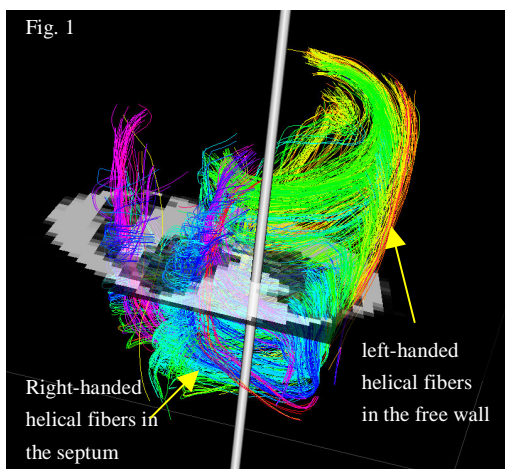


Fig. 1. Asymmetric geometry of fiber pathway: Left-handed helical fibers (in green and yellow) arise from the basal free wall, course downward to the apex, and turn upward along the septum and become right-handed helical fibers (in blue and red).

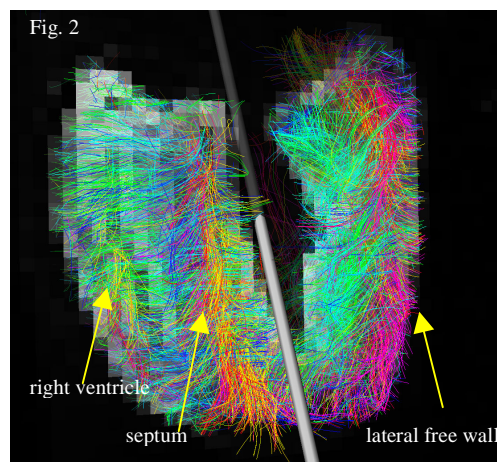


Fig. 2. Asymmetric pattern of sheet architecture: sheets in the outer free wall (in pink) are in coherent orientation with those in the inner septum (in yellow), whereas sheets in the inner free wall (in green) are consistent with those in the outer septum (in blue).

Conclusions

A clearer view of global fiber and sheet architecture of the LV myocardium can be shown by DSI tractography. Being capable of resolving intersecting fiber orientations, DSI tractography plays an indispensable role in depicting complex sheet architecture. This technique can be further applied to various disease models to study functional significance of the asymmetric patterns of the myocardial fibers and sheets.

Reference [1] Streeter. Handbook of Physiology, vol 1. American Physiological Society, 1979. p61–112. [2] LeGrice et al. Am J Physiol 1995;269:H571–H582. [3] Wedeen et al. Proc. ISMRM 2000, p82. [4] Torrent-Guasp. Madrid: Fundacion Juan March, 1973. [5] LeGrice et al. Circ Res 1995;77:182–193. [6] Magnusson et al. Proc. ISMRM 2005, submitted.