Diffusion Spectrum Imaging Resolves Complex 3-Dimensional Myocardial Fiber Architecture in Normal and Infarcted Myocardium

D. E. Sosnovik[1], G. Dai[1], M. Novikov[2], A. Rosenzweig[2], and V. Wedeen[1]

[1]Martinos Center for Biomedical Imaging, Massachusetts General Hospital and Harvard Medical School, Boston, MA, United States, [2]Cardiology, Beth Israel Deaconess Meical Center and Harvard Medical School, Boston, MA, United States

Background and Aims: The elucidation of 3D myocardial fiber architecture in normal and diseased hearts has been impaired by methodological limitations. Diffusion tensor imaging (DTI) has previously been used to image myocardial fiber architecture both ex vivo and in-vivo. The principal Eigenvector of the diffusion tensor in a voxel can be used to determine the average direction of myofiber orientation in that voxel. The limitations of DTI, however, allow only a single average fiber orientation to be calculated for each voxel, and DTI is thus not able to image more complex myocardial fiber architectures. Diffusion spectrum imaging (DSI) has been recently introduced for MR tractography and has been shown to be able to resolve extremely complex fiber architectures. DSI has been used to image fiber tracts in the brain but has, as of yet, not been applied to cardiac imaging. The aim of this study was thus to assess the ability of DSI to image complex fiber architecture in both normal and infarcted myocardium.

Methods: DSI was performed on excised rat hearts, immersed in Fomblin, on a 4.7 Tesla scanner (Biospec, Bruker, Billerica MA) using a dedicated 10 mm diameter solenoid coil. Permanent ligation of the left coronary artery was performed on the rats (n = 5) 2 weeks prior to sacrifice and imaging. Age-matched rats with normal hearts (n = 4) were used as controls. DSI images were acquired with a 3D diffusion-encoded spin echo EPI sequence. 515 diffusion encoding q-vectors were sequentially applied during the DSI acquisition, with a maximum diffusion encoding gradient (B-max) of approximately 10000. Other parameters included: Voxel size 400 um isotropic, TR 750 ms, TE 40 ms, Nex =1. Total acquisition time per heart was approximately 12 hours. Tractography was performed, as previously described, by identifying the orientation maxima of the orientation density function. Fibers were color coded according to the helix angle made with the long axis of the heart.

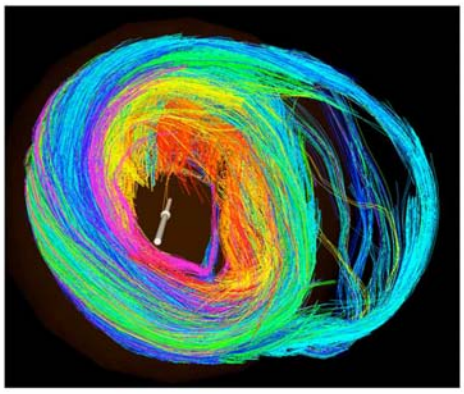

Figure 1

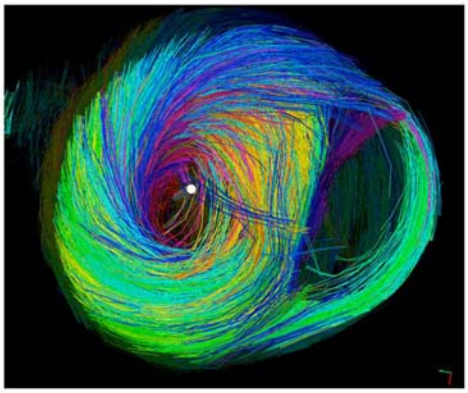

Figure 2

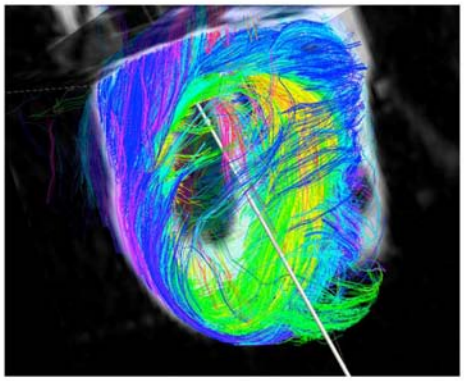

Figure 3

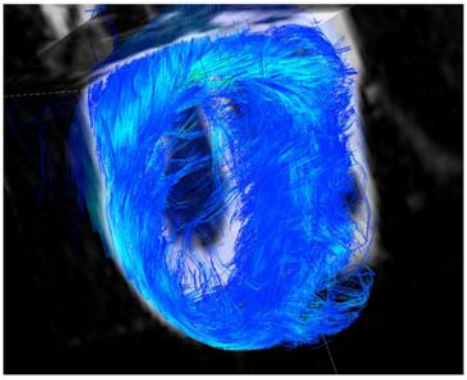

Figure 4

Results: High quality fiber maps could be obtained in all 9 hearts imaged. The expected transmural anisotropy in fiber helix angle was clearly visible, as shown in Figure 1. In addition, complex and crossing fiber orientations could be clearly seen at the insertion points of the papillary muscles, the insertion point of the right ventricle into the left ventricular septum and the left ventricular apex (Figures 1,2). The spiral pattern of the myofibers at the left ventricular apex can be clearly seen, for instance, in Figure 2 .The infarcted hearts all revealed severe thinning in the infarct zone with virtually complete loss of fiber architecture in the subendo-cardioum. Fiber orientation in the border zone of the infarct assumed a more tangential orientation compared to normal (Figure 3). These tangential fibers can be likened to a purse-string around the infarct, and may represent an adaptation to increased wall tension and an attempt to limit infarct expansion. The Laplacian of diffusion in the perinfarct zone was also shown to be decreased (Figure 4). This is consistent with an increase in fiber disarray and suggestive of a proliferative and disordered healing process.

Conclusion: The feasibility and value of performing diffusion spectrum imaging (DSI) in the myocardium has been demonstrated in this study. Complex 3-dimensional fiber anatomy could be resolved with this technique in both normal and pathological hearts. DSI has been performed in the brain in vivo and attempts are underway adapt the technique to in vivo cardiac imaging as well. DSI thus has the potential to provide novel insights into myocardial injury and repair and aid the development of novel therapeutic strategies.