

Study of Myocardial Fiber Length Distribution with Diffusion Tensor MRI

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Introduction

The complex architecture of the heart, where fibers are branched and organized in overlapping spiral bundles, makes it difficult to analyze cardiac mechanics [1]. DTI is a new means to elucidate the microscopic anatomical characteristics of the myocardium. Numerous studies [2-3] have been reported, most of which focus on fiber orientation, especially the fiber helix angle which refers to the angle between the projection of the diffusion tensor eigenvector on the tangential plane and the transverse plane. Results indicate the fiber helix angle roughly ranges from -90° to 90° from epicardium to endocardium (see Fig. 1). However, the mechanical performance of the myocardium depends on several other factors intrinsic to the contractility, such as the myocardial fiber length. In this study, fiber length distribution as a function of fiber helix angle was investigated in multiple short-axis slices of the left ventricles. The aim is to provide supplementary structural information on myocardial fiber architecture and cardiac mechanics.

Method

Imaging experiments were conducted on a 3T Philips Achieva MR imager with a quasar gradient. The formalin-fixed porcine heart samples (N=5) were suspended in a cylinder filled with formalin and placed in an 8-channel SENSE head coil. DTI was performed along the short-axis of left ventricle using spin echo EPI (SE-EPI). Imaging parameters were as follows: TE=45 ms; TR=1.0 s; FOV=130x130 mm²; slice thickness=3 mm; slice gap=0 mm; diffusion b=800 s/mm²; number of gradient directions=15; matrix size=128x128; number of slices=15; and NEX=40. The total scan time for each heart sample was ~50 minutes. The image co-registration and three-dimensional reconstruction of fiber tracks were obtained by using the PRIDE software package (Philips Medical Systems; Best; Netherlands). Fiber length and helix angle were calculated pixel-by-pixel on each slice. Left ventricle myocardial papillary muscles and right ventricle were excluded in the analysis. Effect of fiber tracking termination criteria was examined by using varying fractional anisotropy and directional thresholds but their influence was found to be negligible on the overall pattern of fiber length distribution.

Results

With each short-axis slice, average fiber length was computed for each helix angle range that has 10° step. Fig. 2 illustrates the result of five representative slices from base to apex among five samples. Fibers at middle and upper ventricle (slice 4, 6 & 8) are generally longer than those near apex (slice 10 & 12). In each slice, the longest fibers usually have small helix angles within -20° and 20° . Fibers with large helix angles are usually shorter. That is, long fibers likely run circumferentially rather than longitudinally. By weighting the fiber length by respective fiber number, major fiber bundles can be identified. As shown in Fig.3, the long fibers with small helix angles dominate the myocardial fiber architecture in terms of total length of fibers. Fig.4 shows that, if two fiber bundles with different helix angles are tracked from the same slice, their paths and lengths will be totally different. The bundle with a small helix angle of -4.6° spirals circumferentially with long fiber length, while the bundle with a large helix angle of 59.6° runs from endocardium down towards apex and then up back to epicardium with relatively short fiber length.

Discussion

Distribution of fiber length with respective fiber helix angle was investigated in fixed porcine heart samples using DTI. In general, the fibers at middle and upper ventricle are found to be longer than those near apex. Long fibers likely run circumferentially with small helix angles, forming the dominant fiber bundles in myocardium. Although DTI-tracked myocardial fibers are of virtual nature, they are likely related to the sarcomeres, which are the contractile protein units that are responsible for producing contraction force along the sarcomere or fiber direction. At long sarcomere length, the calcium affinity of the contractile proteins increases and the ability of calcium to activate contraction enhances [1]. Given this, our result suggests that the long fibers that have small helix angles and spiral circumferentially contribute more to the myocardial contraction than those run longitudinally. This is also consistent with the previous finding that the principal thickening is predominantly radially oriented throughout the myocardium in cardiac deformation [2]. To our knowledge, the present study is the first report on the myocardial fiber length distribution.

References

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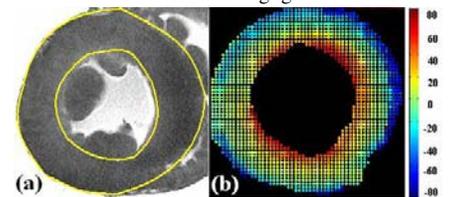


Fig.1 LV myocardium anatomical image (a) and fiber helix angle map (b). The helix angle ranges from -90° to 90° from epicardium to endocardium.

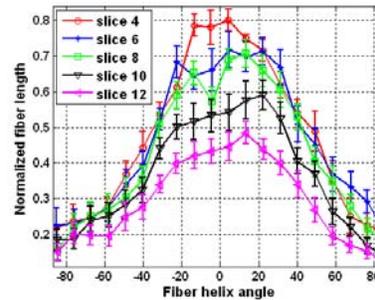


Fig.2 Distribution of normalized fiber length within five short-axis slices among five porcine heart samples. Fibers with small helix angles are longer than those with large helix angles. Fibers at middle and upper ventricle (slice 4, 6 & 8) are generally longer than those near apex (slice 10 & 12).

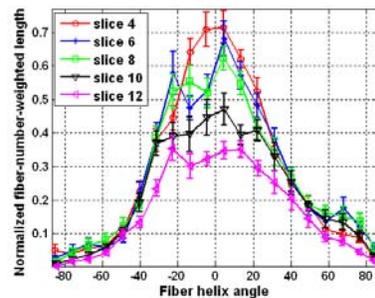


Fig.3 Distribution of normalized fiber-number-weighted fiber length within five short-axis slices located from base to apex among five porcine heart samples. It can be seen that the bundles made up of long fibers with small helix angles within -20° and 20° dominate the fiber architecture.

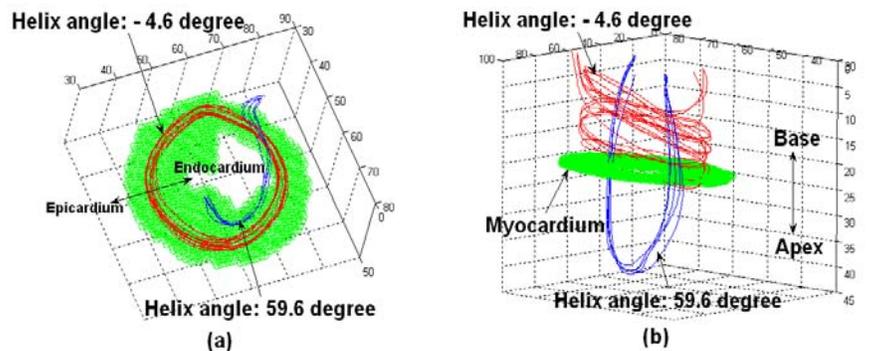


Fig.4 Transverse (a) and sagittal (b) view of two bundles tracked from the same slice but with different helix angles. For the bundle in red with a small helix angle of -4.6° , it spirals circumferentially with long fiber length. While, for the bundle in blue with a large helix angle of 59.6° , it runs from endocardium down towards apex and then up back to epicardium with short fiber length.