Heterogeneity of DTI Diffusion Anisotropy in the Myocardium

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Introduction. MR diffusion tensor imaging (DTI) (1) has emerged as an efficient and accurate means to characterize the 3D myocardial structure of the heart (2). To date, cardiac DTI studies have focused mostly on the analysis of the spatially-varying fiber architecture obtained from the orientational information in the diffusion tensor. However, the scalar quantities including the diffusivities and anisotropy have simplistically been assumed to be uniform throughout the entire heart (3,4), and the validity of this assumption remains largely untested. The current study examines these diffusion tensor scalar indices as functions of myocardial ventricular transmural depth and circumferential and longitudinal slice locations.

Methods. DTI (3D acquisition, 0.78 mm isotropic-resolution) of excised and fixed normal adult male sheep hearts (N = 4) was performed on a 2.0 T MRI instrument (5). Regions of interest on the left ventricle (LV) were defined on 5 equally-spaced cardiac short-axis slices covering the majority of LV and 4 orthogonal 20°-wide sectors (septal, posterior, lateral, and anterior) on each slice. Within each sector, profiles as a function of the normalized transmural depth of the fractional anisotropy (FA) (6), principal diffusion tensor eigenvalues (primary, secondary, and tertiary), mean diffusivity, and fiber helix angle were obtained. To examine the transmural variations, one-way ANOVA was performed on the measurement average in each quartile transmural depth. Moreover, the FA was empirically fitted to a step-ramp function, yielding the transition point, slope and intercept for each profile. Two-way ANOVA was performed for comparison of each fitted parameter among the slice locations and circumferential sectors. Lastly, to determine if a link exists, paired Student's t-test was performed between the FA profile transition point and the location where fiber helix angle is zero.

Results and Discussion. Analyses of the scalar index profiles are summarized in Fig. 1. The FA profile follows a step-ramp appearance, staying relatively constant from epicardium to midwall then decreasing steadily toward the endocardium. The average FA in the endocardial zone is significantly lower (25.7%) than that of the epicardium. Additionally, no significant change of the primary eigenvalue and the mean diffusivity, but significant increases of the secondary (7.9%) and tertiary (12.9%) eigenvalues were found. Although sorting error induced by image noise can artificially bias the distribution of the diffusion tensor eigenvalues, this is unlikely since it only increases the difference between the eigenvalues. The lower FA and higher secondary and tertiary diffusivities are consistent with larger (cross-sectional area) myocytes (7), lower myocyte density (8), and larger extracellular volume fraction (8) found in the endocardium by histological studies.

Statistical tests reveal significant regional difference in the midwall-endocardium slope of FA between the septum and the posterior or lateral LV free wall. Moreover, the FA profile transition point coincides with the location where myocardial fibers are oriented exactly in the circumferential direction (i.e., fiber helix angle is zero). Combined, these findings indicate that scalar indices derived from DTI are sensitive to the transmural variation in cellular arrangements of the myocardium, and the heterogeneity must be taken into account for accurate functional modeling of the heart.

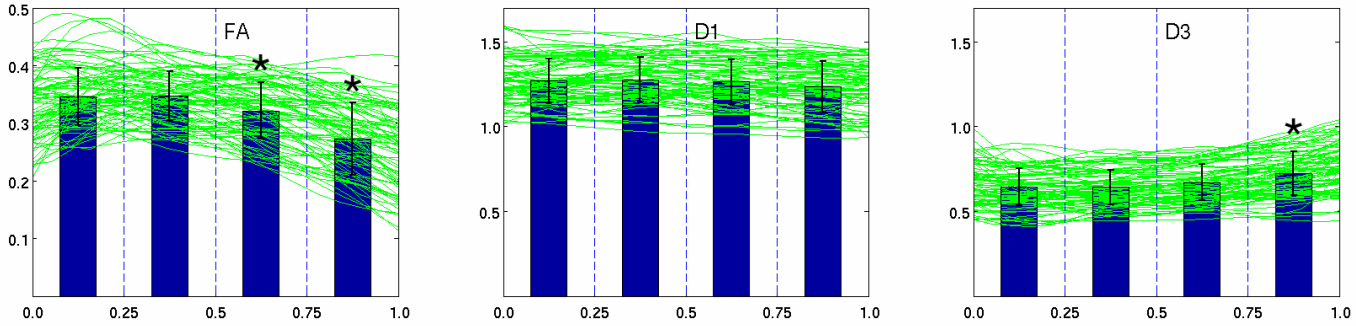

Figure 1: Profiles as function of normalized transmural depth (0.0 and 1.0 corresponding the epicardium and endocardium, respectively) for the diffusion tensor FA, primary and tertiary eigenvalues. Profiles (solid lines) obtained for all specimens and circumferential and longitudinal slice locations (n = 80 total) are shown. The overlaid bar graphs represent the mean and standard deviation of the parameter in each quartile segment of the transmural depth. Asterisks (*) denote regions where the parameters are significantly different. The unit for diffusivity measurements is 10^{-3} mm^2/s.

Reference.

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