Visualization of high-resolution myocardial strain and diffusion tensor using super-quadric glyphs

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Introduction: Tensor data are frequently a result of magnetic resonance imaging (MRI). Most commonly they arise in diffusion tensor imaging (DT) of the brain and heart as well as in the strain fields of deforming myocardium. Creating informative and intuitive visualizations of anatomical structure is challenging due to the multi-variate nature of tensor data. Herein we present a novel technique for visualizing canine myocardial DT data and high resolution myocardial strain data.

Methods: High resolution (390µm x 390µm x 800µm) DTMRI using 16 encoding directions was performed on excised formaldehyde fixed canine myocardium using a fast spin echo 3D diffusion encoding sequence at 1.5T. For high resolution (1.5mm x 1.5mm in plane, 6mm thickness sinc interpolated to 3mm) quantification of myocardial strain tensors the DENSE technique was used [1]. In each case the local tensor fields were computed and decomposed into the eigenvalues and eigenvectors.

The shape of a real symmetric tensor, as determined by its eigenvalues, can be parameterized by the geometric anisotropy metrics C_S, C_P, C_L [2]. There are four basic configurations: $\lambda_1 = \lambda_2 = \lambda_3$ (spherical, high C_S), $\lambda_1 < \lambda_2 = \lambda_3$ (planar, high C_P), $\lambda_1 > \lambda_2 = \lambda_3$ (linear, high C_L), and $\lambda_1 > \lambda_2 > \lambda_3$ (cuboid). Superquadric implicit functions provide a means of creating a continuum of shapes between these four configurations (Figure 1) [3]. In comparison to existing glyphs based on ellipsoids or boxes, these glyphs have the advantage of clarifying shape differences without inappropriately emphasizing the tensor orientation determined by its eigenvectors (e.g. if representing $\lambda_1 = \lambda_2 = \lambda_3$ with a cube, the face normals visually imply eigenvector directions that are not meaningful). When all eigenvalues are equal, the superquadric glyph is spherical, reflecting the numerical indeterminancy of the eigenvectors. For the case of three distinct eigenvalues, the cuboid glyph indicates the eigenvalues with its edge lengths, and the eigenvectors with its face normals. When two eigenvalues are equal (either planar or linear in shape), the glyphs depict the indeterminancy of the corresponding eigenvectors with circular cross-sections. Qualitative visualization of field structure may be improved with exaggerating tensor shape, by increasing the deviatoric component of the tensor [4], while fixing its determinant and eigenvectors, so as to maintain glyph volume and orientation.

Herein the DTMRI data was downsampled 3x. The glyph length scales of the diffusion tensors depict the eigenvalues of the diffusion tensor, and the glyph orientation represent the eigenvectors of the diffusion tensor. For strain tensors the directionality is obtained from the eigenvectors of the Lagrangian strain tensor, but the glyph length scales are obtained from the strain tensor's stretch ratios, thereby depicting deformation relative to the unit cube. Shape exaggeration was used only for strain tensor visualization.

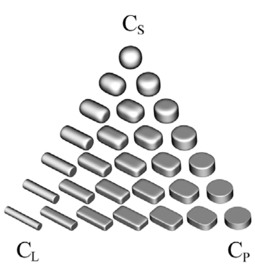

Fig. 1 Glyph continuum.

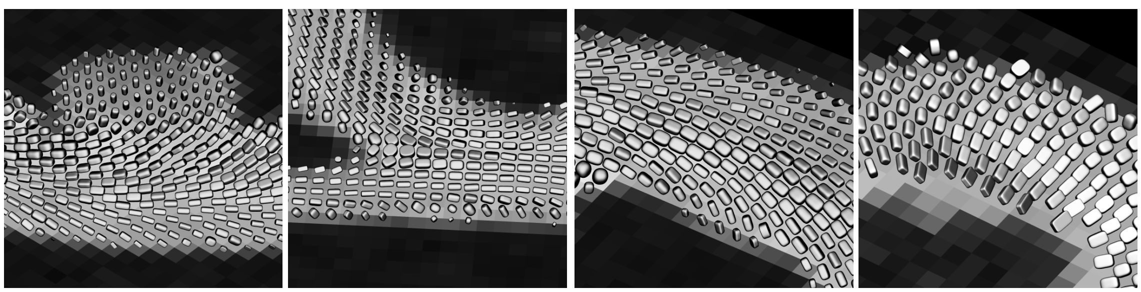

Fig 2a. Papillary muscle fibers 2b. RV insertion fibers 2c. LV free wall fibers 2d. LV free wall strains

Results: ***DTMRI***: Tensors in the papillary muscles are more cigar shaped (high C_L) and are oriented to predominantly align along the long axis of the papillary muscle (Figure 2a). Diffusion tensors near the right ventricular insertion to the left ventricular myocardium appear more disk like (high C_P) indicating fibers that are branching out to course along the right ventricular free wall and the interventricular septum (Figure 2b). The disk orientation is still largely in the short-axis imaging plane. The left-hand transmural helix of fiber orientation is clearly demonstrated in Figure 2c. In general the myocardial DTMRI tensors are higher in C_L than in C_P or C_S. ***DENSE***: Transmural DENSE strain measures demonstrate the tendency of epicardial shortening to parallel the epicardial fiber direction and for endocardial fibers to lie perpendicular to the primary shortening direction on the endocardium as previously reported (Figure 2d) [5]. Strain tensors in neighboring regions do not exhibit the same helical pitch indicating that diffusion and strain tensors do not remain co-axial. A gradient in radial thickening across the wall is clearly evident.

Discussion: This class of superquadric functions, combined optionally with shape exaggeration, is useful for visualizing the spatial patterns of variation in tensor fields of both myocardial DTMRI and DENSE strain maps. The qualitative visualization can be used to guide subsequent quantitative analysis of these tensor fields, and to refine methods of tensor field acquisition and processing.

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