Elucidating Neural Structure in Diffusion Tensor MRI Volumes using Streamtubes and Streamsurfaces

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Introduction

Tensor-valued diffusion rate measurements in the nervous system have the potential to elucidate connectivity and other microstructural information[1]. We present a new method for visualizing 3D volumetric diffusion tensor MRI images. We distinguish between linear anisotropy and planar anisotropy and represent values within the two regimes using streamtubes and streamsurfaces, respectively. Streamtubes represent structures with primarily linear diffusion, typically fiber tracts; streamtube direction correlates with tract orientation. The cross-section shape and color of each streamtube are used to represent additional information for the diffusion tensor matrix at each point. Streamsurfaces represent structures in which diffusion is primarily planar. We also generate anatomical landmarks to identify the positions of prominent structures, such as eyes, skull surface, and ventricles. The final models are 2D surface geometries that can be imported into many interactive environments.

In the literature, researchers have successfully designed visualization methods for 2D slices of diffusion tensor fields. These include ellipsoids[2] as well as a normalized version of the ellipsoids and a painting-motivated method[3]. Directly extending these methods to volumes would not only be expensive but would also result in self-obscuring geometry. Two approaches have been explored for visualization of 3D second-order tensor fields. One uses volume rendering[4], the other uses a geometric representation[5]. We extend the latter approach, originally applied to tensors related to fluid flow instead of diffusion, to visualize microstructural information in biological tissues.

Methods

We distinguish between structures exhibiting linear anisotropy and those exhibiting planar anisotropy. Streamtubes and streamsurfaces, respectively, represent these two types of diffusion. Streamtubes represent linear structures, where diffusion is much faster in one direction. The trajectory of each tube sweeps along the principal direction of diffusion, and the cross-section shape is an ellipse representing the diffusion rates in the directions perpendicular to the trajectory. We normalize the maximum radius of the ellipse to a constant value so that the size of the streamtube is predictable while its aspect ratio is preserved. The color of the streamtube shows how anisotropic the diffusion is. Streamsurfaces represent surface structures, where diffusion is faster within a plane than perpendicular to the plane. The surface we generate is an approximation of the integral surface perpendicular to the direction of slowest diffusion. Colors are mapped to the surfaces to show how anisotropic the diffusion is.

Our algorithm begins by generating many streamtubes and streamsurfaces and then culls those down to a representative subset. Initially, every voxel with a linear or planar anisotropy value greater than some threshold has a representative streamtube or a streamsurface. The criteria for selecting the subset to display include the size of the geometry, the average anisotropy in the region containing the geometry, and the similarity of the geometries. Geometries with low scores on these criteria are discarded. A representative subset of geometries is kept and displayed in the final image.

Results

Figs 1 and 2 illustrate results of our method applied to data acquired from a human brain (data courtesy Dr. Susumu Mori, Johns Hopkins). Many gross features are readily apparent in the results; several are identified in the figures. There are 426 streamtubes in the final image after the culling process, compared to about 900,000 streamtubes initially generated.

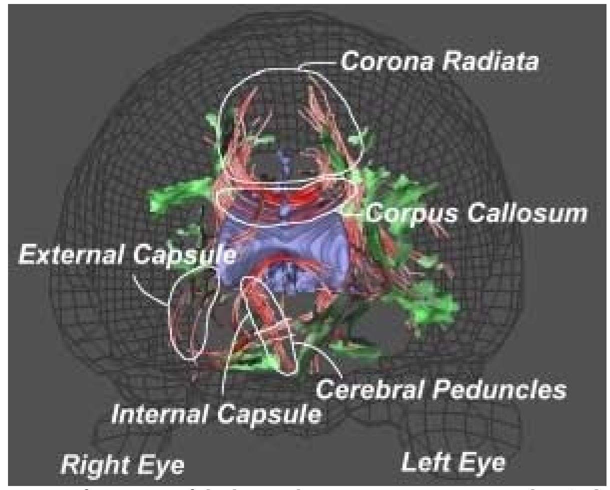

Fig 1. A front view of the human brain image using streamtubes (red), streamsurfaces (green) and anatomical landmarks (blue ventricles and wireframe brain surface). Anatomical features, including the corpus collosum and corona radiata, are clearly visible in the image.

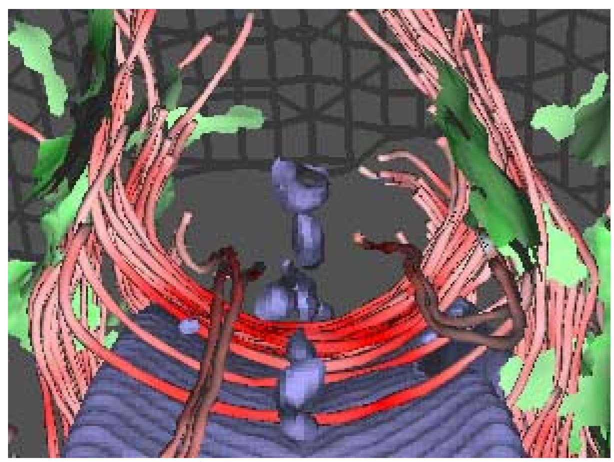

Fig 2. A close view of the corpus collosum in the human brain using streamtubes, streamsurfaces, and anatomical landmarks.

Discussion

We are continuing to investigate the more subtle features that may be visible and the tradeoffs among the several selection criteria for choosing streamtubes and streamsurfaces for display. Early results show promise for understanding connectivity in a volume and suggest that more anatomical context and additional interactivity will help make exploration more effective.

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References

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