Visualization of the Interaction of Multiple Sclerosis Lesions with Adjacent White Matter Fibers Using Streamtubes and Streamsurfaces

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Introduction

Multiple sclerosis (MS) is a chronic disease of the central nervous system that predominantly affects young adults during their most productive years. Pathologically, MS is characterized by the presence of areas of inflammation, demyelination and axonal injury in the brain white matter. In order to study the effect of MS lesion on the white matter, we acquire diffusion tensor imaging (DTI) data on MS patients and employ streamtubes and streamsurfaces to visualize the DTI data. We also register structural data sets with DTI data sets and generate isosurfaces of the MS lesions and the ventricles. The simultaneous visualization of all the models has the potential to elucidate the complex relationship between the MS lesions, the white matter neural fibers, and the affected gray matter regions.

Take home messages

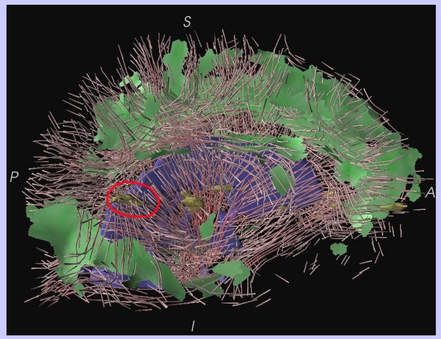
- Streamtube and streamsurface models help visualize the relationship between MS lesions and the white matter structures.
- The visualization show a range of white matter behaviour within and near lesions.
- By seeding from the lesion areas, streamtube models have the potential to illustrate affected white matter structures and their relationship to potentially multiple lesions.

Background

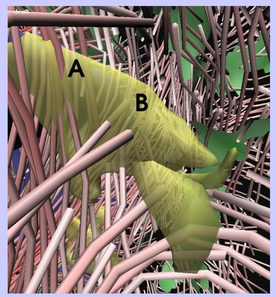
DTI measures the diffusion of water molecules. In biological tissues, the primary direction of the diffusion correlates with the orientation of structures such as in muscles or neural fibers. Therefore DTI reveals the white matter fiber structures [1]. DTI has been applied to study various white-matter diseases [2]. While demyelination is central to the onset of MS, the study of injury to the axon has become an important new area of MS research. Axonal injury is now considered the important contributor to disability and possibly conversion to progressive stages of disease. By visualizing axonal transection by confocal microscopy [3] and accumulation of amyloid precursor protein [4] in pathology specimens, researchers have found evidence of primary injury to axons in the early inflammatory stages of MS. In advanced stages of MS, there is direct evidence of significant neuronal dropout for example in corpus callosum [5]. In vivo, there is circumstantial evidence for neuronal tract injury in early MS [6, 7], based on neuronal tract degeneration in corticospinal tract and across the corpus callosum (transcallosal bands) after single, focal inflammatory demyelinating events. That these in vivo responses to individual MS lesions represent axonal injury is supported by an informative case study where confocal microscopy reveals empty myelin cylinders in neuronal tracts in spinal cord related to a distant subacute brainstem MS lesion [8]. While experiments evaluating MS neuronal tract and focal lesions are underway, it has become clear that the analyses are limited when a priori assumptions are made about the anatomical location of lesions relative to fiber tracts. A comprehensive tool including DTI and other structural images is required to incorporate all the available information to understand the complex interactions between an inflammatory lesion and intersecting fibers.

Methods

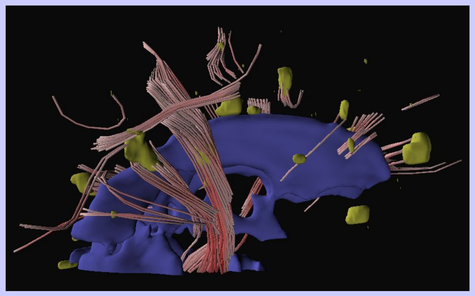
We visualized DTI data together with structural MRI data. We acquired these datasets using 3T MRI from a MS patient with early disease and a low lesion load. The DTI data sets are 256×256×45 volumes with voxel size of 0.875×0.875×1.75mm. Visualization of the DTI data includes red streamtubes representing regions of linear diffusion anisotropy, green streamsurfaces representing regions of planar anisotropy, and blue cerebrospinal fluid regions for anatomical context [9]. Focal MS lesions from the structural MRI are registered with the DTI data set and represented as yellow surfaces.

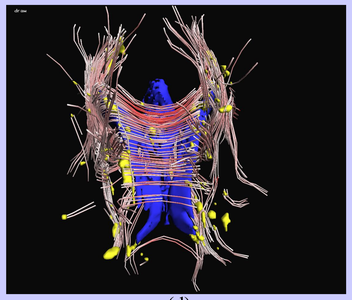


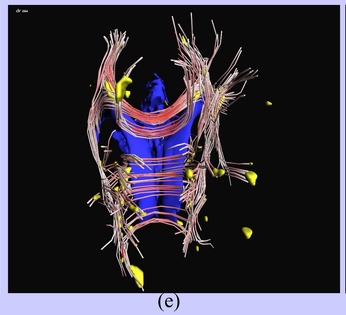
(a)

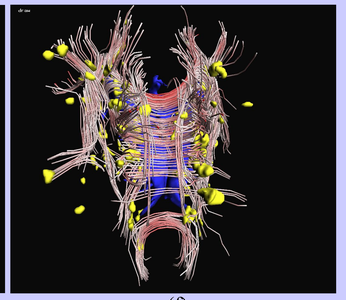


(b)


(c)


(d)


(e)


(f)

Results

- A whole-brain visualization as shown in (a) provides context for MS lesions within the complex connectivity of human white matter.
- Examine the visualization in more detail (b), it is clear that streamtubes sometimes pass through these lesions (A) and sometimes break within them (B). Both behaviors are consistent with demyelinating lesions.
- (c) shows lesions, ventricle, and only the subset of streamtubes that contact the surface of the MS lesions. This view provides perspective that can be utilized to determine the relationship between focal lesions and the neuronal tracts that are anatomically related.

Difference between subjects

- We employ the same visualization technique as in (c) to 3 different subjects (d,e,f).
- The difference in streamtube structures reflects the different magnitude and location of MS fiber at risk suffered by the three patients, a perspective that would not be possible by standard imaging approach.
- The similarity and difference between the models across these subjects can be useful for studying the injury from MS lesions at different stages of disease, and the effect of treatment.

Acknowledgments

This work is supported in part by the National Multiple Sclerosis Society (Neuronal Tract Degeneration in Early MS), NSF (CCR-0086065), and the Brain Science Program at Brown University.

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