

# 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 demyelination and T-cell predominant perivascular inflammation 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.

## Related Work

DTI measures the diffusion of water molecules. In biological tissues, the primary direction of the diffusion correlates with the orientation of the fibrous structures such as 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 both datasets using 3T MRI from a MS patient with early

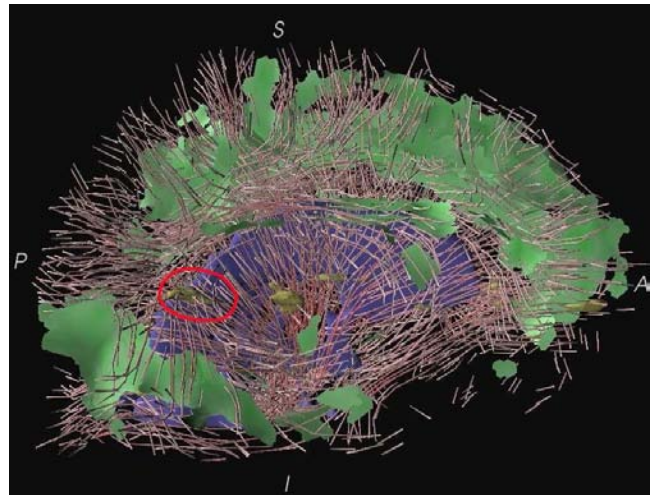


Figure 1: Whole-brain visualization of a diffusion imaging dataset from a MS patient. The visualization shows the lesion mask in semi-transparent yellow surfaces along with the streamtubes model, the streamsurfaces model, and the ventricles. The lesion mask was collected in a separate acquisition, segmented manually, and registered with the DTI data set. The circled region is detailed in Fig. 2.

form of the disease and a low lesion load. The DTI data set is a  $256 \times 256 \times 45$  volume with voxel size of  $0.875 \times 0.875 \times 1.75$ mm. 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.

## Results

A whole-brain visualization as shown in Fig. 1 provides context for MS lesions within the complex connectivity of human white matter. We displayed this visual representation in several interactive environments, including a standard desktop and a fishtank virtual reality (VR) display environment. Stereo display in the VR environment helps the user determine the 3D structural relationships between lesions and white matter structures.

Examine the visualization in more detail (Fig. 2), it is clear that streamtubes sometimes pass through these lesions and sometimes break within them. Both behaviors are consistent with demyelinating lesions. A third possible behavior, which we did not observe here would be for lesions to displace white matter fibers. We hypothesize that the latter behavior would be more consistent with neoplasm or rare tumefactive MS lesions, and our visualization method may help distinguish neoplasm from MS lesion, a task that

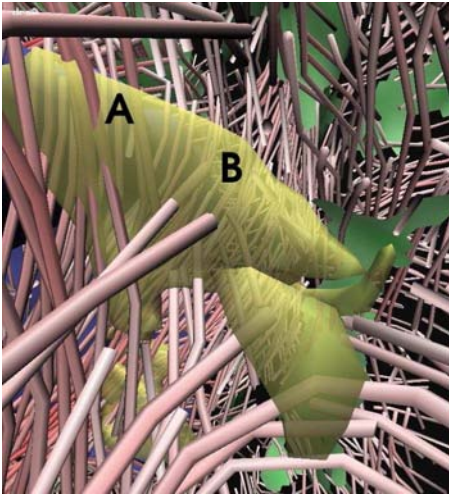


Figure 2: A detailed view of the white matter fibers near the MS lesions. The streamtubes around the lesion area give some clues about structural changes in the white matter near the lesion. Note that the streamtubes sometimes continue through the lesions (A) and sometimes break within them (B).

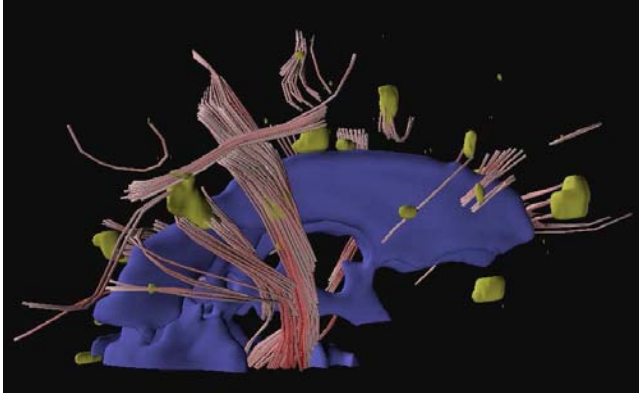


Figure 3: The same brain and view as Fig. 1, but showing only streamtubes that contact the lesions. This visualization highlights the relevant white matter structures.

is at times difficult with conventional MR imaging.

Fig. 3 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. From this visualization it is possible to determine which specific fibers are involved, their direction and their potential functional significance, all of which is difficult or impossible with conventional 2D or 3D imaging.

## Discussion and Conclusion

The visualization approach we describe helps elucidate where lesions are located in the human brain and how extensively they affect white matter structures. There is no other non-invasive method for making these observations. These results suggest that such visualization methods may be valuable to observe the progression of MS over time, to improve our understanding of the underlying pathophysiology and to assist in differential diagnosis.

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