Estimation and Comparison of Brainstem Fiber Orientation Via Diffusion MRI Tractography and Polarization Sensitive OCT

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Abstract

Diffusion MRI-based tractography methods reconstruct neural pathways but often lack detailed microstructural information. This study compares fiber orientation distribution in the human brainstem obtained through Constrained Spherical Deconvolution tractography and Polarization Sensitive Optical Coherence Tomography.

Introduction

Neurodegenerative diseases are a wide range of conditions that result from progressive damage to nervous system connections that are essential for mobility, coordination, and cognition. An important imaging technique to assess the microstructural changes caused by these conditions is **diffusion Magnetic Resonance Imaging** (dMRI)–based tractography, which provides a visual map of the white matter nerve tracts represented by **glyphs**, based on the diffusion of water in the brain.

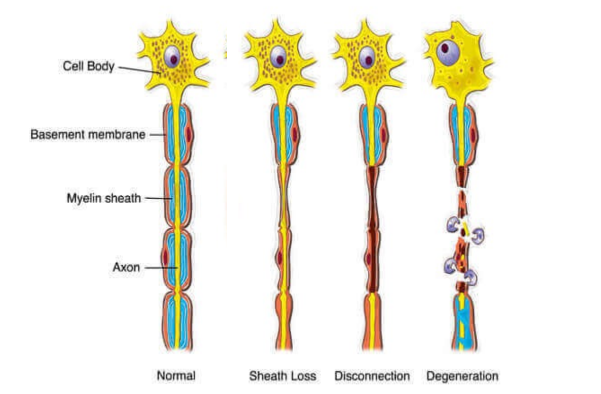

Figure 1. White matter tract degeneration[3]

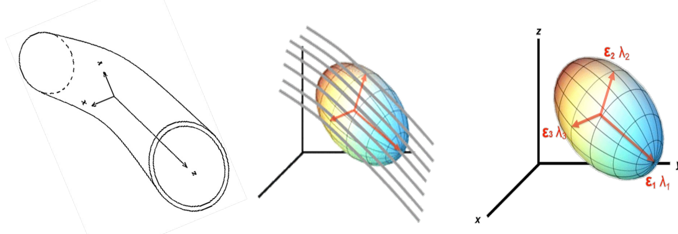

Figure 2. Diffusion tensor ellipsoid[4]

However, it is limited by its **low specificity** and **limited resolution** of milimeters or hundreds of microns compared to the typical size of nerve fiber bundles of around 10-20 μm. This might lead to a misinterpretation of the brain structure, especially in complex regions such as crossing fibers[1].

Polarization Sensitive Optical Coherence Tomography (PS-OCT) is an optical imaging method used to validate and assess how biologically accurate dMRI is. It works based on the changes in polarization of backscattered light, and one of its main properties, the **optic axis**, extracts information about the orientation of nerve fibers which are wrapped in a myelin sheath, a highly birefringent component[2].

Methods

A fixed human brainstem sample was imaged using a 7T Bruker Biospec MRI scanner with a spatial resolution of **300 μm**. Using the software MRTRIX3, tractography was performed on this sample to generate glyphs representing the orientation of the fibers.

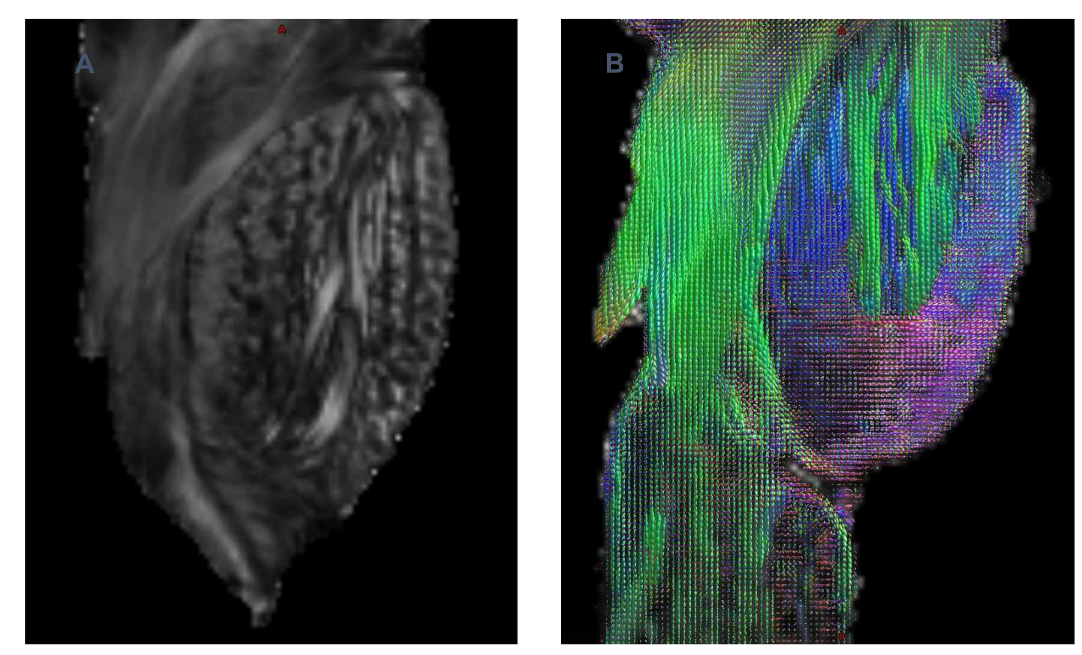

Figure 3. (A) Axial MRI scan of the sample. (B) Glyph map generated with MRTRIX3.

The same sample was imaged using a Thorlabs PS-OCT set up selecting a FOV of 9 mm for both x and y, and 2.53 mm for z. The pixel size selected was **10 μm** for both x and y, and 2.47 μs for z.

Figure 4. (A) PS-OCT set up. (B) Selected ROI. (C) Average intensity of the ROI obtained with PS-OCT.

En-face maps were generated from the optic axis by extracting 50 slices in z and selecting the highest frequency angle for the same pixel position (x,y) in each of the slices. The same process was performed for groups of **30x30 pixels** in the same slice to downsample the map and match the dMRI spatial resolution.

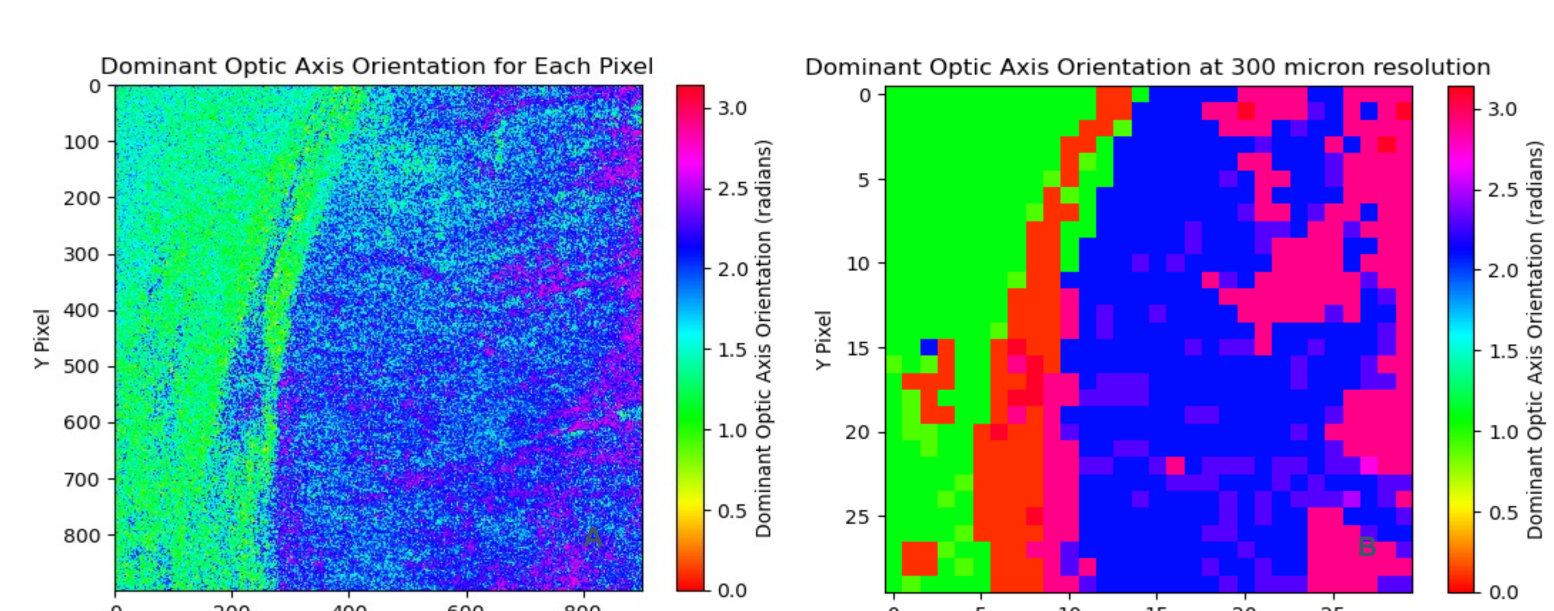

Figure 5. (A) Generated en-face map of the optic axis. (B) New map for groups of 30x30 pixels.

Results

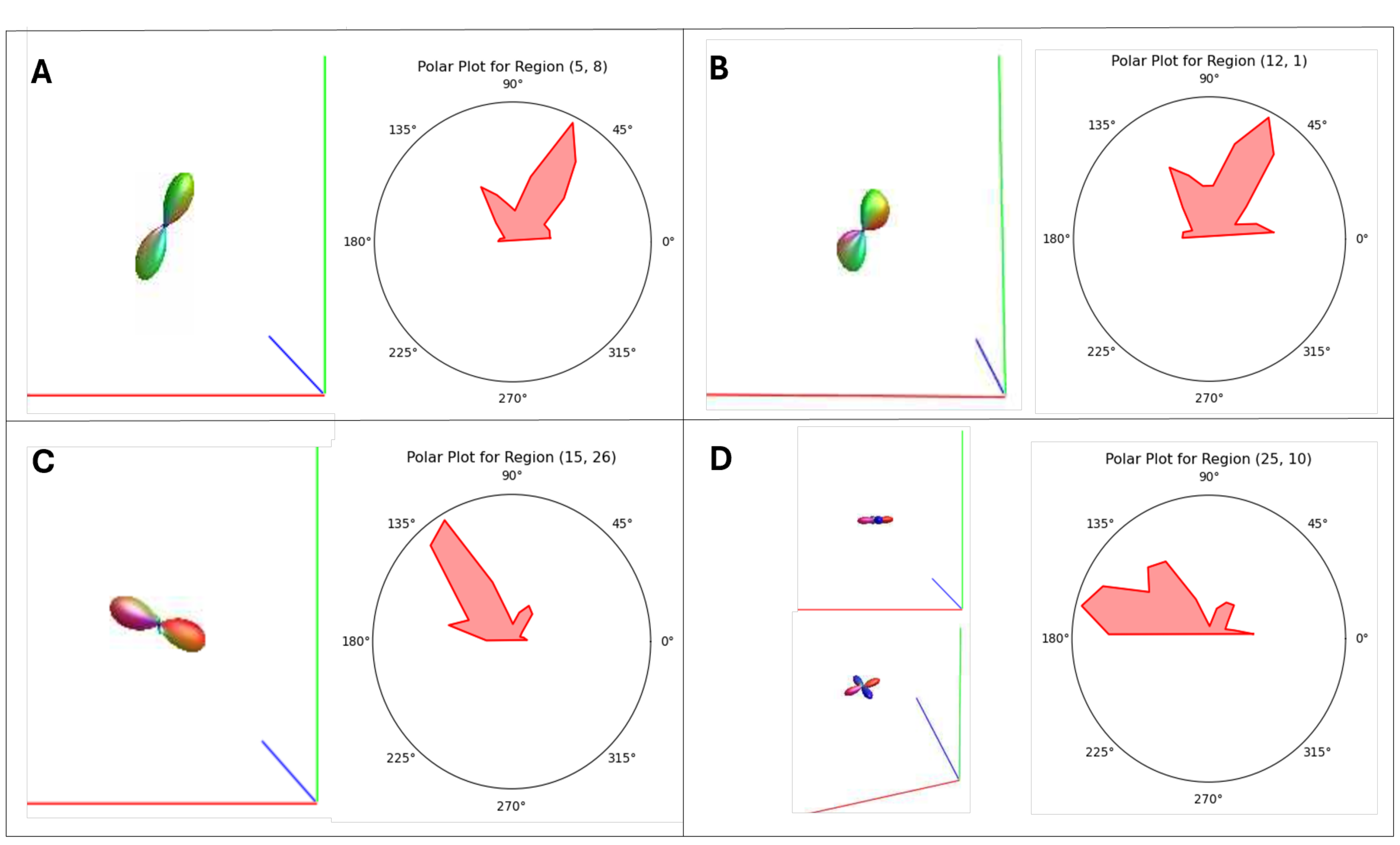

Figure 6. Glyph and PS-OCT polar representation for regions of: (A) , (C) Coherent fibers . (B) Crossing fibers. (D) Crossing fibers where one of them is travelling in a direction perpendicular to the xy plane.

Conclusions and Future Work

- PS-OCT shows promise as a tool for validation of dMRI data and differentiation of fiber bundles in architecturally complex regions such as the brainstem.
- PS-OCT is not sensitive to fibers oriented perpendicular to the imaging plane.
- Conduct co-registration between dMRI and PS-OCT maps for direct quantitative comparison.
- Perform imaging at different inclination angles to generate 3D fiber orientations using PS-OCT.

Acknowledgments and References

Thank you to all the members of the Biomedical Optics and Optical Measurement Lab, and the Multi-Scale Brain Imaging Lab. Special acknowledgments to Dr. Travis Sawyer and Dr. Elizabeth Hutchinson.

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[3] Website: “Medatrio: Degeneration & regeneration of peripheral nerves”.
[4] Website: “Medscape: Diffusion Tensor Imaging”, and “Questions and Answers in MRI”.

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