

Using Optical Coherence Tomography to Validate Diffusion MRI

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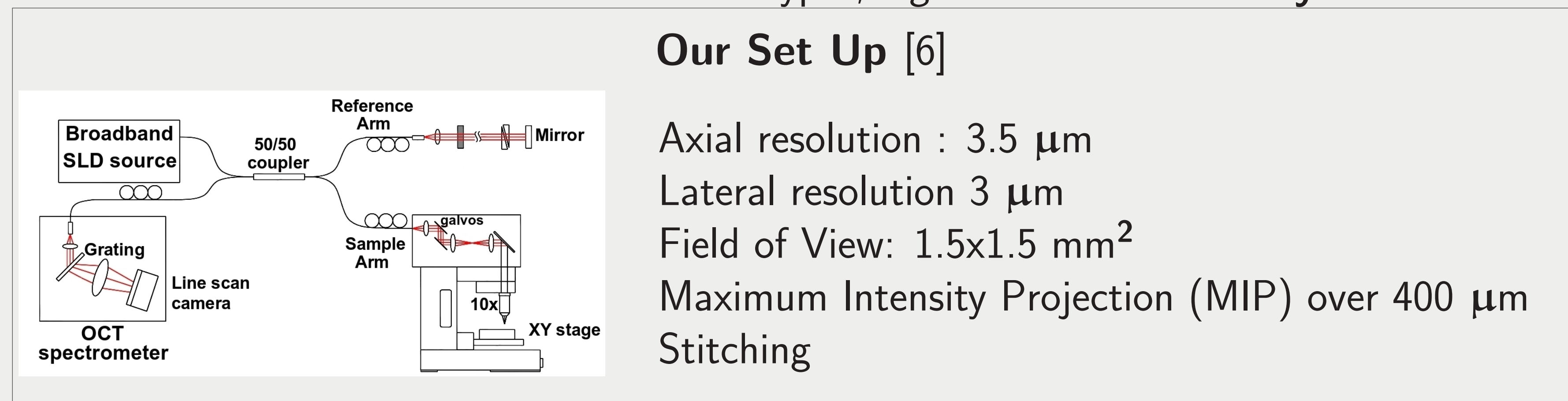


Introduction

Diffusion-weighted MRI (DW-MRI) allows us to probe the microstructure of the white matter (WM) by estimating the preferential directions of the diffusion of water molecules at every voxel. Although DW-MRI is now widely used to study WM integrity in health and disease, its validation has been challenging due to the absence of ground truth regarding the true fiber orientations and connectivity of the brain. Tracer studies can be used for this purpose [2]. However, such tracers, like Dil [3], penetrate tissues very slowly, which limits their use in the human brain. Optical imaging, mostly using polarization, has emerged as a promising alternative [1, 7]. Here we propose to image WM fibers using Optical Coherence Tomography (OCT) with the goal of validating DW-MRI in *ex vivo* samples.

Methods and Materials

Optical coherence tomography OCT is an optical technique providing 3D high resolution images up to several hundreds of microns in depth in biological tissue [4]. This technique avoids cutting, mounting or staining and greatly reduces deformations in the tissue. OCT detects differences in refractive index between tissues types, *e.g.* cell bodies and myelinated fibers.



Tissue Preparations Fixed temporal lobe samples were used for this study. DW-MRI data was acquired on a 4.7T small-bore Bruker system with a solenoid coil (300 μm resolution, 2 low-b images, 20 DW images with $b=4028$, $TE=28\text{ms}$, $TR=320\text{ms}$, $FA=180^\circ$). A tensor was fit to the data at every voxel and the primary eigenvector of the tensor was extracted for comparison with the maxima of the OCT-derived ODFs. The samples were then sectioned to collect 50 μm thick slices for histological staining. The remaining flat-faced tissue block was imaged with OCT.

Qualitative comparison Fig. 1A shows the MIP of the OCT imaging in a gyrus in the isocortex, where the fibers are clearly visible. Fig. 1B shows the gallyas stain slice of a similar tissue sample, where the fibers are stained in dark.

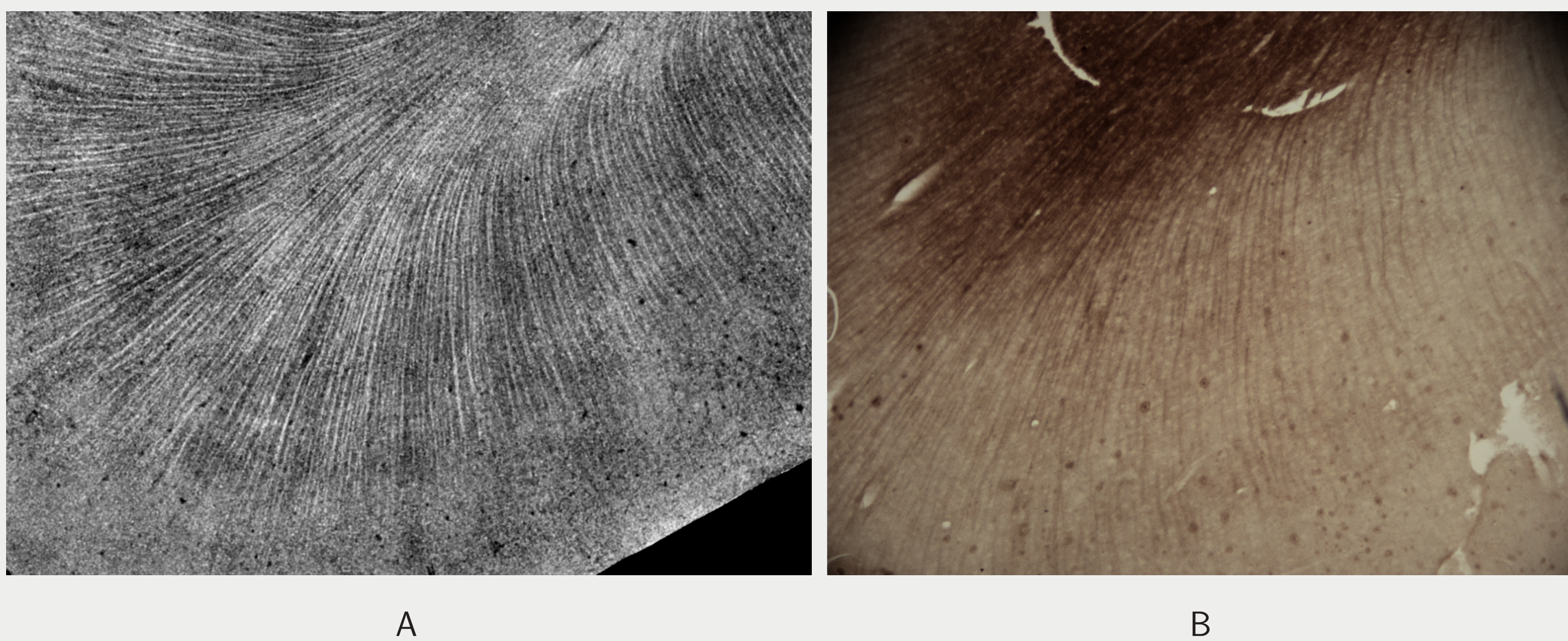
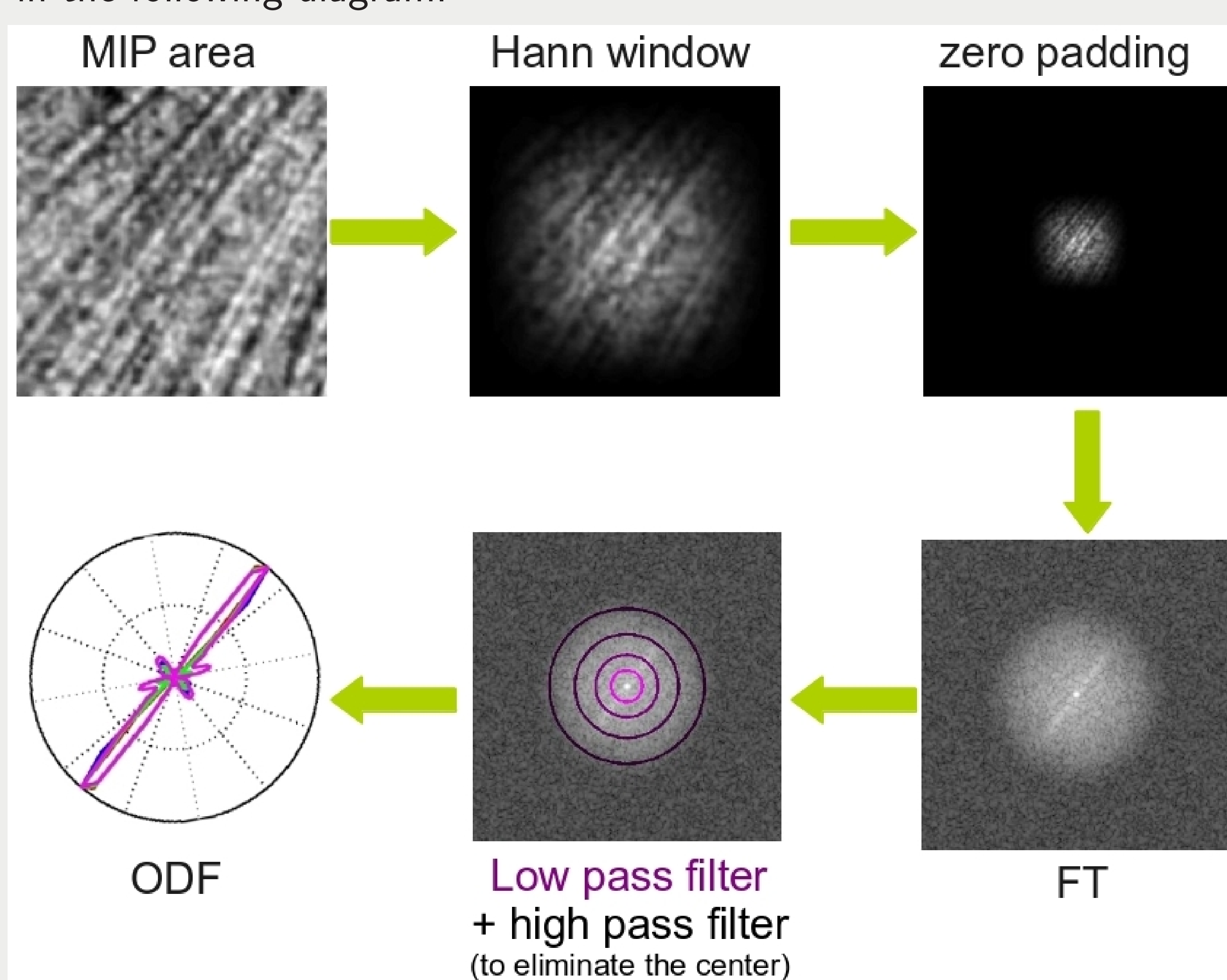


Fig. 1: A: MIP of the OCT data on part of isocortex sample, B: Gallyas stain on a similar sample.

Orientation Density Function Processing

The in-plane fiber orientations in the isocortex sample are computed using a windowed Fourier analysis on the MIP images. The process of estimating the Orientation Density Functions (ODF) is described in the following diagram.



ODF Examples

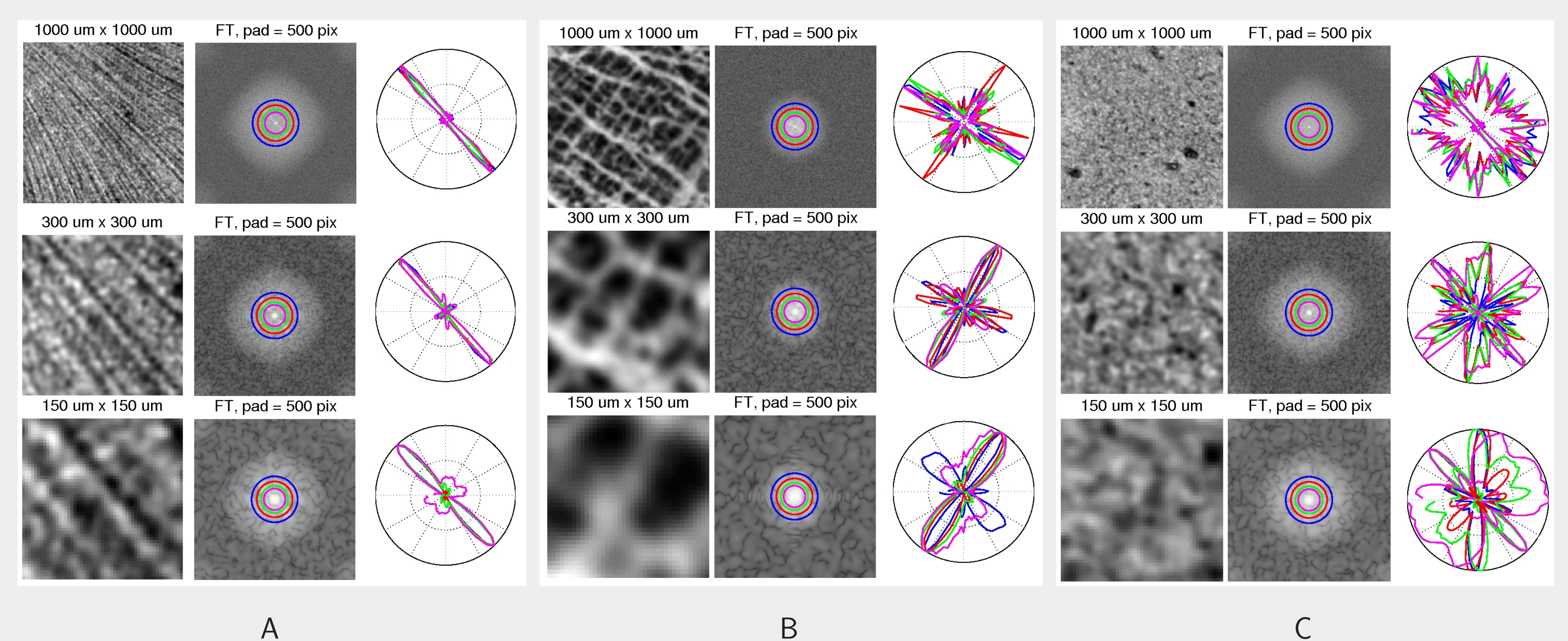


Fig. 2: ODF reconstructions for A: 1 visible fiber direction, B: 2 visible fiber directions and C: no visible fiber.

The figure shows the ODF for different study cases (A: 1 fiber orientation visible, B: 2 fiber orientations, C: no visible fiber) for different window sizes (1mm typical *in vivo* resolution, 300 μm typical *ex vivo* resolution and 150 μm). The colored circles represent the cut-off frequency of the low-pass filter.

Preliminary Results

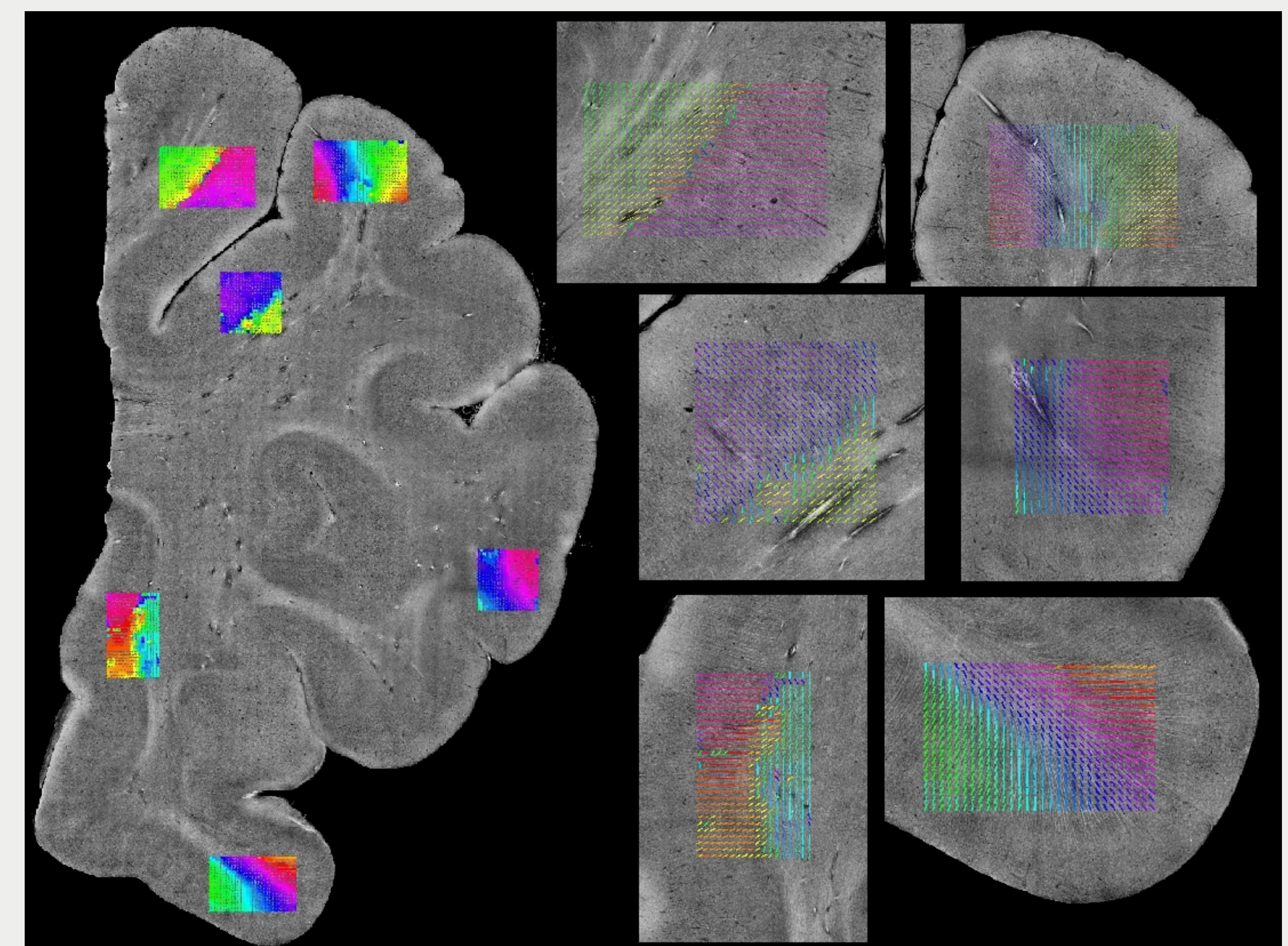


Fig. 3: Preferential direction of the fibers for various regions of interest assessed by the Fourier analysis of the MIP image obtained by OCT.

Advantages of OCT

- ▶ **High resolution**
OCT can image individual fibers, which allows the visualization of complex structures (crossing fibers, kissing fibers, grid...)
- ▶ **3D reconstruction of ODF at high resolution**
- ▶ **Cyto- and myelo- architecture obtained simultaneously¹**

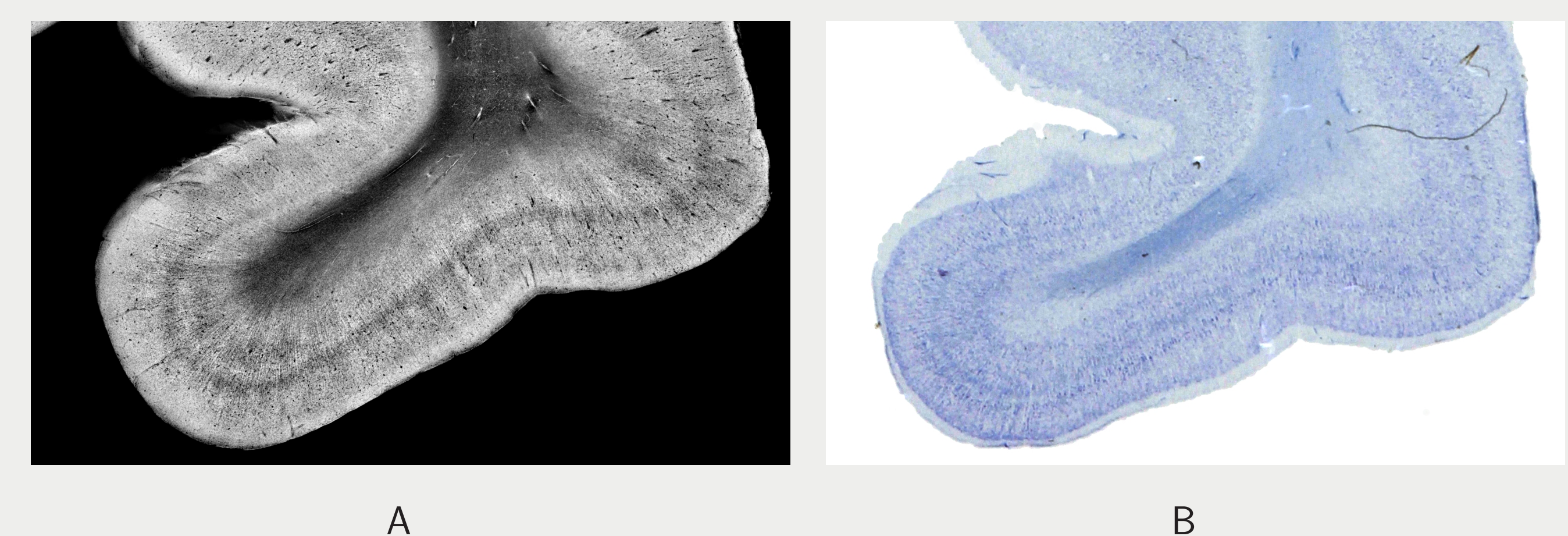


Fig. 4: A: Average Intensity Projection of OCT data and B: corresponding Nissl stain of part of isocortex.

1. Cytoarchitecture of cortex imaged by Optical Coherence Tomography, poster 3639

Conclusion and Future Work

The high resolution that can be attained by the OCT image processing approach described here makes it a promising tool for the validation of DW-MRI and perhaps for resolving crossing fibers by acquiring OCT data with a 1 μm resolution. Although we used 2D images in this preliminary study, OCT holds useful information in all 3 dimensions. In the future we will perform 3D reconstruction of a volume of several cm^3 by adding a vibrotome to our setup [5]. We also plan to take advantage of the birefringence of the myelin sheath surrounding the fibers by adding polarization sensitivity to the system. Finally, we intend to explore the use of OCT-derived information as priors for *in vivo* ODF estimation and tractography.

References

- [1] Markus Axer, Katrin Amunts, David Gräßel, Christoph Palm, Jürgen Dammers, Hubertus Axer, Uwe Pietrzyk, and Karl Zilles. A novel approach to the human connectome: ultra-high resolution mapping of fiber tracts in the brain. *NeuroImage*, 54(2):1091–101, 2011.
- [2] Julien Dauguet, Sharon Peled, Vladimir Berezovskii, Thierry Delzescaux, Simon K Warfield, Richard Born, and Carl-Fredrik Westin. Comparison of fiber tracts derived from *in-vivo* DTI tractography with 3D histological neural tract tracer reconstruction on a macaque brain. *NeuroImage*, 37(2):530–8, 2007.
- [3] R F Hevner. Development of connections in the human visual system during fetal mid-gestation: a Dil-tracing study. *Journal of neuropathology and experimental neurology*, 59(5):385–92, 2000.
- [4] David Huang, Eric A Swanson, Charles P Lin, Joel S Schuman, William G Stinson, Warren Chang, Michael R Hee, Thomas Flotte, Kenton Gregory, Carmen A Puliafito, and James G Fujimoto. Optical Coherence Tomography. *Science*, 254:1178–1181, 1991.
- [5] Timothy Ragan, Jeremy D Sylvan, Ki Hean Kim, Hayden Huang, Karsten Bahlmann, Richard T Lee, and Peter T C So. High-resolution whole organ imaging using two-photon tissue cytometry. *J. Biomed. Opt.*, 12(1):014015, 2012.
- [6] Vivek J Srinivasan, Harsha Radhakrishnan, James Y Jiang, Scott Barry, and Alex E Cable. Optical coherence microscopy for deep tissue imaging of the cerebral cortex with intrinsic contrast. *Opt. Express*, 20(3):2220–2239, 2012.
- [7] Hui Wang, Adam J Black, Junfeng Zhu, Tyler W Stigen, Muhammad K Al-Qaisi, Theoden I Netoff, Aviva Abosch, and Taner Akkin. Reconstructing micrometer-scale fiber pathways in the brain: Multi-contrast optical coherence tomography based tractography. *NeuroImage*, 58(4):984–992, 2011.