Linking brain tissue capturing modalities: ultra-high resolution synchrotron imaging and low resolution MRI

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Abstract

Tissue from the different white matter regions of a monkey brain was prepared and imaged by phase contrast tomography at the synchrotrons DESY and ESRF. An initial segmentation of the volumetric images reveals the relative trajectories of blood vessels and axons, axonal twisting and a complex microstructural environment never before described.

The acquired anatomical information can contribute to the improvement of existing biophysical MRI models such that they reflect the true microstructural anatomy in the brain.

Background

Neurodegenerative diseases, such as Alzheimer's, cause anatomical changes to axons and their surrounding myelin sheaths. Non-invasive MRI methods can estimate these changes, but are limited to resolutions on the order of mm and the biophysical models [1,2] on which they are based make incorrect assumptions about 3D axon morphology which skew the results i.e. they assume that axons are straight. X-ray phase contrast tomography enables high-resolution 3D imaging of the microstructural tissue environment, required to improve the biophysical axon model and realise advances in in-vivo histology with clinical MRI.

X-ray Phase Contrast Tomography

Tissue biopsies from the white matter of an Old World Vervet monkey were extracted as shown in Figure 1, stained with Osmium (to give contrast to the fatty myelin sheaths around the axons), embedded in EPON or paraffin and imaged at beamline P10 of PETRA III (DESY) and ID16A of ESRF at varying resolutions and fields of view.

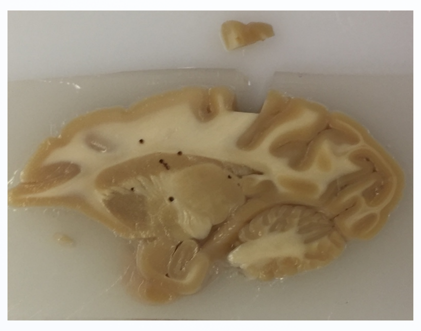

Figure 1. Sagittal slice of monkey brain showing various locations from which biopsies were taken.

Funding

This project is funded by the Capital Region Research Foundation (grant number: A5657)

Initial Segmentation

The volumetric synchrotron images were downsampled and filtered to make operations on them less computationally intensive. Blood vessels could be segmented by thresholding the lighter areas of the image and manually initialising region growing snakes in ITK-Snap. For the axon segmentation, a manual segmentation of a single slice was performed and used to train a myelin classifier. The posterior probability of the myelin obtained from the classifier was thresholded and combined with region growing snakes to segment the interiors of the axons. Initial segmentations are shown in Figures 2-5.

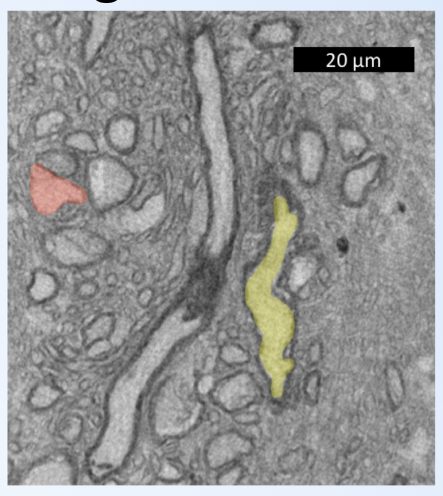

Figure 2. Data obtained from ID16A, ESRF, showing a slice through a crossing fibre region of the monkey brain. Axons are shown in yellow and blood vessels in red.

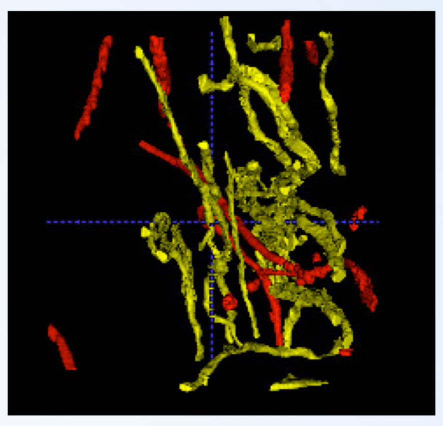

Figure 3. Crossing fibre region of the monkey brain, ESRF data. Axons (yellow) and vessels (red).

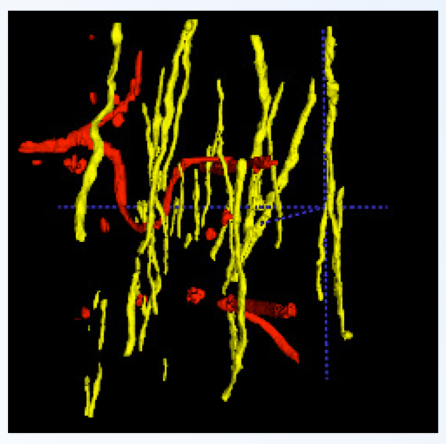

Figure 4. Mid-body corpus callosum of the monkey brain, ESRF data. Axons (yellow) and vessels (red).

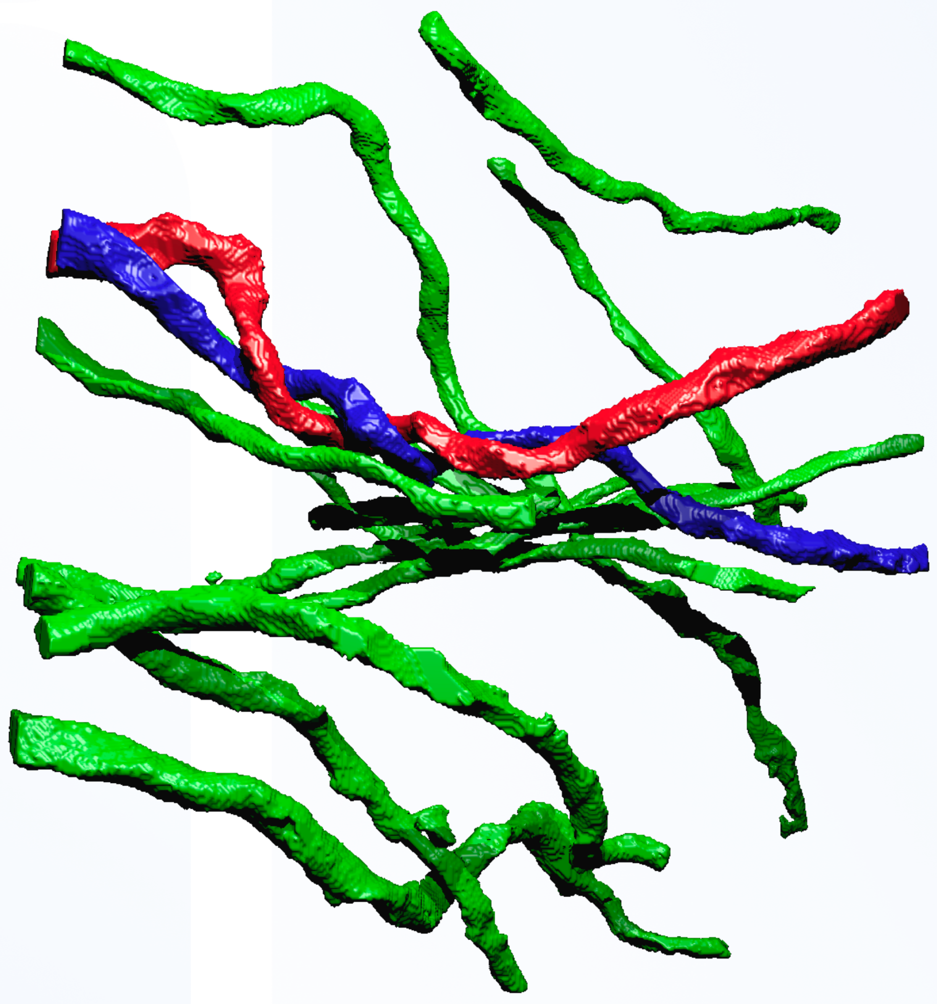

Figure 5. Crossing fibre region of the monkey brain, ESRF data. Axonal twisting displayed in two axons shown in red and blue. Surrounding axons are shown in green.

Perspective

Phase contrast tomography at synchrotrons has provided access to unique, 3D information with regards to the microstructural environment in the brain. Further studies could involve the use of a disease model to compare microstructural characteristics between healthy and diseased tissues.

References

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[2] H. Lundell, C. K. Sønderby, and T. B. Dyrby, "Diffusion weighted imaging with circularly polarized oscillating gradients," *Magn. Reson. Med.*, vol. 73, no. 3, pp. 1171–1176, 2015.