Multimodal, multi-scale imaging of human vagus nerve at the I13-1 Coherence beamline

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Electrical stimulation of the human vagus nerve (HVN) is used to treat epilepsy and depression and shows promise for extension to other disorders such as inflammatory and cardiac diseases. However, the architecture of the nerve (i.e. the organisation of its internal fibres and their functional mapping to different organs) is still poorly understood, which prevents targeted neurostimulation and limits the therapeutic expansion.

X-ray imaging has recently enabled the visualisation and tracing of HVN fascicles across extended nerve segments at the scale of 10s of micrometres. While this is an important first step, tracing individual fibres within the nerve at the sub-micron scale is required for precise, functionally selective neurostimulation. X-ray phase contrast techniques enable this kind of volumetric imaging thanks to their sensitivity to soft tissue contrast and the possibility of sub-micron resolution.

At the I13-1 beamline, we performed multi-scale imaging of HVN using a combination of micro-computed tomography (micro-CT) and ptycho-tomography. Micro-CT was used to image the whole nerve (~2 mm diameter), resolve A and B fibres (2 – 20 µm), and select regions of interest (ROIs) for further scanning. A ~300 µm punch of such an ROI was then imaged with ptychography to resolve the smaller C fibres (0.2 – 1.2 µm). Due to the large size of the samples, ptycho-tomography scans were performed off-axis over 360 degrees, pushing the limits of sample size that can be imaged at the beamline. These results are then used to trace the path of individual fibres within the nerve.

While in micro-CT mode, we also employed beam tracking (BT), another phase contrast imaging technique which relies on modulating the illumination into beamlets and tracking changes to those beamlets to obtain attenuation, phase and scattering (or “dark-field”) contrast. The dark-field images contain information about the presence of sub-pixel features and their rough direction, so they can be used to pinpoint areas which are good candidates for further ptychographic imaging.

Being able to alternate techniques within one instrument is important for efficient imaging of large samples with multi-scale features, such as HVN. With this work, we have improved the understanding of the internal structure of the HVN by enabling individual fibre tracing. Furthermore, we have shown the potential for multi-scale imaging of biological tissue at I13-1, and pushed the boundaries for the size of samples that we can image.