Erasmus Joint Master Project 2026

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Multi-modal imaging of neuromelanin in the human brainstem: characterization of Magnetic Resonance Imaging (MRI) through Monte-Carlo simulations based on X-ray Phase Contrast micro CT (XPCT).

XPCT is a valuable tool for imaging of the microvasculature (1) and to study the spatial distribution of neuromelanin in the substantia nigra (2). Neuromelanin is important in the healthy brain to maintain iron homeostasis and naturally accumulate in dopaminergic and noradrenergic cells during aging (3, Fig. 1). In Parkinsons disease, there is a loss of dopaminergic cells in the substantia nigra linked with neuromelanin. Several MRI methods have been introduced to sense neuromelanin, but the exact mechanisms leading to neuromelanin sensitivity are incompletely understood. Recent work points towards a role of its magnetic properties on MRI relaxation properties (4). Besides MRI signal relaxation, maps of magnetic susceptibility can be obtained by inverse modelling of local magnetic field effects (5).

The MRI signal depends on multiple factors such as relaxation times, local magnetic field effects, and diffusion of water molecules occurring at spatial scales of a few tens of µm. This length scale is far below typical voxel sizes of MRI ranging from 60-300µm in ex vivo tissue measured at 14.1T to 300-800µm in vivo at 9.4T to 800-2000µm for clinical MRI scanners operating at 3T. Precise simulations of the MRI signal benefits from detailed knowledge about the underlying tissue structure gained from XPCT. Recently we used novel tools for performing Monte-Carlo simulations of the MRI signal (6) to predict fMRI signals based on the blood-oxygen-level-dependent (BOLD) effect based on 3D maps of the microvasculature obtained from XPCT of the human brainstem (Fig. 2).

The primary goal of the present thesis is to advance our understanding of the influence of neuromelanin on the MRI-signal especially linked with its magnetic susceptibility. The thesis work could also help to better define constraints for neuromelanin sensitive MRI such as sequence type, parameters and voxel size for the successful detection of neuromelanin.

Methods:

- Establish 3D geometric models of neuromelanin and the microvasculature from XPCT measurements performed at the SYRMEP beamline.
- Set-up forward models to obtain maps of the local magnetic field with 1 µm voxelsize, using realistic values for the magnetic susceptibility.
- Perform Monte-Carlo simulations of the MRI signal in presence of neuromelanin and microvasculature for gradient echo MRI sequences.
- Generate simulated MRI images from the XPCT-based 3D models and compare with measured MRI images.

Skills: interest in Brain-tissue interaction with X-rays, MRI (bio)physics, magnetism, interest in Parkinson’s disease and neurodegeneration. Understanding of C++ and python or Matlab programming, and interest in developing skills for simulations

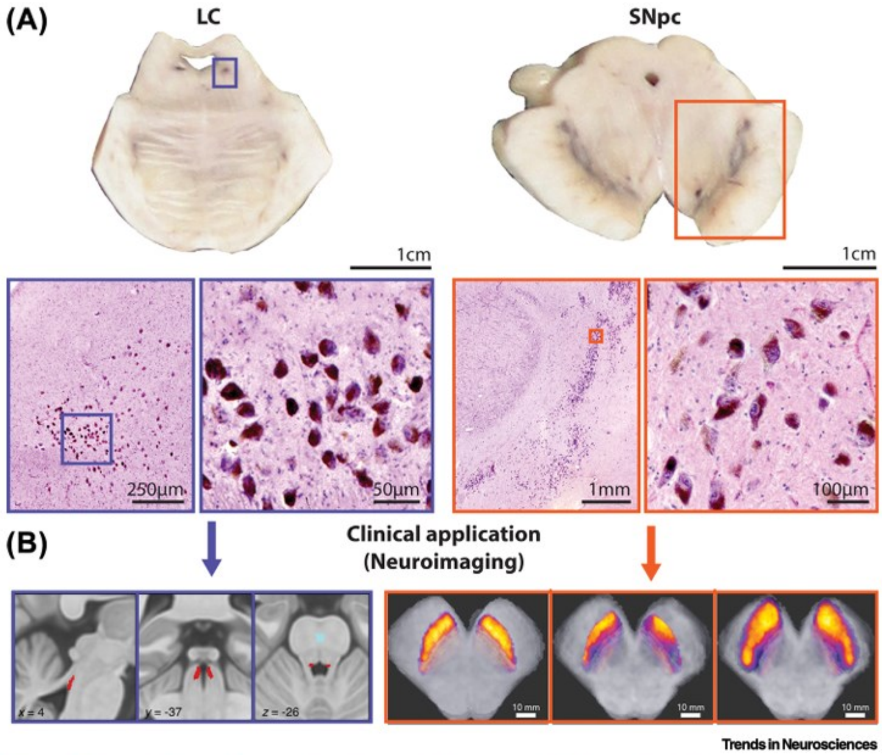

Figure 1. Concentrations of neuromelanin pigmented neurons in the human brainstem. (A) There is a high concentration of neuromelanin-containing neurons in the locus coeruleus (LC) and substantia nigra pars compacta (SNpc). (B) The LC and SNpc can be imaged in clinical settings using neuromelanin-specific and iron sequences on magnetic resonance imaging scanners. Reproduced, with permission, from [116–118] in (A), and [119,120] in (B). From ref. 3

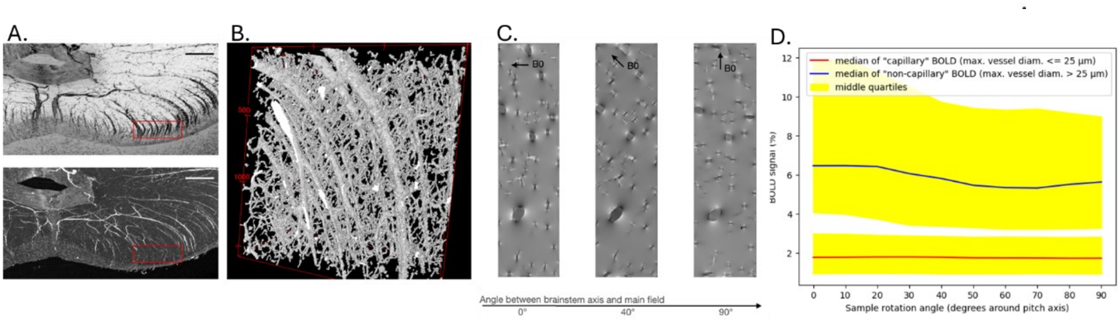

Fig. 2 A. XPCT of the microvasculature in the human brain stem (from Ref. 1); B. segmented 3D model of the microvasculature with a voxel size of 1μm. C. simulations of the magnetic field based on the BOLD effect and realistic values for the magnetic susceptibility at different orientations of the vasculature with respect to the external static field. D. Contributions from the blood capillaries and large venules to the fMRI signal.

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6. GitHub - aghaeifar/SpinWalk: SpinWalk, a framework for Monte-Carlo simulation to model spins random walk within a network. SpinWalk paper: