High-resolution diffusion-weighted imaging of the orientational structure of motor and somatosensory cortex in human cadaver brain

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Introduction: Understanding brain connectivity has been greatly assisted by the ability of diffusion-weighted MR imaging (DWI) to demonstrate the orientational structure of fibre bundles. This is possible not only in brain white matter but has also been recently shown within the cortex [1,2]. In cadaver brain specimens, even the layer dependence of fibre orientation can be measured [3,4] with good spatial resolution, allowing a closer look at cortical areas such as primary motor (M1) and somatosensory (S1) cortex which have been claimed to show striking orientational structure in-vivo [1,2]. Because the normally dominant orientation of cortex is radial, the reported tangential orientational structure within S1 cortex is of great interest. In this study we examined a short post-mortem-time block of fixed human cadaver brain containing S1 and M1 cortex, in order to evaluate these claims at much higher spatial resolution.

Method: All experiments were performed on a 9.4T micro-imaging system (Bruker Avance 400, Micro 2.5 gradient system, Germany) using a 25 mm inner diameter birdcage coil (Bruker, Germany). Scans were performed on excised blocks ($1.5x1.5x1cm^3$) of formalin-fixed human cadaver brain (post mortem delay = 28h) containing part of the motor and somatosensory cortices. A pulsed-gradient spin-echo (PGSE) sequence (TE = 26 ms, TR=1600 ms, b=1820 s/mm^2, 60 directions + 5 b=0, resolution 242µm isotropic, 7 adjacent slices, 12 averages) was used, and the DWI analysis was performed with in-house software and MRTrix [5].

Results: Within both M1 and S1, a predominantly tangential diffusion direction was observed (Fig. 1 (i)) close to the WM/GM boundary and also close to the cortical surface, while the diffusion direction was more radial in the middle cortical layers. While the volumes of grey matter showing tangential orientation in M1 and S1 are roughly equal (Fig 1(ii)), the volume fraction of the radial component is much larger in M1 cortex. In the map of fibre orientational distribution functions (fODFs) this is reflected in a greater density of fibre crossings near the WM/GM boundary (Fig 1(iii)), decreasing further away from the WM.

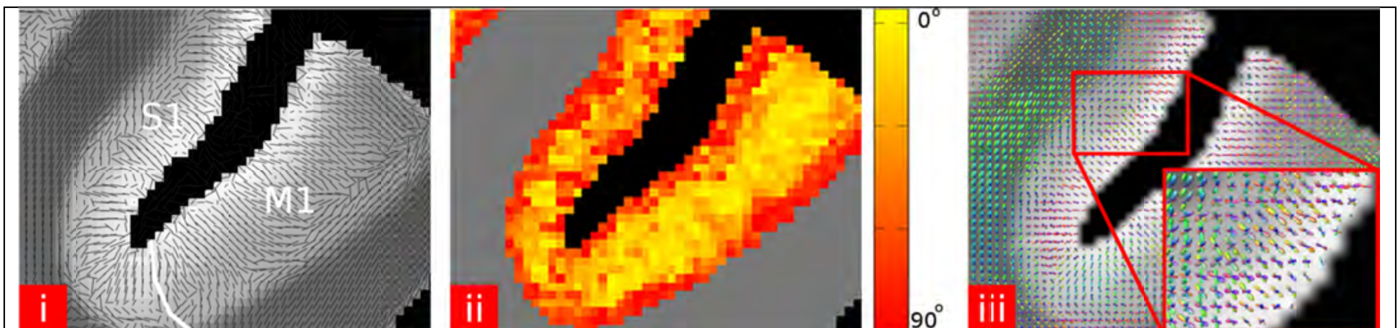

Fig.1: A slice through a cadaver brain block containing part of the primary motor (M1) and somatosensory (S1) cortex.
(i) Orientation of the principal eigenvector of the diffusion tensor, which is roughly tangential at the M1/S1 boundary.
(ii) The radiality index, defined here as the angle between the first eigenvector and the cortical surface normal (90° - tangential, 0° - radial). More tangential diffusion can be observed near the WM/GM boundary and the cortical surface, while the main diffusion direction is radial in the middle cortical layers.
(iii) The fibre orientation distribution function (fODF). This shows a higher number of fibre crossings in the cortical layers adjacent to the WM/GM boundary.

Discussion: For the first time using DWI, we have observed layer dependence of the predominant fibre orientation within both cortical areas M1 and S1. The samples examined were cadaver brain blocks, and the diffusion properties may have changed after death and fixation, but the post-mortem time was short, and the tissue appeared to be in good condition. The cortical volumes showing tangential diffusion in the superficial and deep layers were approximately equal in both areas. However, the volume fraction showing radial orientation was significantly higher in M1. The underlying microanatomical substrate is the arrangement of cells and fibres in vertically oriented columns which is much more pronounced in M1 than in S1. The observed tangential diffusion orientation in S1 in earlier studies [1,2] with lower spatial resolution may reflect partial volume effects, and the apparent angular coherence of this tangential orientation [2] might simply correspond to the coherent orientation of the underlying WM, which may contain U-fibres (See Fig. 1(i)). High DWI spatial resolution is clearly of great importance for correct conclusions regarding cortical orientational structure in the cortex.

References: [1] Anwander et al. ISMRM 2010 (#109), [2] McNab et al. ISMRM 2011 (#412), [3] Leuze et al. ISMRM 2011 (#1070), [4] Kleinnijenhuis et al. ISMRM 2011 (#2085), [5] Tournier et al. Neuroimage 2004; 23 (3): 1176-1185