Q-Ball Imaging of Gyral White Matter Architecture in Macaque Cortex

D. S. Tuch[1], M. H. Khachaturian[1,2], W. Vanduffel[1]

[1]MGH-NMR Center, Martinos Center for Biomedical Imaging, Charlestown, Massachusetts, United States, [2]Department of Nuclear Engineering, MIT, Cambridge, Massachusetts, United States

Purpose - High angular resolution diffusion imaging (HARDI) provides a powerful tool for mapping subvoxel neural histoarchitecture. However, HARDI studies to date have focused primarily on deep white matter pathways. Here, using q-ball imaging in macaque cortex, we show that gyral white matter exhibits significant intravoxel fiber crossing architecture. The crossing structure may be due to the dispersion of fibers at the gyral crown, or to the rapid bending of the white matter insertions into gray matter along the cortical surface-normal direction.

Background - High angular resolution diffusion imaging methods such as diffusion spectrum imaging and q-ball imaging can resolve composite intravoxel fiber structure including intravoxel fiber crossing and divergence [1, 2]. While HARDI methods have been applied to deep white matter structures, the methods have not been employed to investigate the fiber architecture of more superficial white matter such as the white matter insertions to the gyral wall. Mapping the white matter structure within gyri is challenging due to the small dimension, the low diffusion anisotropy, and the lack of strong anatomical reference.

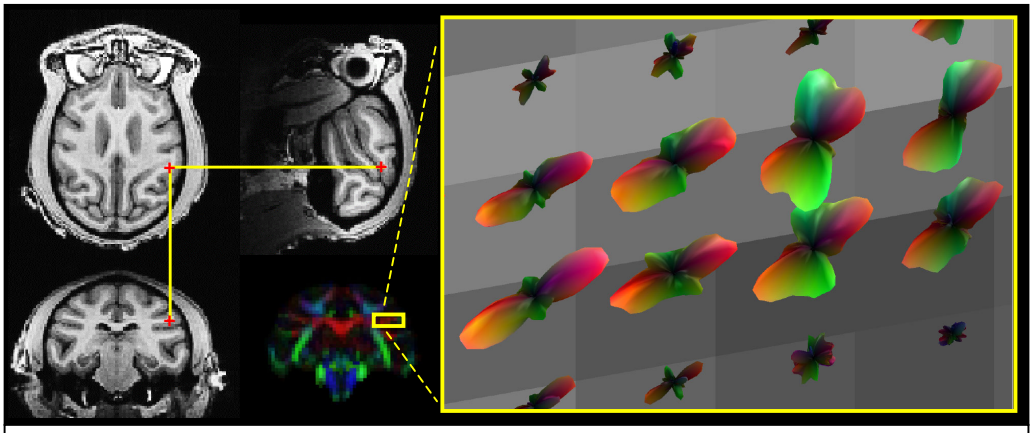

Fig 1. Diffusion orientation distribution function (ODF) map from supramarginal gyrus (SMG) (yellow box). The RGB map at bottom middle shows the orientation of the peak diffusion direction. In the ODF orbital maps at right, the medio-lateral (ML) fiber population (red) projects to the gyral crown, and the anterior-posterior (AP) fiber component (green) increases in magnitude towards the crown. The smaller ODFs are located in gray matter. Note that the AP fiber component is consistent with the AP deflection of the gyral morphology at the crown as can be seen in the axial turbo flash image at top left. The emergence of the AP component at the crown of SMG can also be seen on the RGB image.

Methods - Diffusion MRI data of 2 anaesthetized macaque monkeys were collected on a Siemens 3T Allegra using a custom-built 10cm surface coil. The voxel resolution was 1.1mm×1.1mm× 3mm. The diffusion sampling scheme consisted of two nested shells. Each shell consisted of n=492 direction which were obtained from the vertices of a 7-fold regularly tessellated icosahedron. The imaging parameters for the first shell were TR/TE = 3000/110ms, b=4000s/mm^2, and for the second shell TR/TE = 3100/135ms, b=8000s/mm^2. For each voxel, the diffusion orientation distribution function (ODF) was reconstructed using the Funk-Radon transform [2]. The Funk-Radon transform was implemented using spherical radial basis function interpolation with a spherical Gaussian kernel with FWHM=8°. The diffusion ODF maps were visualized as directionally color-coded orbital plots.

Results - Fiber crossing structure was observed in primary motor gyrus and supramarginal gyrus. The crossing component was found to increase in magnitude with proximity to the gyral crown (Fig 1).

Conclusions - Q-ball imaging can resolve subvoxel fiber crossing in gyral white matter. The crossing structure may be due to the rapidly bending insertions to gray matter or the dispersion of fibers at the gyral crown. To determine the anatomical basis of the cross-fiber component it will be necessary to acquire diffusion data with both high spatial and angular resolution. The ability to map gyral white matter histoarchitecture with diffusion imaging will ultimately enable the tractography program to examine detailed connectivity within individual gyri.

References

1. Lin, C.P., et al. Neuroimage, 2003. **19**(3): p. 482-495.
2. Tuch, D.S., et al. Neuron, 2003 (in press).