Mesh-based fMRI-driven-tractography for automated analysis of non-parcellateable brains with pathology

Lee Bremner Reid[1,2], Kerstin Pannek[3], Roslyn Boyd[2], and Stephen Rose[1]

[1]e-Health Research Centre, CSIRO, Brisbane, Queensland, Australia, [2]Queensland Cerebral Palsy and Rehabilitation Research Centre, University of Queensland, Queensland, Australia, [3]Department of Computing, Imperial College London, London, United Kingdom

Target Audience: Researchers interested in acquiring diffusion measures of subjects with brain pathologies that prevent normal analyses.

Purpose: In subjects with brain pathology, automated diffusion MRI (dMRI) analyses are often impossible to perform due to an inability to register brains to brain atlases and to perform cortical parcellation. Even in cases where alignment with atlases is achieved, brain plasticity may result in relocation of functional regions, invalidating regions of interest (ROIs) defined by such atlases. An alternative method is use fMRI activation to define an ROI, which is then used to seed tractography. Voxel-based fMRI analyses, however, explicitly and implicitly (during motion correction) smooth in image space. This smoothing can cause 'activation' to cross sulci and may result in inaccurate seeding regions for tractography. This study demonstrates a novel mesh-based fMRI/dMRI analysis that avoids these issues and uses brain activation meshes to seed and constrain tractography.

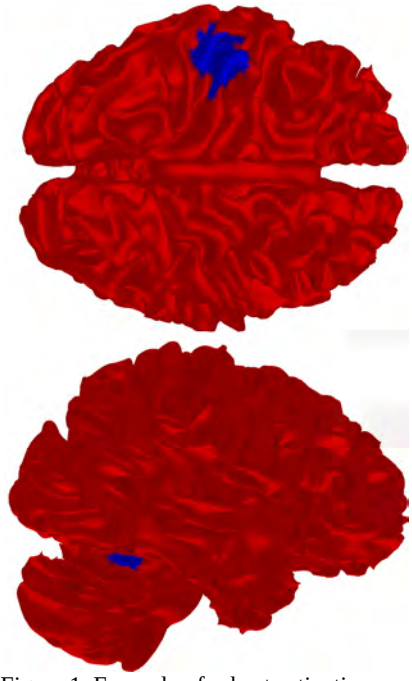

Figure 1. Example of robust activation detected via mesh-based fMRI.

Methods: T1 (MPRAGE), T2 Haste, HARDI (64 directions; b=3000s/mm^2), and fMRI (task: hand tapping) images were collected from 14 children with unilateral cerebral palsy (CP) for whom cortical parcellation with Freesurfer was difficult or impossible. Subjects were processed individually. HARDI and fMRI data were distortion corrected to enable accurate registration with structural images. For each brain, a mesh of the grey-matter/white-matter interface was created from tissue-segmented structural images using in-house software. Each mesh was moved into fMRI space, and values projected using nearest-neighbour interpolation, adjusting positions for head movement in each frame without reslicing. Frames with excessive movement were rejected. Analyses were performed using SPM8 code that was adapted to accept anisotropically-spaced mesh data at all processing stages, including 8mm FWHM surface smoothing. Meshes were then moved into dMRI space and triangles of three connected statistically-significantly activated ($p<0.05$ FWE) nodes were used to define seeding regions for tractography. To ensure tracts represented corticospinal tract connections, manually drawn inclusion masks of the posterior limb of the internal capsule (PLIC) and brain stem were used. The mesh surface was also used to proactively constrain tractography to white matter. Mean upper-corticospinal tract fractional anisotropy (FA) values were extracted for each subject by averaging FA at each track step for all tracks between the seeding region and PLIC.

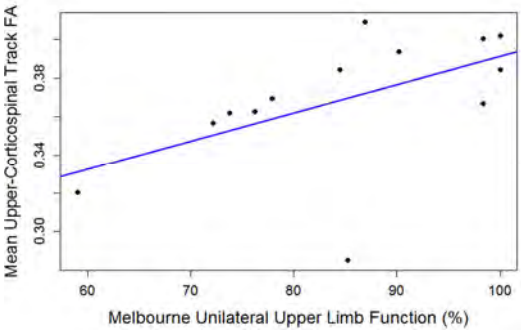

Figure 3. Mean Upper-Corticospinal Track FA versus Melbourne Unilateral Upper Limb function

Results: Meshes were successfully generated for all but one subject. For tapping of the unimpaired hand, areas of significantly increased fMRI activation were commonly found in pre- and post-central gyri, predominantly on the contralateral side of the brain, as well as the ipsilateral cerebellum (Figure 1). Functional MRI for tapping of the hemiplegic hand showed bilateral and unilateral activations in the primary sensorimotor cortices in all subjects. fMRI-seeded tractography was successful in all remaining subjects (Figure 2). After adjustment for age, tracks based on tapping of the hemiplegic hand suggested a correlation between upper limb function (Melbourne Assessment of Unilateral Upper Limb function) and upper-corticospinal mean track FA ($p=0.08$; $R^2=0.44$; Figure 3). This trend was not apparent for data based on tapping of the unimpaired hand ($p=0.4$; $R^2=0.07$).

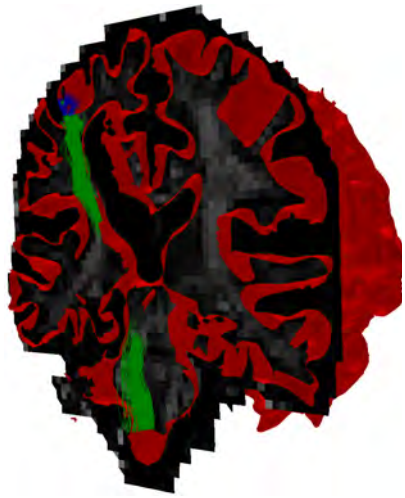

Figure 2. Coronal view of structural mesh (red), fMRI activation (blue, top left), FA image, and tractography (green) in a subject with a periventricular lesion.

Discussion: This study has demonstrated a novel data processing pipeline that allows diffusion measures to be taken from sensorimotor tracts without need for cortical parcellation. The mesh-based fMRI approach is novel and avoids tracking from non-relevant areas due to data blurring from both motion correction and explicit smoothing. This is particularly useful for studies of more severe brain damage, where cortical parcellation is impossible due to pathology. In this demonstration, our pipeline has revealed plausible activation patterns and correlations between resultant diffusion measures and upper-limb function.