Investigating the Relationship Between the Disruption of Primary Sensorimotor Pathways and Hand Function in Congenital Hemiplegia: An MRI Structural Connectivity Study

S. Rose[1], K. Pannek[1], A. Guzzetta[2], and R. Boyd[3]
[1]Centre for Clinical Research, University of Queensland, Brisbane, Queensland, Australia, [2]Department of Developmental Neuroscience, Stella Maris Scientific Institute, Pisa, Italy, [3]Queensland Cerebral Palsy and Rehabilitation Research Centre, University of Queensland, Brisbane, Queensland, Australia

Introduction: Damage and subsequent plasticity of afferent sensory and descending corticospinal pathways plays an integral role in determining paretic hand function in congenital hemiplegia. However little is known regarding the relationship between the disruption of sensorimotor thalamic pathways projecting into the primary motor cortex and motor control. In this study, we introduce an automated strategy for investigating the relationship between the structural connectivity of motor networks that anatomically link the brain stem (bs) and precentral gyrus (preCG) with paretic motor function.

Methods: Structural MRI (1 mm isotropic resolution) and HARDI data (68 diffusion encoding directions, b = 3000 mm/s^2, 2.3 mm isotropic resolution) were acquired from 16 participants with congenital hemiplegia (9 left and 7 right) using a Siemens 3T Trio scanner. All subjects had MRI evidence of unilateral damage to the affected periventricular area containing the corticospinal tract (CST). Paretic hand function was assessed using the Jebsen Test of Hand Function (1), Melbourne Assessment of Unilateral Upper Limb Function (MUUL) (2) and the Assisting Hand Function (AHA) (3). For each subject, the cortex of each hemisphere was parcellated into 33 regions based on gyral and sulcal structure using Freesurfer with the FOD calculated using constrained spherical harmonic deconvolution (CSD) (4) and probabilistic diffusion tractography performed using Mrtrix. Fifty streamlines were seeded for every voxel of the entire brain volume. To ensure generation of connectivity indices in diffusion space, whole-brain track density maps were nonlinearly registered to the sMRI and the inverse transformation applied to the parcellated cortical masks (5). From this whole brain analysis, CST and sensory (spinothalamic-corticothalamic) projections linking preCG and bs were automatically extracted, see Figure 1. A thalamic mask generated from the Freesurfer parcellation was used as an inclusion mask to ensure that the sensory pathways only included streamlines that projected through the thalamus and not the posterior limb of the internal capsule (PLIC), see Figure 2. As the streamline count for these projections are not quantitative, we generated an asymmetry index for each pathway for every participant using the following expression, AI = (C – I) / (C + I); where C and I represent the number of streamlines within the CST and sensory pathways for the contralesional and ipsilesional hemispheres, respectively. The relationship between AI and hand function scores were assessed using the Pearson product-moment correlation.

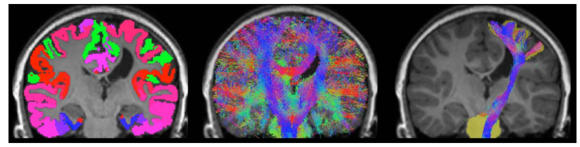

Figure 1. Freesurfer parcellation of the cortex (left), whole brain tractogram (middle) and extracted corticospional tract (right).

Results: There was a reduction in the number of streamlines in CST and spinothalamic-corticothalamic pathways within the ipsilesional hemisphere compared to the contralesional side. We found no correlation between the AI generated for the CST's and motor function score that reached a level of statistical significance. In contrast, we found significant correlations between the AI generated for the sensorimotor thalamic projections and paretic hand function scores. These correlations were 0.80, -0.67 and -0.62 for the Jebsen, MUUL and AHA scores respectively.

Discussion: The concept of using structural connectivity to measure WM reorganisation in the developing brain has a number of useful advantages. The technique enables the interrogation of multiple cortical networks, in an automated fashion, without the need for registration of sMRI and HARDI images across subject groups. Our data supports the concept that preservation of afferent sensorimotor thalamic pathways that directly project into the primary motor cortex has more influence on motor function control of the paretic hand than preservation of corticospinal tracts. This has significant implications for planning neurorehabilitation therapy in children with cerebral palsy.

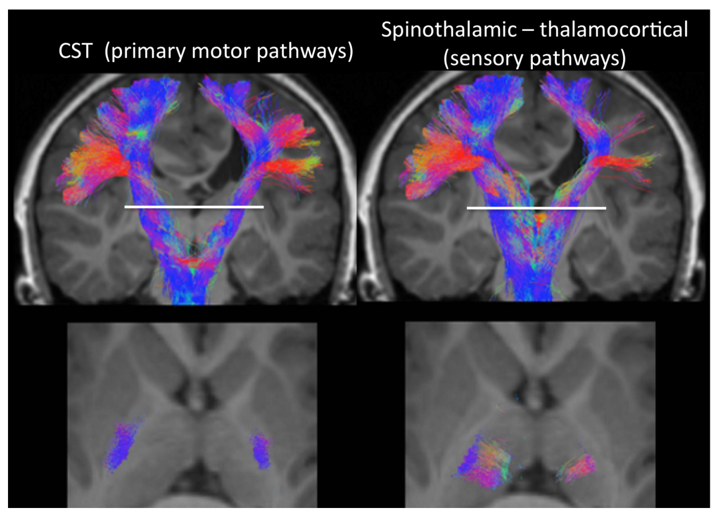

Figure 2. Representative images showing the automated delineation of primary motor (CST) and sensorimotor (spinothalamic-corticothalamic) pathways for a participant with right hemiplegia. The images on top represent all CST (left) and sensory pathways (right) projected onto a single coronal slice of a high resolution structural image, whilst the bottom axial images show CST projecting through the posterior limb of the internal capsule (left) and sensorimotor pathways projecting through the ventral lateral nucleus (right) at the level of the internal capsule (white line).

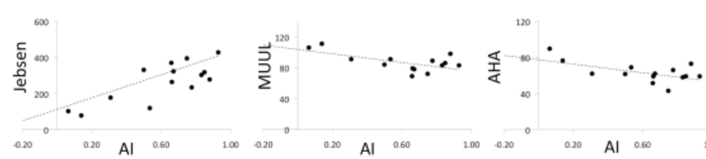

Figure 3. Scatter plots showing the correlation between the AI generated for the sensori-thalamic pathways and parietic hand function scores.

References: (1) Agnew P et al., The Aust J of physiothearpy 1982;28(20):23-9; (2) Johnson LM et al., Dev Med Child Neurol 1994;36:965-73; (3) Krumlinde-Sundholm L et al., Scand J Occup Ther 2003;10:16-26; (4) Tournier J-D et al., Neuroimage 2007, 35:1459; (5) Pannek K et al., Neuroimage 2010;53(3):1044-53