Comparison of thalamus parcellation by cortical projections using three tractography methods in neonates

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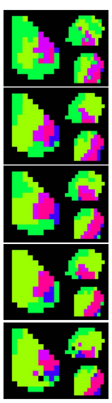
Introduction: Performing tractography between the thalamus and cortex has been demonstrated to allow the subdivision of the thalamus according to the number of connections found to each cortical region in both adults[1] and two-year olds[2]. Thalamic parcellation of the neonatal brain could provide valuable information about a period of rapid brain development. We explored the potential to achieve this by comparing the performance of different tractography algorithms in neonates.

Methods: We acquired 32-direction SE-EPI diffusion-weighted images, b-value $1000 smm^{-2}$, from 5 neonates with median age at scan of 41^{+6} weeks (40^{+4} to 42^{+1} weeks). The data was post-processed for eddy current correction and registered to T2 anatomical images for thalamus and cortical region definition. Cortex and thalamus segmentation is accomplished using tissue classification[3] and then manually defining 6 cortical regions. Three tractography models were considered: the partial volume (PV) model in FSL[4], constrained spherical deconvolution with probabilistic tracking (CSD) using MRtrix[5], and global fibre reconstruction (GR) using DTI&FiberTools software[6]. The PV model and CSD were used to perform tracking from a thalamic seed mask (PV_Thal, CSD_Thal) as well as wholebrain tracking (PV_wb, CSD_wb), and the GR model performs whole brain tractography. For tractography using the PV model and seeding from the thalamus, the output is an image for each cortical mask showing the number of samples which successfully reached the classification masks. Having determined the number of paths connecting each thalamic voxel to each cortical mask, a hard segmentation of the thalamus was produced by labelling each voxel with the cortical region to which it was most strongly connected. Also the centres of mass (CoM) of the complete sets of connections between the thalamus and each cortical mask were calculated for each method. The results were assessed anatomically by the variance in the segmentations for each region of the thalamus across subjects, by the fraction of voxels labelled identically with each method and by calculating the distances between the CoM obtained with the different methods.

Results: Figure 1 shows the labels obtained by each method in three orthogonal planes through the thalamus of one subject, colour-coded by the cortical region to which they are connected. With all methods more than 99% of voxels in the thalamus were labelled. On average over the 5 subjects >63% (63-82%) of thalamic voxels were labelled identically using the different methods. The highest agreement was between the CSD_Thal and CSD_wb tracking methods, which employ the same fibre model (82%).When considering just the results using a whole brain tracking approach the average agreement in labels was greater than 75% (75-77%). Figure 2 shows the standard deviation in the percentage volume for each region of the thalamus calculated using each method over the 5 subjects. The highest variance is found with the PV_Thal method, and the lowest variance is with the GR method. The occipital region was not labelled in the hard segmentations with most methods due to the low number of paths found to this region of the cortex. Figure 3 shows the distance between the CoM for each method, averaged over the 6 cortical regions and across the 5 subjects. The scale reading radially out in the plot is the measured distance (mm) between the CoM calculated with each method. Each line represents a method and each vertex of the plot also represents a method. A visual comparison was also made with the Mai atlas[7] to assess the pattern of connectivity in relation to the adult thalamus; the pattern of connectivity was similar.

Figure 1: Three planes in the thalamus shown. From top: PV_Thal; PV_wb; CSD_Thal; CSD_wb; GR.

Labels: Yellow=Frontal; Pink=Motor; Blue=Occipital; Purple=Parietal; Red=Sensory; Green=Temporal.



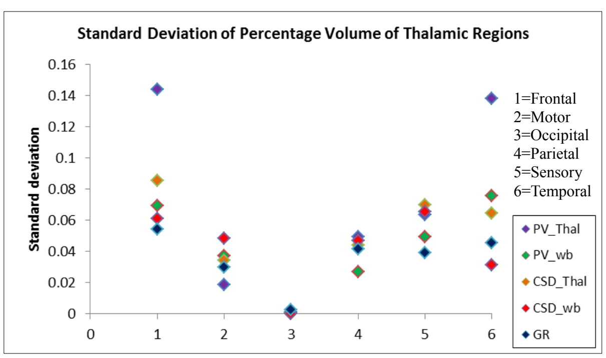


Fig 2: Percentage volume for each region of the thalamus calculated with each method and averaged over 5 subjects.

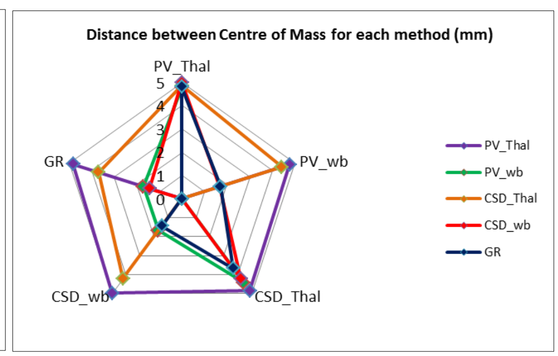


Fig 3: Distance between centre of mass calculated using each method averaged over the 6 cortical regions and 5 datasets.

Discussion: All the methods tested were able to produce a parcellation of the thalamus. The whole brain tracking approaches for parcellation of the thalamus show a closer agreement with each other with >75% of voxels labelled identically and they produced the most consistent results in terms of location of CoM, as shown in Figure 3. Using the thalamus as the seed region for generating paths displays less consistency. More information on the individual thalamus to cortical region connectivity images may be useful in the analysis. Although connections were detected between thalamic voxels and occipital cortex these were insufficient to lead to a label after hard segmentation. To address this issue and also to better represent strengths of connection we are currently exploring soft labellings based on the individual connectivity distributions to each cortical region.

References: [1] Behrens et al., *Nat. Neurosci.,* 2003, 6:750-7. [2] Counsell et al., *NeuroImage*, 2007, 34:896-904. [3] Xue et al., *Inf. Proc. Med. Imag*., 2007, 20:257-69. [4]Behrens et al., *Magn. Reson. Med*., 2003, 50:1077-88. [5] Tournier et al., *NeuroImage*, 2007, 35:1459-72,. [6] Reisert et al., *MICCAI*, Workshop DMFC, 2009. [7] Mai et al., 3rd ed. 2007.