Propagation of Probabilistic Tractography of the Optic Radiation for Neuronavigation in Epilepsy Surgery

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Introduction: Around one-third of patients with focal epilepsy fail to respond to drug therapy and should be considered for surgical treatment. Anterior temporal lobe resection (ATLR) is a well established and effective treatment for temporal lobe epilepsy[1]. However, the decision to proceed to surgery must be balanced against the risks of significant neurological deficits from surgical damage to eloquent grey matter and white matter tracts. Meyer's loop of the optic radiation is vulnerable to damage during ATLR with postoperative visual field deficits seen in between 52% and 100% of patients and up to a quarter of patients failing to meet UK criteria for driving after surgery[2]. The optic radiation shows significant anatomical variability between subjects[3] and cannot be delineated on conventional clinical MRI sequences. Tractography can demonstrate the optic radiation and the distance between the temporal pole and Meyer's loop obtained by tractography is predictive of the post-operative visual field loss[4]. Whilst deterministic tractography can be performed in real-time using intraoperative DTI scans[5], it does not accurately depict Meyer's loop[6]. Probabilistic tractography is more accurate but time-consuming. Commercial software performs only rigid registration between images so cannot account for the brain shift during surgery, which may be up to 11mm in the optic radiation[5]. Thus propagation of preoperative probabilistic tractography of the optic radiation to intraoperative images using non-linear registration techniques accounting for brain shift and deformation and the subsequent integration into the neuronavigational suite should improve the outcome from epilepsy surgery. We describe the validation of such a technique which can potentially be used in real-time in a cohort of patients undergoing ATLR using pre- and postoperative images.

Method: Preoperative and postoperative structural MRI and DTI scans were acquired on 16 patients (8 males, age 17-56 years) undergoing ATLR (10 left, 6 right) with a 3T GE Excite II scanner. Sequences included a coronal T1-weighted volumetric acquisition (170 contiguous 1.1mm slices, 256x256 matrix, 0.9375x0.9375mm in-plane resolution) and a diffusion-weighted acquisition (cardiac-triggered single-shot EPI, 60 contiguous 2.4mm axial slices, 6 non-diffusion weighted plus 52 diffusion weighted images, b-value 1200mm^{2}s^{-1}, matrix 96x96 zero-filled to 128x128, reconstructed voxel size 1.875x1.875x2.4mm). The optic radiation was delineated on the preoperative data using the multi-tensor model and probabilistic tractography as implemented in the Camino software toolkit with a previously described method[4]. This was propagated to the post-operative image with non-regid registration performed using a refactored version of the Free Form Deformation (FFD) algorithm[7;8]. The registration scheme combined information from structural and fractional anisotropy (FA) data in a normalized mutual information (NMI) similarity measure. Structural MR images capture information at the interfaces between the different brain tissues whilst FA images provide information about organizational structure of the white matter fibre bundles. The reformulated NMI allowed complementary information present in both imaging modalities to be utilized in a single registration scheme. The degree of resection was quantified by the maximum antero-posterior distance between the anterior of Meyer's loop on the propagated tractography and the resection margin (A-P distance, Figure 1). Pre and postoperative visual fields were assessed by Goldmann perimetry using three isoptres (V/4e, V/2e, I/2e) but only the largest (V/4e) was used for analysis. The degree of postoperative visual field loss was quantified as 1 – ([area of upper quadrants in both eyes contralateral to resection (i.e. the quadrants affected by damage to Meyer's loop)] / [area of upper quadrants in both eyes ipsilateral to resection (i.e. the unaffected quadrants)].

Results: 8 patients (50%) suffered a postoperative visual field loss, ranging from 10-92% of the upper quadrant (mean 51%). The propagated optic radiation did not overlie the resection area in any of the patients without visual field loss and the resection margin was 1.9-30.0mm (mean 6.8mm) anterior to Meyer's loop. In the 8 patients with visual loss, the propagated optic radiation was 7.5-31.9 (mean 15.5mm) anterior to the resection margin. The largest resection is illustrated in Figure 2. In patients with visual loss, there was a significant correlation between the A-P distance and the degree of visual field loss (Pearson correlation coefficient 0.809, one-tailed p=0.008). The mean calculation time (standard deviation) using a CPU implementation was 20.5 minutes (3.2 minutes). Significant speed increases through the use of GPUs (graphical processing units) has been shown previously[7;8]. In particular, implementation of the modified NMI similarity measure on the GPU is beneficial as this consumes a significant part of the computation time.

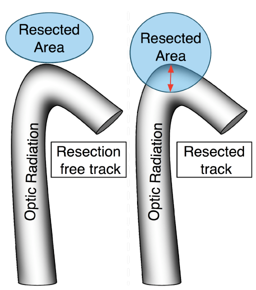

Figure 1: Measurement of antero-posterior extent of resection (from Meyer's loop to resection margin)

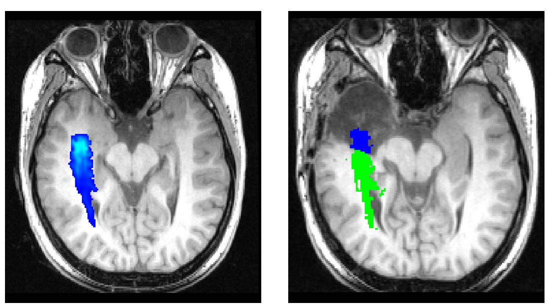

Figure 2: *(Left)* Preoperative T1 image and optic radiation; *(Right)* Postoperative T1 image with propagated preoperative tractography showing part of the optic radiation was resected (blue) in a patient who developed a severe visual field deficit

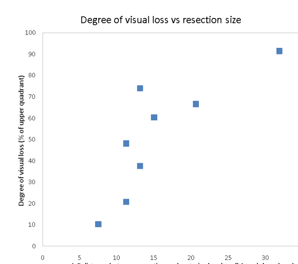

Figure 3: Correlation between A-P extent of resection and degree of visual field deficit in those patients with a deficit. There was no overlap between the resection and optic radiation in those without a visual field deficit.

Conclusion: We have shown that preoperative tractography can be accurately propagated to postoperative images using a non-linear algorithm that accounts for brain shift. The results obtained are highly predictive of the degree of visual loss. As MRI and DTI scans can be acquired intraoperatively, application of this technique in the operating theatre will enable tractography data to be available in the neuronavigation system. The transfer time of the patient from an interventional MRI scanner back to the operating table is approximately 7-10 minutes. Future work including porting the algorithm to a GPU implementation will enable the computation time to be reduced such that results are available within this timeframe.

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