Clinical Neurology and Neurosurgery 122 (2014) 87–91

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Can DTI fiber tracking of the optic radiations predict visual deficit after surgery?

Pierre-Yves Borius [a,b,*], Franck-Emmanuel Roux [a,b], Luc Valton [b], Jean-Christophe Sol [a,b], Jean-Albert Lotterie [a,c], Isabelle Berry [a,c]

[a] INSERM, Imagerie Cérébrale et Handicaps Neurologiques UMRS 825, Université de Toulouse, UPS, Toulouse, France
[b] Pôle Neuroscience, CHU, Toulouse, France
[c] Nuclear Medicine Department, Toulouse, France

ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form 2 April 2014
Accepted 20 April 2014
Available online 5 May 2014

Keywords:
Tensor diffusion imaging
Temporal lobectomy
Optic radiation
Tractography
Epilepsy

ABSTRACT

Object: Sparing optic radiations can be of paramount importance during epilepsy surgery of the temporal lobe. The anatomical heterogeneity of the Meyer's loop of the optic radiations could be assessed by means of diffusion tensor tractography. We used temporal lobe surgery as a lesion model to validate this method.
Material and methods: We analyzed the distance between the temporal pole (TP) and Meyer's loop (ML) and the correlation between visual impairment and the percentage of virtual fibers injured. MRI studies were performed in 18 patients and 13 controls. Diffusion tensor imaging (DTI) with fiber tracking was performed using four different algorithms and various gradient directions (15 or 32) and fractional anisotropy (FA) thresholds (0.18, 0.20, and 0.22). To find the best DTI model, we tested each gradient direction and FA threshold on 16 operated patients by pre- and post-operative visual field testing that analyzed the percentage of virtual fibers damaged on 3-month-post-operative MRIs.
Results: Marked individual differences were noted in the TP-ML distances (mean: 25.4 mm; range 18.2–38.3 mm; standard deviation: 4.7) but with no significant difference between patients and controls ($p = 0.9$). The percentage of virtual fibers reconstructed by tracking and damaged by surgery was correlated with visual impairment. Significant differences appeared between algorithm types. The tensor-line algorithm with 15-direction resolution and an anisotropy threshold of 0.18 seemed to be the most relevant. A threshold of 5.5% of injured virtual fiber could predict a visual defect with a sensitivity of 71.4% and a specificity of 87.5%.
Conclusion: Optic radiation tractography by DTI could be a useful method to assess an individual patient's risk of postoperative visual deficit.

1. Introduction

Diffusion tensor imaging (DTI) allows us to visualize the different fasciculi of the white matter *in vivo* [1–2]. This tool is used as an aid for planning and surgical resection [3,4,5,6,7]. However, the creation of a virtual atlas of fibers using algorithms has no value in clinical settings because it is based on qualitative plausibility criteria [8]. Epilepsy surgery could be used as a lesional model to validate this technique. Anterior temporal lobectomy with amygdalo-hippocampectomy is an efficient treatment for selected cases of drug resistant temporal lobe epilepsy (TLE) [9–10]. It is reported this surgical procedure causes optic tract injury in Meyer's loop leading to a superior quadranopsia in 50–90% of operated patients [11]. Nevertheless, this visual field defect is variable and difficult to predict on anatomical landmark only because of the individual anatomical variability of Meyer's loops [12]. The distance between the temporal pole and the anterior edge of Meyer's loop can vary between 20 and 60 mm [13].

DTI could predict the position of Meyer's loop and help with surgical planning. Various tractography algorithms are available [14] and their parameters are multiple. The choice of a suitable one should be a trade-off between the fiber tract of interest, the available computation time and the clinical relevance. The aim of this study was first to reconstruct the optical tract with different algorithm parameters and evaluate the consistency of the temporal pole–Meyer's loop (TP–ML) distance with data in the literature. The second aim was to validate the model by comparing the percentage of virtual fibers injured and quantifying the visual functional deficit.

* Corresponding author. Tel.: +33 491 386 564; fax: +33 491 387 871.
E-mail address: pierre-yves.borius@hotmail.fr (P.-Y. Borius).

http://dx.doi.org/10.1016/j.clineuro.2014.04.017

2. Material and methods

2.1. Patients and control group

Eighteen patients (12 females; mean age: 40 years; age range: 20–60 years; standard deviation: 12) with drug-resistant TLE were selected by a multidisciplinary epilepsy team (neurosurgeons, neurologists, and neuroradiologists) and were included prospectively in this DTI study. Of the 18 patients, 12 patients were included in a group in which TP–ML measurements were taken and 16 were included in a second group for model validation. According to EEG and imaging data, the laterality of epilepsy was in the left hemisphere in 6 cases and in the right in 12 cases.

The surgical procedure chosen in all cases was an anterior temporal lobectomy with amygdalo-hippocampectomy. The distance between the temporal anterior pole and the resection cavity was planned to be 30 mm on the superior temporal gyrus and 45 mm on the middle and inferior temporal gyri in all patients. All patients underwent an ophthalmological assessment which included a Goldmann visual field and an automated perimetry test (Octopus®) before and 3 months after surgery. The visual function was evaluated using various Octopus® parameters: mean defect (MD), which is the difference between the normal sensitivity for the patient's age and the patient's retinal sensitivity; loss variance (LV), which evaluates the non-uniformity of the visual field point by point; the mean light intensity (dB); and the MD of the region of interest, which was the upper contralateral quadrant here.

The data of thirteen healthy volunteers (mean age: 28 years; age range 24–54 years; standard deviation: 7.6) were used for the control group. Like our patients, they all had a complete ophthalmological assessment and DTI tractographies to evaluate TL–MP distances.

2.2. Imaging and fiber tracking

A 1.5 tesla Philips INTERA magnetic resonance imaging (MRI) unit was used for the scanning protocol, which included T1 weighted volumetric sequences before and 3 months after surgery (gadolinium, TE = 4.6 ms, TR = 17 ms, matrix = 256 × 256, section thickness = 0.8 mm), and DTI with echo planar imaging before surgery (TE = 86 ms, TR = 6740–7700 ms, matrix = 122 × 122, section thickness = 2.2 mm, isotropic voxel = 2.2 mm, $b = 1000\,\mathrm{s/mm}^2$, encoding of 15 and 32 axis gradient directions).

Fiber tracking was performed using the "Sisyphe" software developed in our research department [15]. In all, four algorithms were used. Three algorithms were deterministic: streamline (fiber assignment by continuous tracking) [16], tensor-deflection (with $\alpha = 1$) [17] and tensor-line (with $w_{\mathrm{punct}} = 0.2$) [18]. We also used a probabilistic algorithm developed by Hagmann et al. [19] (with $\alpha = 2$, $\lambda = 0.8$, 10 fibers per seed voxel). The fiber diameter was 0.2 mm. The number of seeds, in millimeters, was one. The maximal angle was 45°. The minimal trajectory size was 40 mm. The fractional anisotropy (FA) threshold was varied: 0.18, 0.20 and 0.22.

All seed ROI (regions of interest) were segmented on an anatomical template, which was co-registered with each patient's or healthy volunteer's MRI. Eight ROIs were used for deterministic algorithms. The lateral geniculate body and visual cortex were used as germ and inclusion ROIs, respectively. The sagittal stratum was used as inclusion ROI. Five exclusion ROIs were considered to perform the virtual dissection, and eliminate the bundles that could contaminate the optic tracts: inferior longitudinal fasciculus, uncinate fasciculus, superior longitudinal fasciculus, inferior occipito-frontal fasciculus, superior occipito-frontal fasciculus, occipito-temporal fasciculus, and splenium fibers. For the probabilistic algorithm, only the two germ ROIs (LGC and CV) were necessary.

2.3. Data analysis

The first part of the study focused on the TP–ML distance, which was measured in 12 patients and in the 13 healthy volunteers. Measurements were made along the hippocampal axis between the temporal pole and the front edge of the right or left virtual optic tract reconstructed according to the different parameters.

The second part of the study was to validate tractography. The data of 16 operated patients were analyzed. The resection volume was segmented on the postoperative MRI at 3 months and used as exclusion ROI. The percentage of virtual fibers "injured" by this resection was obtained from the ratio of the number of fibers passing through the cavity over the total number of fibers reconstructed. Then, this percentage was correlated with the visual field defect quantified by Octopus® parameters (Fig. 1).

Statistical analysis was performed with MANOVA, and non-parametric regression (Spearman test) with Statistica software (Statsoft®). The p threshold was 0.05.

3. Results

3.1. TPML distance

The TPML distance was measured on 12 patients and the control group. More than 3000 measurements of TP–ML distance were performed, including different combinations of the chosen parameters (tensor direction, algorithm, fractional anisotropy, and connectivity threshold). Mean TP–ML in patients was 25.5 mm (range 18.2–38.3; standard deviation: 5.5 mm); mean TP–ML in volunteers was 25.3 mm (range 19.8–34.7; standard deviation: 4 mm). There was no statistically significant difference in TP–ML between patients and volunteers ($p = 0.9$). Overall, the mean TP–ML measurement for both groups combined was 25.4 mm (range 18.2–38.3 mm; standard deviation: 4.7 mm). The mean distance was 22.3 mm with the tensor-deflection algorithm and 22.8 mm with the tensor-line algorithm. Results with these two algorithms differed significantly from those of the streamline algorithm, which had a mean distance of 25.5 mm, and the Hagmann algorithm, which had a mean distance of 30 mm. (Fig. 2).

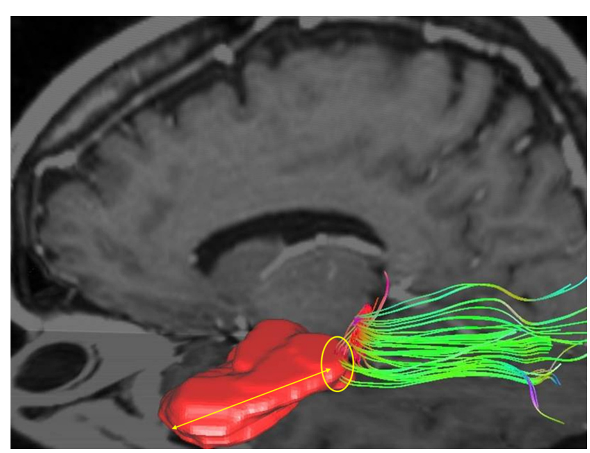

Fig. 1. 3D view of a resection cavity (red) after temporal lobectomy and optic radiations reconstructed by tractography. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) This 32-year-old patient had drug-resistant temporomesial epilepsy with hippocampal sclerosis. Virtual fibers at the intersection of the cavity are considered to be injured (circle). The double arrow symbolizes the distance between the anterior temporal pole and the anterior part of Meyer's loop (32 mm).