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Automated Tractography of Four White Matter Fascicles in Support of Brain Tumor Surgery

Stephan Meesters\textsuperscript{1,2}, Geert-Jan Rutten\textsuperscript{2}, Luc Florack\textsuperscript{1}

\textsuperscript{1}Eindhoven University of Technology, Eindhoven, The Netherlands
\textsuperscript{2}Elisabeth-TweeSteden Hospital, Tilburg, The Netherlands

Introduction
Knowledge of eloquent white matter fascicles is imperative for the planning of brain surgical procedures to prevent the loss of sensory processing, linguistic ability and motor skills. Diffusion-weighted tractography methods have made it possible to accurately reconstruct these white matter structures in-vivo \cite{1}. While these methods have already shown added value in neurosurgical decision making, few neurosurgeons have access to this information because data analysis requires skilled and experienced personnel \cite{2}. In the current work, an automated "turn-key" tractography pipeline is introduced for four eloquent fascicles and its results are evaluated on the clinical imaging data of brain tumor patients.

Methods
The data processing pipeline is outlined in Figure 1 for the automated tractography of the Optic Radiation (OR), Inferior Fronto-occipital Fasciculus (IFOF), Corticospinal Tract (CST) and the Arcuate Fasciculus (AF). Estimation of regions of interest (ROIs) to seed and restrict the tractography are done by parcellation of the brain in cortical and sub-cortical areas. Spatially Localized Atlas Network Tiles (SLANT) \cite{3} uses deep learning to compute a patient-optimized whole brain segmentation of 133 anatomical regions. Further refinement is achieved by the use of the Morel stereotactic atlas of the thalamus \cite{4}, adding an additional 44 anatomical regions. The Morel atlas was coregistered linearly using NiftyReg to the thalamus segmentations of SLANT to provide robust patient-specific segmentations. Segmentation of the tumor core, tumor edge and edema was done with a convolutional neural networks approach \cite{5} trained on Multimodal Brain Tumor Segmentation (BRATS) Challenge data of annotations of low and high-grade gliomas. The segmented tumor core provides an additional exclude region for tractography to reduce false positives. Tractography was performed with the MRTrix software package \cite{6} using the constrained spherical convolution-based probabilistic iFOD2 method included in \textit{tckgen}. Diffusion data was preprocessed used the preprocessing script of MRTrix, which uses FSL’s \textit{eddy}.

Results
Tractography results of the four fascicles are presented for one example patient in Figure 2. The pipeline was evaluated on the data of five patients who were candidate for brain surgery, which was acquired using a clinically-applicable diffusion weighted imaging protocol (b=1500, n=50, duration time of 8 minutes) acquired on a 3T Philips Achieva Scanner using the 32-channel...
SENS head coil. All tractograms were reviewed by an experienced neurosurgeon (GR), and were found to be consistent with anatomical knowledge. In Figure 2A (bottom-right) a mass effect can be observed where the IFOF is pushed inferiorly, but could still be successfully reconstructed. Similarly in Figure 2D the AF is pushed medially due to a mass effect. The SLANT method appeared to produce robust results even in the presence of tumor tissue, and, in all cases, did not apply a false label to the tumor core.

Conclusion
A framework was introduced for the automated tractography of four clinically-relevant white matter fascicles. Initial investigations show that the pipeline produces robust results. As a next step, we will validate its performance in a larger group of neurosurgical patients, including patients with very prominent mass effects or edema. While (quantitative) validation of tractography results remains an open problem, indirect approaches are possible such as comparison to the results of electrocortical stimulation [7] or post-operative functional outcome [8]. In future work the analysis pipeline will be further optimized to correct for free water in peritumoral edema, which may improve the quality of tractography results in close proximity to the tumor.

References


Figure 1: Schematic overview of the data processing pipeline for tractography of four eloquent fascicles: the optic radiation (OR), inferior fronto-occipital fasciculus (IFOF), corticospinal tract (CST) and the arcuate fasciculus (AF). Segmented anatomical regions are coregistered to the DWI space, and used in the tractography either as seeding region, include (AND) region, or exclude region based on anatomical knowledge of the fascicles [9, 10].
Figure 2: Illustration of tractography results for an example patient who was candidate for brain surgery. Shown are the optic radiation (A), inferior fronto-occipital fasciculus (B), corticospinal tract (C) and the arcuate fasciculus (D). Tractograms in the left and right hemispheres are color-coded in yellow and cyan, respectively. In (A) the tractograms of the OR are shown together with an annotation of the ventricular system (yellow). In (B) the tumor core is visualized (in blue). The inset picture shows how the IFOF is pushed inferiorly due to a mass effect. In (D) the tumor is shown to be in close proximity of the arcuate fasciculus and shows a mass effect.