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

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Abstract

Knowledge of eloquent white matter fascicles is imperative 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 [1].
- However, few neurosurgeons have access to this information because data analysis requires skilled and experienced personnel [2].
- An automated "turn-key" tractography pipeline is introduced for four eloquent fascicles and evaluated for brain tumor patients.

Data processing pipeline

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). The three steps of the pipeline are outlined.

Step 1: Estimation of Regions of Interest

- Thalamic segmentation using the Morel stereotactic atlas of the thalamus [4] provides an additional 44 sub-cortical segmentations. The atlas was aligned to thalamic segmentations of SLANT for increased accuracy.

Step 2: Tumor segmentation

- Segmentation of the tumor core, tumor edge and edema was done with a convolutional neural networks approach [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 exclusive region for tractography to reduce false positives.

Step 3: Diffusion-weighted tractography

- Tractography of the four bundles was performed with the MRtrix software package [6] using the constrained spherical convolution. Diffusion data was preprocessed using the preprocessing script of MRtrix, which uses FSL's eddy.

Results

The pipeline was evaluated on the data of five patients who were candidate for brain surgery, acquired using a clinically-applicable DWI protocol (b=1500, n=50). 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

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 electrophorical 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.

Figure 1: Schematic overview of the data processing pipeline for tractography of four eloquent fascicles. Segmented anatomical regions are 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.

References