Intraoperative DTI White Matter Mapping: Neurosurgical Perspective

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- functional/multimodal navigation reduces postoperative neurological deficits
- intraoperative imaging identifies tumor remnants and leads to extented resections
- intraoperative imaging allows compensating for brain shift, so that also DTI can be updated

Navigation systems are the common tool for data representation in the operating room and allow the visualization of structures in the surgical field itself. Functional navigation, i.e. integrating functional data into anatomical navigational datasets, is an important add-on, since it prevents too extensive resections, which would otherwise result in new neurological deficits. Data from magnetoencephalography (MEG) or functional MRI (fMRI) localize cortical functional eloquent brain areas, while tractography based on diffusion tensor imaging (DTI) allows visualizing the course of major white matter tracts like the pyramidal tract, the visual pathway, and speech related pathways. Besides these functional data further information is available for a multimodal navigation setup. Positron emission tomography, MR spectroscopy, and diffusion weighted imaging may provide information on the diffuse tumor border.

The major clinical question is whether the tracking results actually reflect reality. First attempts correlating the DTI findings to intraoperative electrophysiological measurements showed quite some discrepancies which are probably mainly attributable to a distinct shifting of major white matter tracts during a neurosurgical procedure, which could be demonstrated by comparing pre- and intraoperative fiber tracking, acquired by high-field MRI applied during surgery. Maximal safety may require combining electrophysiological brain mapping with functional navigation that integrates fMRI/MEG-data and DTI-based fibertracking acquired before or during surgery. Like cortical eloquent brain areas can be identified by intraoperative electrophysiological mapping, subcortical electrical stimulation helps to identify major white matter tracts intraoperatively. Recent studies emphasize that functional navigation and subcortical stimulation are complementary methods that may facilitate the preservation of pyramidal tracts.

The intraoperative visualization of the course of the pyramidal tract by microscope-based navigation during the resection of supratentorial gliomas has resulted in reduced neurological deficits, which may serve as a proof of concept per se. This is also supported by studies comparing pre- and postoperative reconstructions of major white matter structures in the brain stem well correlating to clinical deficits. Visual field deficits in temporal lobe surgery for pharmaco-resistant epilepsy provide a model to analyze the clinical validity of changes in fiber tracking by correlating the extent of visual field defects with the changes in pre- and intraoperative DTI-based reconstruction of the optic radiation. The significant correlation between postoperative visual field deficits and the extent of alterations of the optic radiation also proved that reconstruction of major white matter tracts can be reliably used in a clinical setting.

The distance of how close a reconstructed major white matter tract can be approached is not yet clearly defined. Analyzing the DTI based navigation data in regard to the distance between tumor and pyramidal tract revealed that a distance of 5 mm seems to be a critical distance, which should be taken into account as safety margin. Additional hulls around the reconstructed 3-D objects representing major white matter tracts are a possibility to visualize these safety margins. These encompassing hulls ideally would vary in thickness respective to the quality and reliability of the reconstructed fiber bundle. In case of noisy unreliable data a thick hull would be added, while in highly reliable data the hull would be thinner.

Intraoperative imaging provides further data that can be visualized during the surgical procedure. Efficient reconstruction and visualization algorithms are necessary to avoid intraoperative delays. By intraoperative imaging the unexpected finding of residual tumor in postoperative examinations is practically eliminated. As a consequence, the surgical goal of a complete or an optimal resection can be achieved without any guesswork. In about one third of all procedures intraoperative MRI results in a change of the surgical strategy, i.e. further resection. Due to the combination of multimodal navigation with intraoperative imaging the optimal extent of a resection by simultaneous preservation of functional integrity can be achieved. The intraoperative images can be used for an update of the navigation system, thus compensating for the effects of brain shift. Additional intraoperative fiber tracking even allows to extent the updating beyond the standard anatomical image data, further reducing postoperative neurological deficits. The DTI data update also allows to reliably compare electrophysiological findings to imaging without inaccuracies caused by brain shift, which might otherwise led to erroneous interpretations.

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