A White Matter Tractography Study of White Matter Reorganization after Surgical Resection of Brain Neoplasms

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Introduction

Brain tumors can infiltrate, displace, or disrupt white matter (WM) structures [1]. The goal of any surgical procedure is to maximize tumor resection while minimizing loss of brain function. This implies preservation of the WM tracts that are responsible for brain function. Of great importance is the preservation of motor tracts, such as the cortico-spinal tracts (CST), and language-relevant tracts, the arcuate fasciculi (AF). WM tractograms are estimates of major WM pathways that are constructed using algorithms that detect long-range patterns of continuity in the diffusion tensor field of a brain [2-5]. The aim of this study was to investigate the potential role of WM tractograms for mapping WM tracts in relation to cerebral tumors before and after their surgical resection. Tractograms of affected WM structures were retrospectively generated to assess the impact of surgery on these tracts in six tumor patients.

Methods

Diffusion Tensor Imaging: DTI data were obtained on six patients with brain neoplasms before and after surgical resection of the brain tumor. The imaging studies were performed on a 1.5T scanner using a single-shot spin-echo EPI pulse sequence with diffusion sensitizing gradients applied in 23 uniform distributed encoding directions [6]. Twenty-one to forty 3mm thick (128x128 matrix and 240 mm FOV) axial slices were acquired to cover the brain volume affected by lesions. The total imaging time varied between 7 and 15 minutes, depending on the number of slices acquired. The diffusion-weighted images were corrected for misregistration from motion and eddy current distortion using a 2D affine registration algorithm in AIR [7] and then the imaged volume was interpolated to isotropic voxel dimensions.

White Matter Tractography: WM tractograms were generated using a tensor deflection algorithm [4]. The propagation of an individual trajectory was generally terminated when it reached a voxel with FA<0.2 or when the angle between two consecutive steps was greater than 45°. The FA threshold was lowered in cases where tracts appeared to have regions of abnormal low anisotropy. Specific white matter tracts were reconstructed by using a multiple region-of-interest (ROI) approach [2, 5]. Fiber trajectories were generated from regions containing cross-sections of the tracts of interest. Subsequently, by using additional ROIs, only the trajectories that followed these tracts were retained. In certain cases, anatomically implausible trajectories have been removed.

Results

The tumor pathologies of the six patients were 1) a grade III astrocytoma disrupting left corpus callosum, displacing left cingulum and corona radiata, 2) a pilocytic astrocytoma centered in left basal nuclei, displacing left callosal genu and CST, 3) a ganglioglioma involving left cerebral peduncle, splaying CST fibers anteromedially and posterolaterally, 4) a giant cavernous angioma medially displacing left corona, 5) a grade IV astrocytoma centered in right centrum semiovale, displacing AF, corona radiata, and corpus callosum, and 6) a cavernous angioma centered in right striatal region and displacing CST. WM tractograms generated from the DTI data before surgery clearly demonstrated these patterns. In many cases, displaced tracts appeared to return to normal or nearly normal anatomical position after the surgical procedure. Representative WMT results are presented below.

In Patient 5, the tumor was surrounded by a large region with low FA. Tractograms of the right AF are presented in Figure 1. The tract was displaced inferiorly by the tumor (arrow). Coronal cross-sections show both the right and the left positions of the AF, with the right AF returning to normal anatomical position after tumor resection. Tractograms and axial cross-sections of internal capsule and corona radiata fibers are presented in Figure 2. In the pre-operative tractogram (Figure 2a), the motor fibers (orange-green) appear to maintain coherence even as they cross low anisotropy regions. The structural organization appears more symmetric and anatomically normal in the post-operative tractogram.

Patient 3 presented with a ganglioglioma involving the left cerebral peduncle. The CST tractograms (Figure 3) show that continuous fiber trajectories exist for both the main bundle and the bundles that have been splayed out by the lesion. The tract appears preserved after the surgery and is closer to normal anatomical position. The volume of the anteriorly splayed fibers appears larger after surgery, which might be a result of fiber decompression after tumor removal.

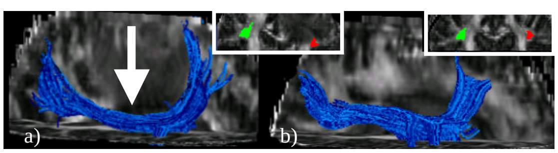

Figure 1 Ipsilateral AF tractogram before (a) and after (b) surgical resection of the tumor (Patient 5). Inset: The positions of both ipsilateral (red) and contralateral (green) tracts are shown in coronal cross-section.

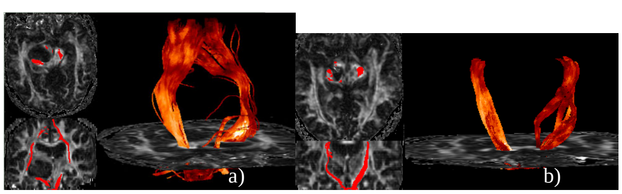

Figure 3 CST tractogram before (a) and after (b) tumor resection (Patient 3). Tract position is overlaid in red onto axial and coronal FA images.

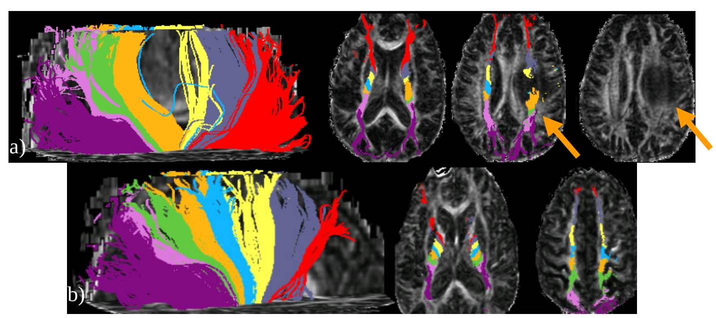

Figure 2 Ipsilateral corona radiata before (a) and after (b) tumor resection in Patient 5. Fiber trajectories were color-coded accordingly to their anterior-posterior position. Their relative position is shown in axial FA maps. A FA threshold of 0.08 was used for terminating fiber trajectories. Continuous trajectories were obtained even through regions of low anisotropy (indicated by arrows).

Discussion

This study shows that WMT enables the three-dimensional visualization of fiber tracts that are affected by tumors. This method can offer valuable information for pre-surgical planning and may be used to evaluate the outcome of the surgery on the preservation and reorganization of white matter tracts. In all of the cases, the WM tractograms showed that the corticospinal tracts were preserved after surgery. The tractogram results were therefore in agreement with the observation that these patients showed the same level or improvement of motor function, which was assessed by clinical evaluation. It also has been shown that the tract coherence may be observed in regions of low anisotropy.

References: [1] Witwer et al. J Neurosurg, 97:568, 2002; [2] Conturo et al. Proc Natl Acad Sci, USA, 96:10422, 1999; [3] Mori et al. Ann Neurol 45:265, 1999; [4] Lazar et al. HBM, 18:306, 2003; [5] Catani et al. Neuroimage 17:77, 2002; [6] Hasan et al. J MRI, 13:769, 2001; [7] Woods et al. J Comp Ass Tom 22:141, 1998.