DiSusion Tensor Imaging of the Corticospinal Tract in Patients with Brain Neoplasms

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Purpose: To maximize the extent of tumor resection and minimize postoperative neurological deficits in patients with brain neoplasms, it is very important to evaluate the integrity of the corticospinal tract (CST) before surgery. We attempted to determine whether CST abnormality in these patients correlates with clinical motor weakness.

Methods: We retrospectively evaluated 19 patients (16 men, 3 women, aged 39 to 70 years) with pathologically proven brain neoplasms with lesions adjacent to the posterior limb of the internal capsule and categorized their motor function as normal or abnormal based on clinical assessment. After correcting raw diffusion tensor image (DTI) data for motion and eddy-current artifacts, we computed fractional anisotropy (FA) and apparent diffusion coefficient (ADC) maps. We manually segmented the CST from the level of the cerebral peduncle to the internal capsule, used the segmented CST as the mask for FA and ADC measurements, and compared normalized FA (nFA) and ADC (nADC) values relative to the contralateral normal side using a 2-tailed, unpaired t-test.

Results: Compared with the normalized values for patients with normal motor function, patients with abnormal motor function demonstrated significantly decreased FA ($P < 0.001$, $0.65 \pm 0.09$ versus $0.85 \pm 0.08$) and significantly increased ADC ($P < 0.01$, $1.49 \pm 0.17$ versus $1.23 \pm 0.22$).

Conclusion: DTI metrics can be used for preoperative evaluation of the integrity of the CST microstructure.

Keywords: brain tumor and motor weakness, corticospinal tract, diffusion tensor imaging

Introduction

The goals of brain tumor surgery are to maximize tumor resection and minimize postoperative neurological deficits from damage to intact functioning brain. Even mild impairment or damage of the corticospinal tract (CST), the major motor pathway, may produce significant sensorimotor deficits. Thus, presurgical knowledge of the microstructural integrity and location of the CST is very important.

Diffusion tensor imaging (DTI) allows noninvasive mapping of white matter tracts, and tractography generated from DTI has been applied to various brain disorders, including tumors, ischemia, multiple sclerosis, and vascular malformations.1-10 Diffusion tensor metrics, such as fractional anisotropy (FA) and apparent diffusion coefficient (ADC), have been widely used to characterize diffusion properties. Abnormal FA and ADC values have been reported in white matter tracts in patients with brain neoplasms,11,12 and recent studies have shown that fiber tracts adjacent to tumor can be reconstructed even if the tumor displaces, disrupts, or invades the tracts.1,13-15 In addition, reports of several studies evaluating these values indicated correlation between white matter changes and motor weakness in patients with brain tumors.12,16 Their DTI findings indicated the potential usefulness of DTI for presurgical evaluation of motor function. However, these studies applied manually drawn regions of interest (ROIs), a time-consuming and subjective method. In this study,
we employed a semi-automatic approach to determine whether CST abnormality detected by DTI in patients with brain tumors correlates with clinical motor weakness.

Materials and Methods

Subjects
We retrospectively evaluated 19 patients (16 men, 3 women, aged 39 to 70 years) with pathologically proven brain neoplasms (15 glioblastomas, one grade IV gliosarcoma, one anaplastic astrocytoma, 2 low grade astrocytomas) located adjacent to the posterior limb of the internal capsule. On fluid-attenuated inversion recovery (FLAIR) images, all tumors were involved in regions of hyperintensity on more than 2 slices, were nonenhancing, and eliminated neither necrosis nor hemorrhage. Motor function was categorized as normal in 12 subjects and abnormal in seven based on clinical assessment, such as Manual Muscle Test (MMT)17 and pathological reflex evaluation, including Wartenberg, Hoffmann, Babinski or Chaddock reflex. Motor function was determined normal if MMT was 5/5 with no abnormal pathological reflex and abnormal otherwise.

Data acquisition
All patients underwent magnetic resonance (MR) examination before surgery on a 3-tesla system (Magnetom Trio, Siemens, Erlangen, Germany) equipped by the manufacturer with a 12-channel phased-array head coil. DTI was acquired with a 12-direction, single-shot, spin-echo, echo-planar sequence with parallel imaging using generalized autocalibrating partially parallel acquisitions (GRAPPA) and acceleration factor of 2. Imaging parameters were: repetition time (TR)/echo time (TE), 4900/83 ms, field of vision (FOV), 22 × 22 cm²; matrix, 128 × 128; b values, 0 and 1000 s/mm²; slice thickness, 3 mm; and 40 slices covering the whole brain. Total acquisition time was 8 min.

Image analysis
We post-processed data off-line using DTISTUDIO, Version 3.0 (Johns Hopkins University, Baltimore, MD, USA), correcting images for motion and eddy-current artifacts using 12-mode affine transformation with automated image registration18 and computing FA and ADC maps. We used continuous tractography (FACT) to reconstruct the CST by placing 2 regions of interests (ROIs) at the lower pons and cerebral peduncle based on fiber assignment.19 We manually segmented the CST from the level of the cerebral peduncle to the internal capsule using MRICro software (Neuropsychology Lab, Atlanta GA, USA)20 and used the segmented CST as the mask for FA and ADC measurements. After normalizing the FA and ADC values relative to the contralateral normal side, we compared data across the 2 groups using a 2-tailed, unpaired t-test.

Results
Figures 1 to 4 show representative images for cases with normal and abnormal motor function. MR imaging findings differed little between the 2 groups. In both cases, the CST deviated but was well preserved in the internal capsule and penetrated into areas of abnormal hyperintensity on FLAIR imaging. We noted reduced FA (P < 0.001) and increased ADC (P < 0.01) from the CSTs in patients with abnormal motor function compared with those with normal motor function (Fig. 5).

Discussion
Our observation of reduced FA and increased ADC in patients with abnormal motor function compared with those with normal function suggests that preoperative determination of CST involvement by DTI aids assessment of motor weakness or its absence.

Increased ADC and reduced FA have been reported to reflect a combination of vasogenic edema and tumor infiltration. Report of the CST, including areas of edema or tumor, showing low FA might represent fiber disruption on an FA map.21 Awasthi and associates reported decrease in FA accompanied by increased ADC to represent infiltration of the white matter by tumor cells and edema.22 Our results also supported a correlation between decreased FA and increased ADC with CST involvement.

ROI location is also very important for DTI measurement. Previous reports have generally depended on visual assessment of anatomic information based on FA maps,12 but this approach is subject to inter- and intraobserver bias or mismatch. In addition, tumors often displaced CST trajectories. We have introduced a semi-automatic approach using the segmented CST as the mask, a technique that is much more objective and reproducible. We focused only on the CST from level of the cerebral peduncle to the internal capsule because it is the most robust part of the CST and easier to separate from other fibers.

Though our results are promising, diagnostic accuracy could still be improved. Kunimatsu and associates reported a strong correlation of CST invol-
Fig. 1. A 52-year-old man with glioblastoma multiforme (GBM) and normal motor function. An area of abnormal intensity on fluid-attenuated inversion recovery (FLAIR) (a) with less contrast enhancement (b) located on the right temporal lobe. The apparent diffusion coefficient (ADC) map (c) showed higher ADC value of the affected corticospinal tract (CST), and the fractional anisotropy (FA) map showed lower FA (d, e). On tractography, the segmented CST on the affected side was located near the tumor (f).

Fig. 2. A case with normal motor function (same case as Fig. 1). The corticospinal tract (CST) is overlaid on B₀ images. The CST segmented from the level of the cerebral peduncle to the internal capsule was used as a mask to measure fractional anisotropy (FA) and apparent diffusion coefficient (ADC) values. Normalized FA (nFA) = 0.973, and normalized ADC (nADC) = 0.927.

Fig. 3. A 63-year-old man with glioblastoma multiforme (GBM) and abnormal motor function. An area of abnormal intensity on a fluid-attenuated inversion recovery (FLAIR) image (a) was located on the left temporal lobe and demonstrated heterogeneously peripheral enhancement (b). The value of the apparent diffusion coefficient (ADC) in the affected corticospinal tract (CST) was higher (c), and the FA value was lower on the FA map (d, e). The segmented CST on the affected side was located near and penetrated into the tumor on tractography (f).

Fig. 4. A case with abnormal motor function (same case as Fig. 3). The corticospinal tract (CST) is overlaid on B₀ images. The CST segmented from the level of the cerebral peduncle to the internal capsule was used as a mask to measure fractional anisotropy (FA) and apparent diffusion coefficient (ADC) values. Normalized FA (nFA) = 0.535, and normalized ADC (nADC) = 1.836.
Fig. 5. Normalized fractional anisotropy (FA) and apparent diffusion coefficient (ADC) values between the groups with normal and abnormal motor function. Patients with abnormal motor function demonstrated decreased FA and increased ADC. Both values have statistical difference (*P < 0.01, **P < 0.001, unpaired t-test).

Movement with muscle strength recovery in patients with stroke by applying spatial normalization using statistical parametric mapping (SPM). Blood oxygen-level-dependent (BOLD) functional MR imaging (fMRI) is the most widely used noninvasive technique to find the area for active functioning and is very useful in guiding ROI placement. Several papers have reported the separation of hand and foot fibers by placing ROIs adjacent to the areas of maximum fMRI activity.

Furthermore, the potential of 1H-MR spectroscopy (MRS) to detect CST involvement has been reported. Stadlbauer and colleagues combined tractography with MRS findings and reported decreased FA and number of fibers per voxel (FpV) and increased ADC in the fiber bundles adjacent to the tumor in patients with sensorimotor deficits; decreased N-acetylaspartate (NAA) and increased choline (Cho) were also detected within the CST.

Though our study did not apply these evaluations at this time, our DTI-based analysis did reproduce results previously reported using more complicated methods, including fMRI or MRS.

Conclusion

DTI can be used to evaluate the integrity of the CST microstructure and aid assessment of the degree of CST involvement in brain neoplasms.

References

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