

MR Tractography for preoperative planning in patients with cerebral tumors in eloquent areas

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Abstract

Resection of the maximum amount of tumoral tissue while preserving the function of the brain within or neighboring the tumor region established itself as a fundamental goal of modern oncologic neurosurgery. A major step in preoperative mapping of eloquent cerebral cortex was taken reliably through the use of functional magnetic resonance imaging. However it does not provide any information about the white matter tracts that may be affected by invasive, intrinsic brain tumors. The advances in diffusion-tensor (DT) imaging techniques have been used to map white matter tracts in the normal brain. The aim of this study was to demonstrate the role of DT imaging in preoperative mapping of white matter tracts in relation to cerebral neoplasms and the way it can influence the operative decision in our practice. Ten patients with brain malignancies within or neighboring eloquent cortical areas (nine glioblastoma and one grade two astrocytoma) underwent DT imaging examinations prior to tumor excision. Anatomical information about white matter tract location, orientation, and projections was obtained in every patient. Depending on the tumor type and location, evidence of white matter tract edema (one patient), infiltration (one patient), displacement (five patients), and disruption (three patients)

could be assessed with the aid of DT imaging in each case. Diffusion-tensor imaging allowed for visualization of white matter tracts and was found to be beneficial in the surgical planning for patients with intrinsic brain tumors. The authors' experience with DT imaging indicates that anatomically intact fibers may be present in abnormal-appearing areas of the brain. Whether resection of these involved fibers results in subtle postoperative neurological deficits requires further systematic study.

Keywords: cerebral eloquent areas, glioblastoma, MR tractography

Introduction

Resection of the maximum amount of tumoral tissue while preserving the function of the brain within or neighboring the tumor region established itself as a fundamental goal of modern oncologic neurosurgery. Taking into account that most patients with tumors in eloquent areas such as the motor cortex present with no or mild neurological deficits, it is fundamental to have a precise representation of the relationship between the neoplastic mass and the normal brain structures, in order to achieve a maximal resection of the tumor without causing neurological deterioration. In glioblastoma cases it is considered that an area of 2-3 cm around the tumor is infiltrated by tumor cells at the moment of

diagnosis¹⁴. In most cases an extensive resection cannot be performed without inflicting serious neurological deficits. However, even an extensive resection does not prevent tumor relapse. However, a complete resection is clearly correlated with a longer survival (1, 11). Tractography is one of the methods that can ensure achieving this goal. Although routine structural MR images can accurately demonstrate brain tumors, as well as important information on the relationship of the tumor with crucial brain structures (such as blood vessels) they fall short in providing precise information on the involvement and integrity of the white matter tracts in the immediate region surrounding tumors. The high-intensity signal often seen in the white matter adjacent to a tumor on T2-weighted or FLAIR images may represent either tumor extension or edema in the surrounding normal white matter tracts. However, more detailed information on the relationship between the expanding mass and white matter tracts is one of the important facts to be taken into account in planning the treatment of patients with eloquent areas brain tumors. Several functional approaches such as fMRI and intraoperative electrophysiological mapping are used in the presurgical localization of eloquent cortex neighboring brain tumors (7, 13). Functional MR imaging allows for the identification of important functional areas of the cerebral cortex that may be invaded by a neoplasm. This imaging modality focuses on cortical structures but does not provide information about subcortical gray matter and white matter, which in many instances may be involved in invasive, intrinsic brain tumors. Diffusion tensor imaging (DTI) can provide a wealth of

information on the white-matter tracts using diffusion anisotropy maps (16). Using directional information, the white matter tract organization is represented using directionally color-coded maps within the whole brain volume regardless of its structural integrity (15). In this study, we look at the role of DT imaging in characterizing the integrity of white matter tracts in patients with eloquent areas brain tumors and its implications in planning the appropriate treatment of these tumors.

Materials and method

Ten patients with intracranial eloquent areas neoplasms were selected for the study. Patients ranged in age from 28 to 66 years of age (mean age 54 years). Postoperatively histology showed glioblastoma in 8 cases, grade two astrocytoma in one case, and pilocytic astrocytoma in one case. The location of the lesions was the left temporal lobe in one patient, frontal lobe in two, insula in four, and parietal region in three. The dominant symptom at presentation was seizures (six patients), followed by paresis (hemi or monoparesis) in four patients, and motor aphasia in four patients. Increased intracranial pressure was manifest in three patients (Figure 1).

Magnetic resonance imaging studies were performed on a standard 1.5-tesla MR imaging scanner (Philips Achieva) with a standard quadrature birdcage head coil. DT MR imaging studies were performed as part of the presurgical tumor imaging protocol. As part of an approved institutional review board protocol, informed consent for the DT imaging portion of the study was obtained from each patient prior to scanning.

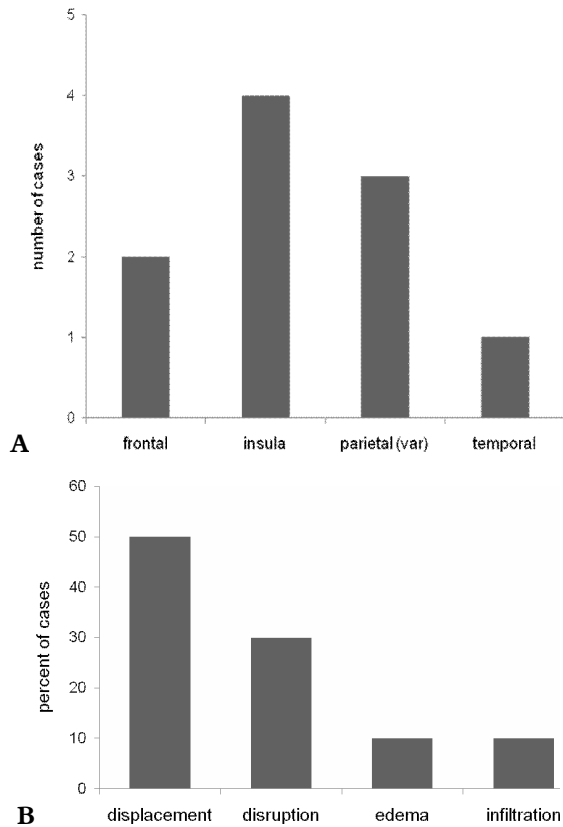


Figure 1 A. Tumor localization for cases that underwent tractography.

B. White matter tracts findings in DTI studies (percent of cases)

Color-coded DT imaging maps were analyzed. In every patient the tumors were isolated to one hemisphere, allowing for comparison between the affected tracts in the hemisphere in which the tumor was located and the contralateral control hemisphere. White matter tracts were then characterized as follows: displaced if they maintained normal anisotropy relative to the corresponding tract in the contralateral hemisphere but were situated in an abnormal location or with an abnormal orientation on color-coded orientation maps; edematous if they maintained normal anisotropy and orientation but demonstrated high signal intensity on T2-

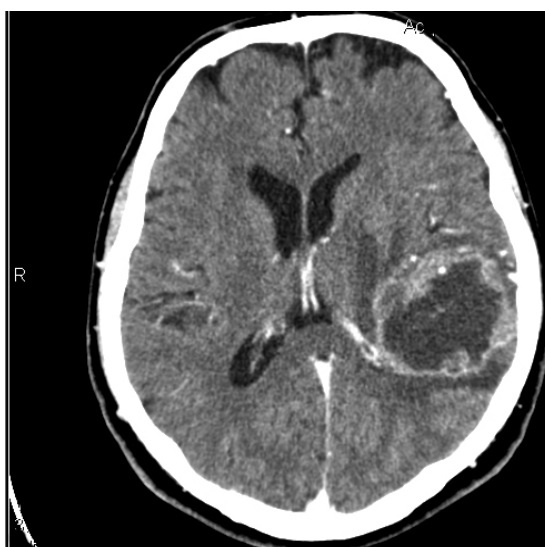
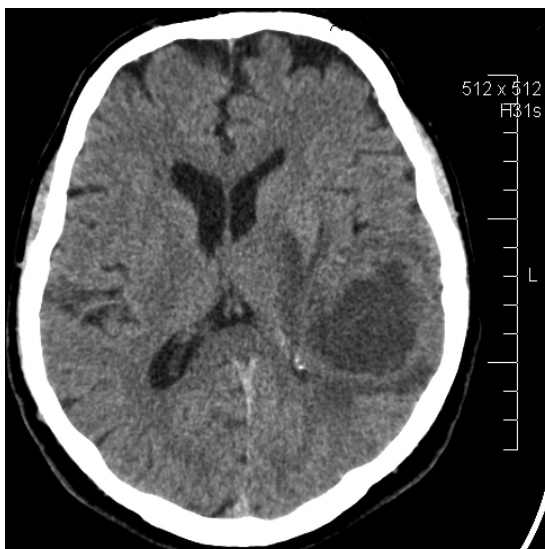
weighted MR images; infiltrated if they showed reduced anisotropy but remained identifiable on orientation maps; and disrupted if anisotropy was markedly reduced such that the tract could not be identified on orientation maps. For tracts categorized as infiltrated, we did not attempt to determine whether anisotropy was reduced as a result of vasogenic edema, infiltration by the tumor, or a combination of these two factors. Such a distinction may not be possible with DT imaging alone and is the subject of ongoing study by our group.

Results

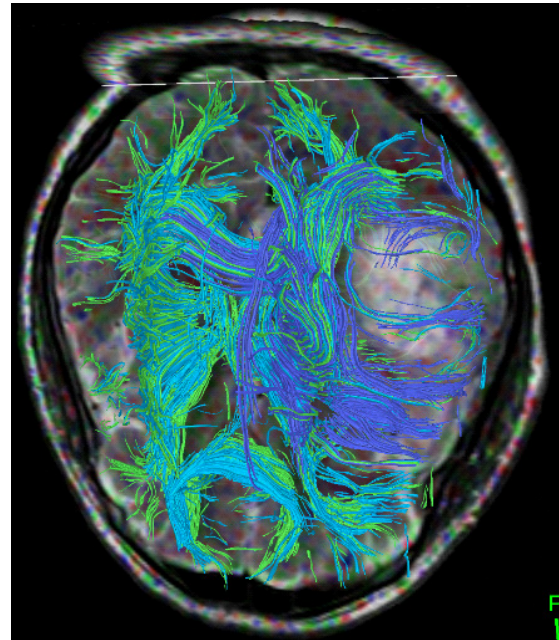
We were able to identify the extent of white matter tracts involvement in all patients using color-coded DT imaging maps and 3D reconstructions. Normal white matter tracts were depicted contralaterally in all patients. The white matter findings were characterized for each patient. White matter involvement by mass occupying lesion was classified according to the criteria of displacement, infiltration, disruption, or edema in relation to the contralateral side. Five large white matter pathways in five patients had deviated from their normal anatomical position when compared with fiber tracts in the contralateral hemisphere. The superior longitudinal fasciculus deviated in a medial or lateral direction in five of the five patients. The corticospinal tracts were deviated in three patients. The location of displacement varied depending on the location of the lesion (Figure 2). Deviation was seen in the corona radiata. Lateral deviation of the fibers streaming within the inferior longitudinal fasciculus of the temporal lobe was demonstrated in one

patient who developed a lesion towards the pole of the temporal lobe.

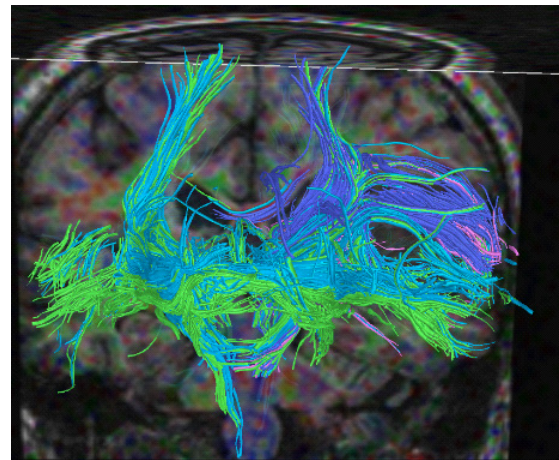
Evidence of white matter tract edema was seen in one patient (one glioblastoma case). In this patient, DT imaging reconstruction showed reduced anisotropy without displacement of white matter architecture, suggestive for tumor invasion (Figure 3). Diffusion-tensor imaging revealed evidence of white matter tract disruption in three patients.



A



B



C

Figure 2 Case of white matter tracts displacement.

A. Preoperative computer tomograph before (left) and after (right) contrast administration showing the parietal tumor (glioblastoma).

B and C. 3D reconstruction DTI showing displacement of the tracts surrounding the tumor

The anterior aspect of the inferior longitudinal fasciculus in the left temporal lobe was obliterated by a glioblastoma. In the second case, a large temporo-insular glioblastoma produced a trimming of the anterior-posterior-directed fibers as well as

projection fibers especially in the corticospinal tract and anterior thalamic radiation (Figure 4), particularly evident when compared to the intact fibers in the contralateral hemisphere. In one case diffuse edema was seen along the peripheral edges of the tumor. In the patient with a glioblastoma, edema along the periphery of the temporal lobe involved the optic radiations in the parietal and temporal regions. The edema pattern, with edema interesting the fiber pathways of the optic radiations, was demonstrated on T2-weighted images as well. DT imaging visualized the anterior/posterior fibers of the optic radiations in their normal anatomical position in relationship to unaffected fibers in the contralateral parietal and occipital lobes.

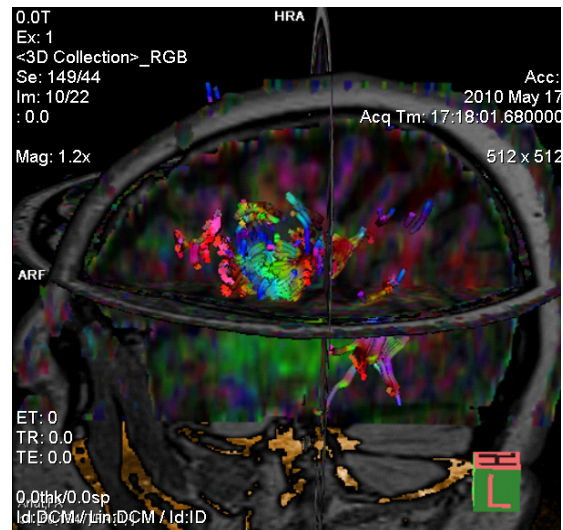
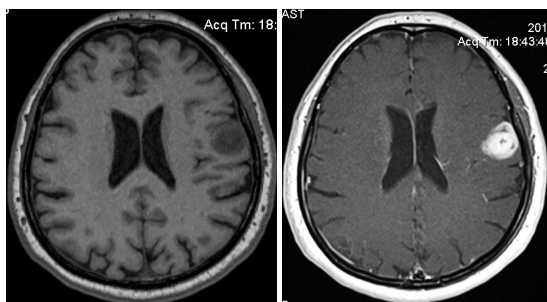
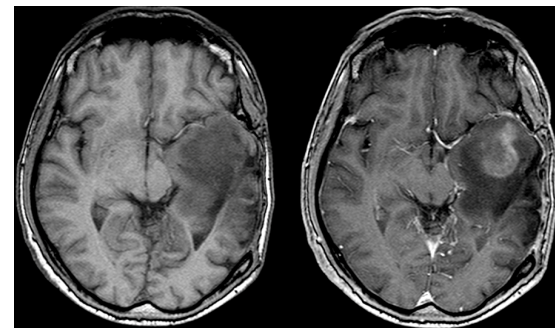


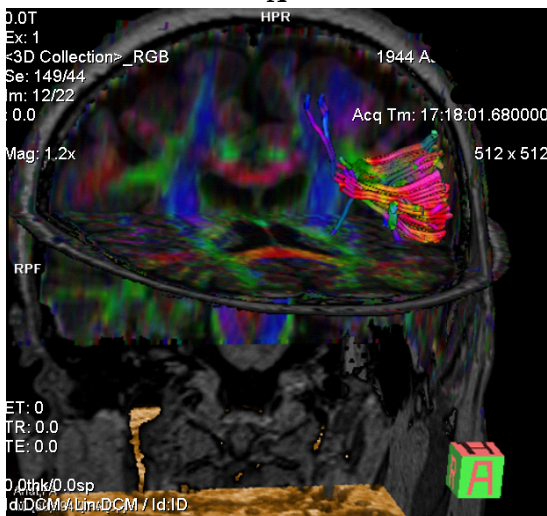
Figure 3 Case of white matter tracts invasion
A. T1-weighted(left) and enhanced T1-weighted (right) preoperative R image showing the parietal tumor (glioblastoma) **B.** 3D reconstructions DTI showing edema of the tracts neighboring the tumor.



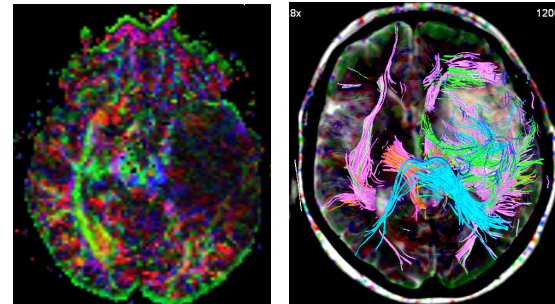
A



B



B



C

Figure 4 Case of white matter tracts disruption **A.** T1-weighted(left) and enhanced T1-weighted (right) preoperative R image showing the temporal tumor (glioblastoma) **B.** 2D DTI image showing the disruption of the tracts within the area of the tumor **C.** 3D DTI reconstruction showing the same disruption of the tracts in the cerebral volume occupied by the tumor.

Discussion

Cerebral tumors may involve both functional cortical gray and white matter tracts. In order to achieve a good neurological outcome, the resection of these lesions requires a detailed understanding of functional anatomical relationships to cortical areas and adjacent white matter connections. This is of paramount importance when the tumor develops within or near an eloquent cortical area in the dominant hemisphere in which motor, sensory, speech, and cognitive functions are situated. Understanding the location of the lesion in relation to the surrounding eloquent tissue represents a critical element in developing an operative plan. Many diagnostic modalities are currently used to define eloquent regions of the brain. Standard MR imaging, positron emission tomography, magnetoencephalography, and fMRI are some of the tools used to investigate the location of functional cortical areas (2, 8). A thorough preoperative delineation of the tumor and a precise mapping of functional areas helps in determining critical relationships of the lesion to the surrounding cortical function. The resulting images can then be used within frameless stereotactic algorithms, allowing for the planning of optimal surgical approaches and determining the degree and volume of tumor resection (10). The goal of using these various mapping techniques is to delineate functional areas so that they can be preserved during surgical resection. Maximal surgical tumor resection has been shown to correlate with longer patient survival and improved long-term functional status (11), representing the main predictor of patient outcome. Current data shows that tumors that grossly invade areas of

functional cortex may still retain functional fiber tracts within the pathological tissue. Diffusion-tensor imaging provides information for tract identification when the white matter tracts are displaced by tumor. Pathological states may affect the DT imaging measurements of intrinsic white matter pathways. Wiesmann and colleagues (16) reported the case of one patient with a tumor in the right frontal lobe who presented with left hemiparesis. Diffusion-tensor imaging documented deviation of fibers in normal-appearing white matter in relation to the anterior commissure – posterior commissure line when compared with measurements in normal patients. Diffusion-tensor imaging represents a valuable preoperative diagnostic tool for evaluating expansive lesions within or close to vital cortical and subcortical structures. Ten cases are analyzed in this study to demonstrate how DT mapping brings complementary information that helps elucidating the complex relationships between the tumor and its surrounding cerebral tissue. Evidence of intact fiber bundles traversing areas of tumor invasion was apparent in two patients. Other patients demonstrated displacement of white matter fibers from their normal anatomical position. In one patient with glioblastoma located centrally within the left hemisphere, the lesion displaced the corticospinal tracts within the corona radiata medially and anteriorly. Knowledge of this displacement assisted in preoperative planning by informing the surgeon of the tract's shifted location, thus allowing for adaptation of the surgical corridor to avoid destruction of the communicating white matter bundles. In this instance the tumor was approached from a temporal posterior direction,

allowing for aggressive resection of the tumor while avoiding the anteriorly deviated motor fibers. This resulted in postoperative improvement of the patient's hemiparesis, presumably due to the elimination of pressure on the corticospinal tracts.

Conclusions

The effect of cerebral neoplasms on white matter pathways is not precisely understood with the aid of standard diagnostic modalities. Diffusion-tensor imaging allowed for the identification of multiple viable white matter pathways within hemispheres involved by tumor. In this initial series of patients the information provided by DT imaging further defined precise relationships between cortical and subcortical white matter structures and cerebral neoplasms. Involvement of white matter tracts represents an important piece of information in planning the surgical approach and in evaluating the extent of a safe resection in patients with intrinsic brain tumors. Our experience with DT imaging indicates that anatomically intact fibers may be present in abnormal-appearing areas of the brain. Careful preoperative planning has to be complemented by intraoperative mapping and monitoring of eloquent cortical areas in order to insure a good neurological outcome of the surgery and valid functional prognostic. In planning these surgeries an equal importance should be attributed to the blood vessels that supply salient areas or tracts with significant functional value.

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