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Diffusion-tensor imaging of white matter tracts in patients with cerebral neoplasm

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Object. Preserving vital cerebral function while maximizing tumor resection is a principal goal in surgical neurooncology. Although functional magnetic resonance imaging has been useful in the localization of eloquent cerebral cortex, this method does not provide information about the white matter tracts that may be involved in invasive, intrinsic brain tumors. Recently, 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.

Methods. Nine patients with brain malignancies (one pilocytic astrocytoma, five oligodendrogliomas, one low-grade oligoastrocytoma, one Grade 4 astrocytoma, and one metastatic adenocarcinoma) 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 (two patients), infiltration (two patients), displacement (five patients), and disruption (two patients) could be assessed with the aid of DT imaging in each case.

Conclusions. 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.

Key Words • brain neoplasm • diffusion-tensor imaging • functional magnetic resonance imaging

Preservation of vital cerebral tissue while maximizing tumor resection is a principal goal in surgical neurooncology. Considering that most patients with tumors in eloquent areas such as the motor cortex are neurologically intact or only slightly impaired, it is essential to distinguish functional brain tissue from tumor tissue to avoid causing neurological deterioration during excision of these lesions.

Although routine structural MR images can accurately demonstrate brain tumors, they do not give precise information about 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 T_2-weighted or FLAIR images may represent either tumor extension or edema in the surrounding normal white matter tracts. More detailed characterization of white matter tract integrity surrounding tumors may be helpful in the surgical planning and treatment of patients with intrinsic brain tumors.

Several functional approaches such as fMR imaging and intraoperative mapping are used in the presurgical localization of eloquent cortex near brain tumors.[11,20,24] 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.

Recently, DT imaging has been used to map white matter tracts in the brain.[13,22,23] Diffusion-tensor imaging measures the diffusion displacement properties of water in a three-dimensional space as a function of image location.[7,8,23] Water diffusion parallel to the white matter tracts is less restricted than water diffusion perpendicular to them. Consequently, the measured image signals are higher for diffusion-gradient encoding perpendicular to the white matter tracts rather than parallel.[2,16] This directional variation in the signal is termed "diffusion anisotropy." By acquiring DW images with at least six noncollinear gradient-encoding directions, it is possible to estimate the DT. The principal eigenvector represents the direction of greatest diffusion, which also corresponds to the fiber tract axis. With this di-

Abbreviations used in this paper: DT = diffusion-tensor; DW = diffusion-weighted; FLAIR = fluid-attenuated inversion-recovery; fMR = functional magnetic resonance.

TABLE 1

*Clinical information and outcome in nine patients who underwent DT imaging prior to resection of their tumors**

Case No.	Age (yrs), Sex	Location of Tumor	Pathological Finding†	Clinical Presentation	Preop Deficit	Postop Deficit	White Matter Involvement
1	48, F	lt insular	Grade 2 oligo	headache	none	none	medial displacement of AF & CS tract
2	24, M	lt frontal	Grade 3 oligo	seizures	none	trans aphasia	infiltration of lt frontal lobe AF
3	26, M	lt frontal/insular	Grade 2 oligo	seizures	none	trans aphasia	medial displacement of AF & CS tract
4	61, M	lt frontal	malignant oligoastrocytoma	headache	none	none	lat displacement of AF & CS tract
5	20, F	lt frontal/insular	pilocytic astrocytoma	rt hemi	rt hemi	improved hemi, trans aphasia	partial disruption of CC, lat displacement of AF, medial displacement of CS tract
6	43, F	lt temporal	Grade 2 oligo	headache	none	none	lat displacement of ILF, medial displacement of brainstem
7	51, F	lt frontal/parietal	Grade 4 astrocytoma	aphasia	aphasia	improved aphasia	disruption of ILF, edema involvement
8	66, M	lt frontal	metastatic adenocarcinoma	seizures	dysarthria	improved dysarthria	edema involvement of optic radiations
9	44, M	rt frontal	Grade 2 oligo	headache, confusion	none	none	infiltration of rt frontal lobe AF

* AF = arcuate fasciculus; CC = corpus callosum; CS = corticospinal; hemi = hemiparesis; ILF = inferior lateral funiculus; oligo = oligodendroglioma; trans = transient.

† Gliomas were graded according to the scale in Daumas-Duport, et al.

rectional information, the white matter tract organization may be represented using directionally color-coded schematic maps of major eigenvector orientation.[22] In this study, we evaluated the role of DT imaging in characterizing the integrity of white matter tracts in patients with brain tumors.

Clinical Material and Methods

Patient Population

Nine patients with intracranial neoplasms were selected for the study (Table 1). Patients ranged in age from 20 to 66 years of age (mean age 43 years). Lesions included oligodendroglioma in five patients (one anaplastic) and a pilocytic astrocytoma, a mixed anaplastic oligoastrocytoma, a glioblastoma multiforme, and a metastatic adenocarcinoma in one patient each. The location of the lesions was the temporal lobe in one patient, frontal lobe in four, insula in one, and frontal lobe/insular region in three. Three patients presented with seizures, four with headaches, one with aphasia, and one with right-sided weakness.

Imaging Studies

Magnetic resonance imaging studies were performed on a standard 1.5-tesla MR imaging scanner (GE Signa; GE Medical Systems, Waukesha, WI), a standard quadrature birdcage head coil, and 40 mT/m imaging gradients (with a maximum 150 mT/m/msec slow rate). Both fMR and 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.

Diffusion-Tensor MR Imaging Acquisition

A single-shot spin-echo echoplanar imaging pulse sequence with diffusion weighting was used to obtain DT-encoded images. The images were obtained using 23 DT encoding directions that were generated with a minimum energy optimization algorithm.[15] This encoding set uniformly distributed the directions over a unit sphere to minimize directional biases. A diffusion weighting of 1000 sec/mm^2 was used, and a single reference image without diffusion weighting was also obtained. The echoplanar imaging readout was obtained with a ramp sampling (effective echo spacing 648 μsec) corresponding to a 128×128 Fourier space matrix. Homodyne reconstruction with zero-filled interpolation was used to obtain 256×256 matrix images. Other imaging parameters were as follows: TR 4500 msec, effective TE 71.8 msec, number of excitations 4 (image-magnitude averaging), field of view 240 mm, 3-mm-thick slices. Acquisition was performed twice for 20 slices to obtain full brain coverage. The top slab extended from the most superior aspect of the brain to the midbrain; the bottom slab extended from the most inferior slice of the top slab to the brainstem. Acquisition of each slab required 7 minutes 30 seconds (15 minutes total scan time).

Diffusion-Tensor Image Reconstruction

Image misregistration from motion and eddy current distortion were corrected using two-dimensional algorithms in automated image registration.[28] The two DT slabs were combined into a single three-dimensional volume. One common overlapping slice between the two slabs was used to ensure good coregistration between the two slab volumes. A 3×3 median filter was applied to each DW image to improve the image signal-to-noise ratio. The combined single-volume slab was interpolated to isotropic voxel dimensions ($0.94 \times 0.94 \times 0.94$ mm^3).

Tensor decoding[15] was then performed on the 23 diffusion-encoded images (postregistration, filtering, and interpolation) to estimate the DT for each location in the image volume. The DT information was then represented by maps of DT, apparent diffusion coefficient (trace/3), fractional anisotropy,[4,23] and anisotropic orientation. The latter

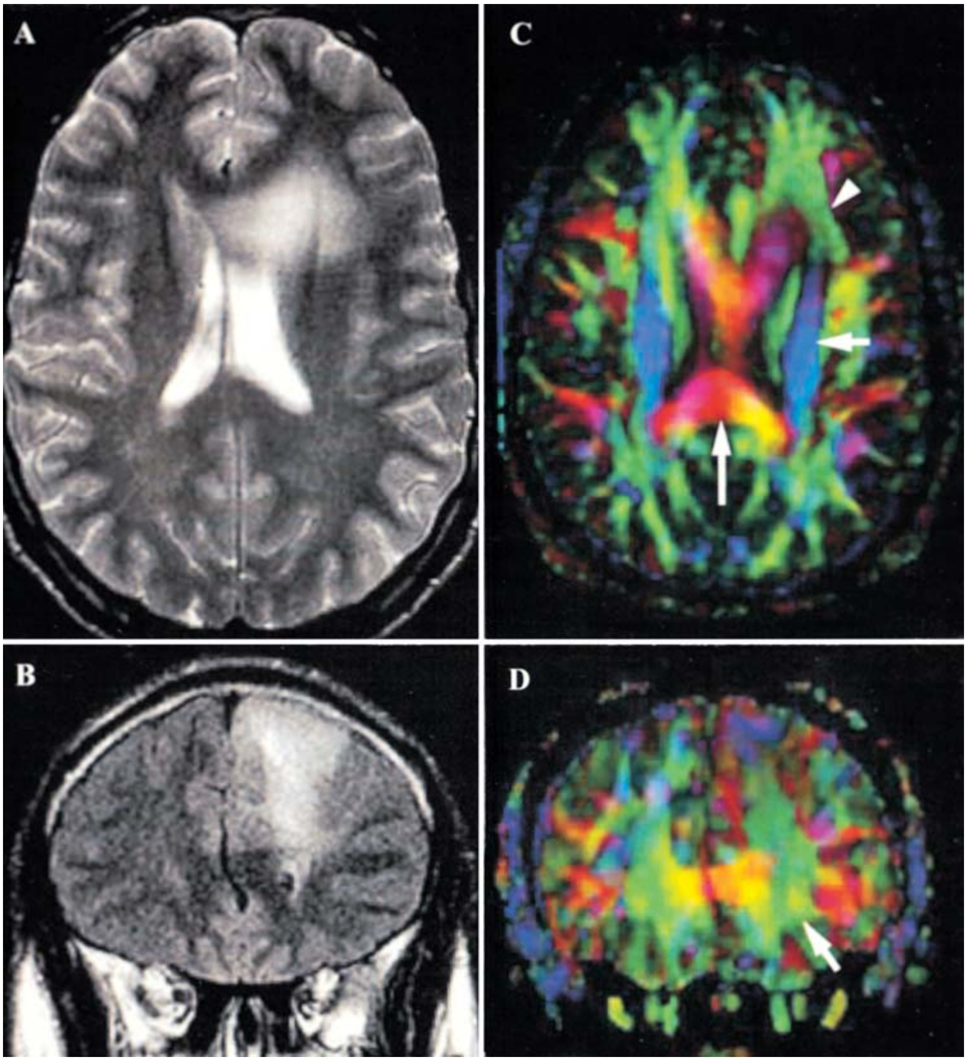

FIG. 1. Case 2. Tumor invasion of white matter tracts in a patient with an oligodendroglioma located in the left frontal lobe. A: An axial T_2-weighted MR image obtained during the preoperative planning period. Diffuse signal changes appear throughout the white matter pathways of the left frontal lobe. B: A coronal contrast-enhanced T_2-weighted FLAIR MR image demonstrating the same signal changes in the left frontal lobe, involving white and gray cortical matter. C and D: The directions of white matter pathways are color coded in these DT images: green, anterior/posterior; blue, inferior/superior; and red, right/left. C: An axial DT image corresponding to the same level as the image in A. The fiber pathways of the corona radiata in blue *(short arrow)*, arcuate fasciculus in green *(arrowhead)*, and corpus callosum in red *(long arrow)* appear in the same anatomical relationship, compared with their corresponding pathway in the contralateral hemisphere. D: A coronal DT image at the level of the genu of the corpus callosum corresponding to the image in B. Note the intact position of the associated white matter tract *(arrow)* in the left frontal lobe in a region invaded with neoplastic cells.

map was generated by mapping the major eigenvector x, y, and z components into red, green, and blue color channels, which were weighted by fractional anisotropy.[22,23] In the color map, white matter tracts in red have a right/left orientation, green tracts are oriented in an anterior/posterior direction, and blue tracts in a caudal/rostral direction. The image processing was performed using a customized DT imaging analysis software toolbox developed in interactive data language (Research Systems, Inc., Boulder, CO).

Tract Evaluation With the Aid of DT Imaging

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 T_2-weighted MR images; infiltrated if they showed reduced anisotropy but remained identifiable on orientation maps; and disrupted if anisotropy was marked-

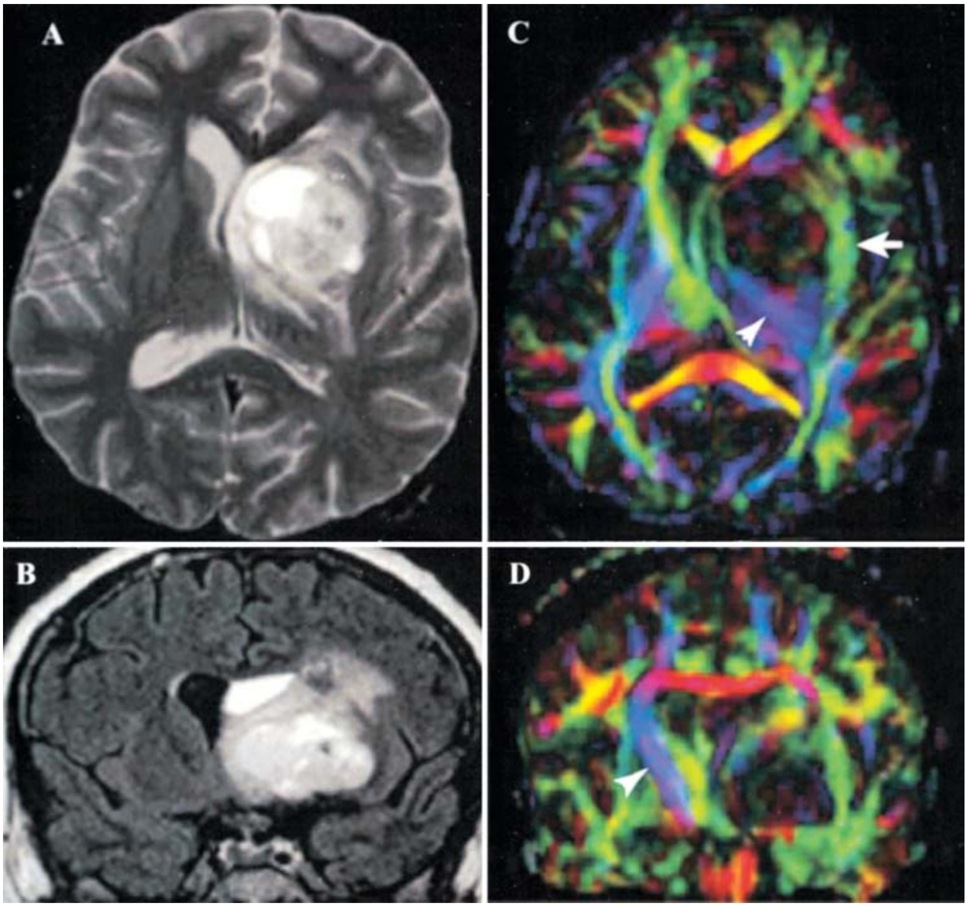

FIG. 2. Case 5. Deviation of white matter tracts in a patient with a pilocytic astrocytoma. A: An axial T_2-weighted MR image. A large, well-circumscribed, cystic, heterogeneously enhancing lesion appears within the white matter of the left frontal lobe corresponding to the location of the lesion. B: Coronal contrast-enhanced FLAIR image at the level of the interventricular foramen demonstrating a large frontal lobe lesion eliminating the left lateral ventricle. C and D: An axial (C) and a coronal (D) DT image demonstrating signal dropout within the region of the left frontal lobe. The green fibers of the arcuate fasciculus *(arrow)* are deviated to the left, over the lateral edge of the tumor. The blue inferiorly directed corticospinal fibers within the corona radiata, (C, *arrowhead*) are deviated posteriorly and medially from their normal anatomical location. The coronal image (D) displays the intact fibers of the corona radiata *(arrowhead)* in their correct anatomical position in the unaffected right cerebral hemisphere. The corresponding fibers in the hemisphere invaded by tumor are absent at this level because of their displacement over the posterior margin of the tumor.

ly 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

Extent of White Matter Involvement

White matter pathway involvement was clearly identified in all patients by using color-coded DT imaging maps. Normal white matter pathways demonstrated on DT imaging appear in the unaffected contralateral left hemisphere in three patients (Figs. 1–3). The figures show DT images in both axial and coronal planes. The white matter tracts were color coded in a universal fashion based on their spatial orientation. Fiber tracts of the corona radiata and corticospinal tracts were represented by a blue color scheme in both axial and coronal images. The corpus callosum was demonstrated by the color red in both images. The green fibers of the arcuate fasciculus were evident in both imaging sequences, extending from the occipital to frontal lobes just lateral to the rostral/caudal fibers of the corona radiata.

The white matter findings were characterized for each patient. White matter involvement by the hemispheric lesion was classified according to the criteria of displacement, infiltration, disruption, or edema in relation to the contralateral side. The involved anatomically assigned pathways in each patient are summarized in Tables 1 and 2.

Nine large white matter pathways in five patients had deviated from their normal anatomical position when compared with fiber tracts in the contralateral hemisphere (Table 2). The arcuate fasciculus deviated in a medial or lateral direction in four of the five patients. The corticospinal tracts were deviated in four patients. The location of displacement

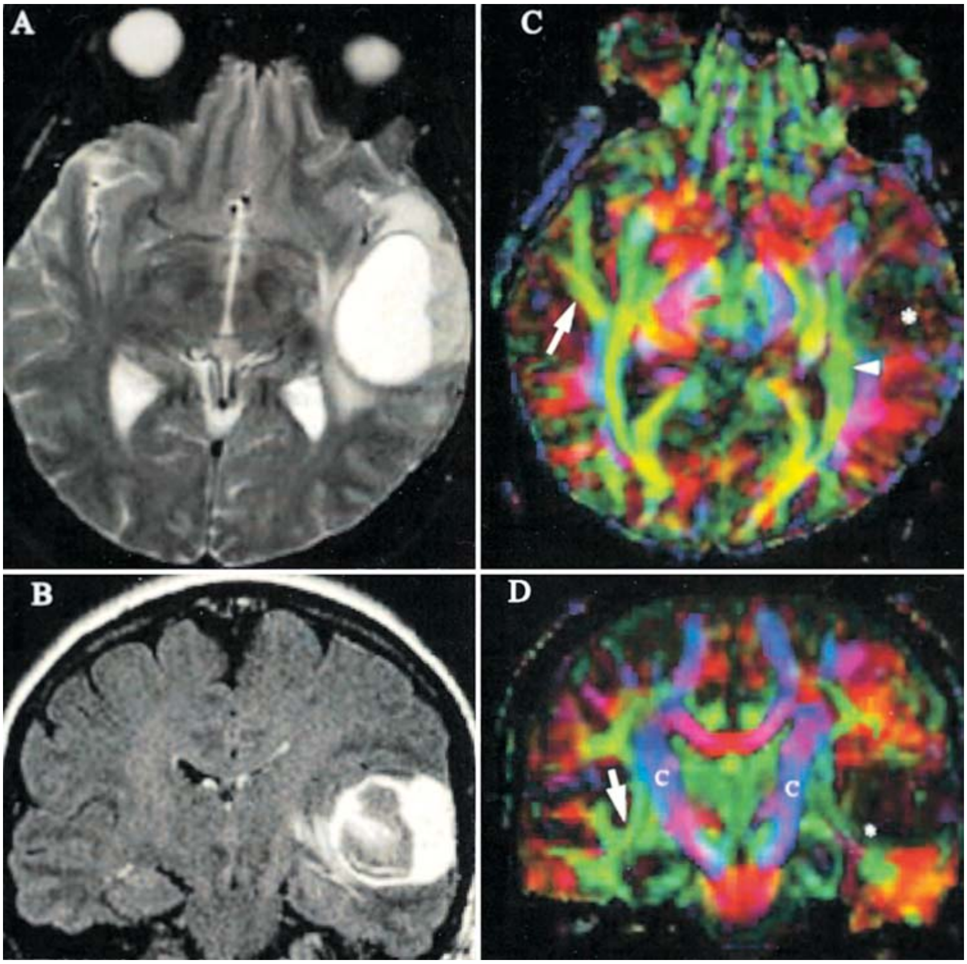

FIG. 3. Case 7. Destruction of white matter tracts in a patient with a Grade 4 astrocytoma. A: An axial T_2-weighted MR image demonstrating a lesion in the left temporal lobe, with an area of surrounding increased signal intensity extending back into the left periatrial white matter. B: A coronal contrast-enhanced FLAIR image exhibiting a large tumor within the left temporal lobe. C: An axial DT image demonstrating the intact green fibers of the inferior lateral funiculus *(arrow)* within the unaffected temporal lobe of the right hemisphere. Corresponding fibers in the contralateral temporal lobe *(asterisk)* are completely obliterated. Within the region of T_2 signal change in the left periatrial white matter, the green (anterior/posterior) fibers of the optic radiation *(arrowhead)* appear in their correct anatomical position. D: A coronal DT image demonstrating that the fibers of the corona radiata (c) are in their orientation in both hemispheres. The green association fibers of the inferior lateral funiculus are evident within the white matter of the right temporal lobe *(arrow)*. The corresponding white matter tracts are no longer present in their normal anatomical location within the left temporal lobe involved by tumor *(asterisk)*.

varied depending on the location of the lesion. Deviation was seen in the mesencephalic peduncle and within the corona radiata. Lateral deviation of the fibers streaming within the inferior funiculus of the temporal lobe was demonstrated in one patient who harbored a cystic lesion in the anterior aspect of the temporal lobe.

Evidence of white matter tract infiltration was seen in two patients who had diffuse frontal lobe oligodendrogliomas. In both patients, DT imaging demonstrated reduced anisotropy without displacement of white matter architecture, thus suggesting tumor invasion. To confirm this observation, we took multiple pathological specimens from the resection margin, which demonstrated neoplastic cells infiltrating white matter tracts in both patients.

Diffusion-tensor imaging revealed evidence of white matter tract disruption in two patients (Table 2). The anterior aspect of the inferior lateral funiculus in the left temporal lobe was obliterated by a Grade 4 astrocytoma. The green anterior-posterior-directed fibers of the inferior lateral funiculus were no longer spatially represented in the temporal lobe in comparison to the intact fibers in the contralateral hemisphere. Diffusion-tensor imaging cortical maps obtained in the second patient demonstrated disruption of left/right (red) fibers in the lateral aspect of the corpus callosum by a large centrally located pilocytic astrocytoma.

In two patients diffuse edema was seen along the peripheral edges of the tumor (Table 2). In the patient with a Grade 4 astrocytoma, edema along the periphery of the temporal lobe involved the optic radiations in the parietal and temporal regions. A similar edema pattern, with edema investing the fiber pathways of the optic radiations, was demonstrated on T_2-weighted images of a metastatic adenocarcinoma located in frontal lobe. In both patients DT imaging visualized the anterior/posterior (green) fibers of the optic radiations in their normal anatomical position in relationship to unaffected fibers in the contralateral parietal and occipital lobes.

TABLE 2

White matter pathway involvement in nine patients harboring brain tumors

Characterization of White Matter Tract Involvement	No. of Patients
displaced	
arcuate fasciculus	4
corticospinal tract	4
inferior lat funiculus	1
infiltrated	
arcuate fasciculus	2
disrupted	
inferior lat funiculus	1
corpus callosum	1
edematous	
optic radiation	2

Illustrative Cases

Case 2: Tumor Invasion of White Matter Tracts

This 24-year-old right-handed man initially presented after experiencing a generalized seizure. There was no evidence of neurological deficits on examination. Magnetic resonance imaging demonstrated a nonenhancing large infiltrative tumor in the left superior frontal gyrus and corpus callosum (Fig. 1A and B). Magnetic resonance spectroscopy revealed a twofold elevation in the choline peak and a mild reduction in the *N*-acetyl-aspartate peak consistent with a neoplastic process.

An fMR image obtained in the patient displayed an intact left hemisphere–dominant language function despite its location adjacent to the tumor in the left superior and middle frontal gyrus. The language tasks performed indicated dominant activation in the left middle frontal gyrus and left angular gyrus. Sensory motor responses were intact along the central sulcus bilaterally. Supplementary motor activation was seen in the superior frontal gyrus and colocalized to the posterior third of the tumor. Diffusion-tensor imaging maps of the white matter in the frontal lobe demonstrated infiltration of the tumor throughout the intact white matter fibers of the arcuate fasciculus and commissural fibers (Fig. 1C and D). There was no evidence of significant destruction or displacement of white matter pathways.

The patient underwent a frontoparietal craniotomy that was performed using Stealth guidance (Sofamor Danek, Memphis, TN). The margin of the tumor (anaplastic oligodendroglioma) was poorly demarcated using ultrasonography. A limited resection was performed, avoiding functional tissue close to mapped language and motor regions of the cortex. Limited dissection of white matter tracts in the frontal lobe was performed in an attempt to preserve the functional fiber bundles represented in the preoperative DT imaging sequences.

Case 5: Displacement of White Matter Tracts

This 20-year-old right-handed woman presented at our institution with a 2-month history of headaches, nausea, and vomiting. Neurological examination demonstrated a moderate right hemiparesis. A prior evaluation at another institution, where she had presented with hydrocephalus, included an MR imaging study that demonstrated a large, mixed, solid, cystic neoplasm with heterogeneous contrast enhancement in the left frontal lobe extending superiorly to involve the caudate nucleus and laterally to involve the insular cortex (Fig. 2A and B). Inferiorly, the tumor involved the basal ganglia and hypothalamus. Before transferring to our hospital the patient had undergone a stereotactic biopsy and placement of a ventriculoperitoneal shunt. The pathological diagnosis had been a low-grade glial neoplasm, most consistent with a pilocytic astrocytoma.

At our institution an fMR image was obtained during the preoperative period to map functional areas in the left frontal lobe. The patient demonstrated left hemisphere language dominance. Broca's area was identified approximately 1 cm superior and lateral to the tumor. White matter tracts were mapped using DT imaging color-coded schemes (Fig. 2C and D). The images displayed the large left frontal mass lesion, with deviation of surrounding white matter fibers. The corticospinal tracts within the corona radiata were deviated posteriorly and medially. The arcuate fasciculus fibers were displaced laterally, draping over the lateral edge to the neoplasm.

The patient was taken to the operating room where she underwent a left frontotemporal craniotomy for resection of the lesion with the aid of Stealth guidance and intraoperative speech and motor mapping. The tumor was approached via the orbital gyri of the frontal lobe to avoid eloquent functional language tissue laterally. During resection of the tumor, care was taken to preserve the laterally displaced fibers of the arcuate fasciculus and posteriorly deviated tracts of the corona radiata. Postoperatively, the patient's hemiparesis improved and eventually resolved on follow up.

Case 7: Disruption or Edema of White Matter Tracts

This 51-year-old right-handed woman presented to our institution after experiencing sudden onset of symptoms consistent with an expressive aphasia. Her examination demonstrated no evidence of neurological deficits. Magnetic resonance imaging showed a 4-cm heterogeneously enhancing lesion in the left temporal lobe with mass effect and surrounding edema (Fig. 3A and B).

The preoperative workup included fMR imaging, MR spectroscopy, and DT imaging mapping. Functional MR imaging demonstrated that the patient was left hemisphere–dominant for language. Magnetic resonance spectroscopy was indicative of a neoplastic process with high cell turnover evident by elevated choline peaks in relationship to *N*-acetyl-aspartate peaks.

Cortical maps produced using DT imaging revealed evidence of involvement of multiple white matter pathways (Fig. 3C and D). The anterior limb of the inferior lateral funiculus was obliterated by the lesion in the temporal lobe. Surrounding edema, shown in the T_2-weighted image, spread out into surrounding fiber pathways involving the optic radiations traveling through the temporal and parietal lobes.

A left temporal lobe craniotomy was performed using the Stealth stereotactic system. Intraoperatively, the posterior aspect of the superior temporal gyrus was significantly widened. A gross, total resection of the enhancing portion of the tumor was performed without entry into the optic radiations. Pathological findings were consistent with a Grade 4 astrocytoma.

Discussion

Intracranial neoplasms may involve both functional cortical gray and white matter tracts. Resection of these lesions requires a detailed understanding of functional anatomical relationships to surrounding tissue and adjacent white matter connections. This is most critical in dealing with eloquent cortical regions in the dominant hemisphere in which motor, sensory, speech, and cognitive functions are situated. An understanding of the location of the lesion in relation to surrounding eloquent tissue assists the surgeon in developing an intraoperative plan.

Many diagnostic modalities are currently used to define eloquent regions of the brain. Standard MR imaging, positron emission tomography, magnetoencephalography, and fMR imaging are some of the tools used to investigate the location of functional cortex areas.[2,6,14,18,19] These preoperative studies aid in identifying regions of the brain involved in the cortical activities of sensation, motor, and speech. Preoperative targeting of these areas helps in determining critical relationships of lesion location and surrounding cortical function. The images can then be fused with frameless stereotactic devices, allowing for the planning of optimal surgical approaches and determining the degree and volume of tumor resection.[19] Preoperative diagnostic studies still must be confirmed by intraoperative cortical mapping of functional areas in many cases. Intraoperative cortical mapping has been shown to maximize the extent of tumor resection and to minimize the associated morbidity of aggressive resections.[5]

The goal of using these various mapping techniques is to delineate functional areas so that they can be preserved during surgical resection. Aggressive surgical resection of brain tumors has been shown to correlate with longer patient survival and improved long-term functional status.[1,9] Some neurosurgeons advocate the removal of cortical tissue appearing grossly abnormal during the operative procedure, that is, based on the premise that areas of functional tissue are either displaced or destroyed by infiltrative tumors.[17]

Researchers of other studies found that tumors that grossly invade areas of functional cortex may still retain functional fiber tracts within the pathological tissue. Using intraoperative cortical stimulation, Ojemann, et al.,[21] limited the extent of resection by demonstrating gross invasion of tumor into cortical and subcortical structures. Skirboll and colleagues,[25] also using intraoperative cortical mapping, found 28 patients with evidence of motor, sensory, and language tissue within the confines of the lesion, regardless of infiltration, swelling, or gross distortion of the tumor. Attempted resection of functional tissue with gross neoplastic invasion resulted in postoperative neurological deficits.[25]

At our institution both preoperative fMR imaging and intraoperative cortical mapping are used if there is concern about compromising eloquent tissue. These diagnostic studies reveal functional regions of cortical gray matter. The location of large functional white matter bundles that course in proximity to or through regions of abnormal signal on imaging studies, however, is not clearly identified using current diagnostic modalities or routine intraoperative mapping. It is unclear if these fibers are displaced or obliterated by supratentorial neoplasms.

Diffusion-tensor imaging provides information on the directionality of water molecules at the cellular level, thus indicating the orientation of fiber tracts. From DW image data sets, the diffusivity of water within tissue can be determined. In tissue with an ordered microstructure, like cerebral white matter, orientation can be quantified by measuring its anisotropic diffusion. Diffusion-tensor calculations permit the characterization of diffusion in heterogeneously oriented tissue.[23] The spatial orientation of myelinated fiber tracts can then be represented as distinct white matter maps in easily read, color-coded directional maps.[22] Recently, various investigators have used directional diffusion information to create maps of white matter connectivity.[3,10,26] These techniques may be valuable 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. Wieshmann and colleagues[27] reported on one patient with a tumor in the right frontal lobe who had presented with a hemiparesis. Diffusion-tensor imaging showed 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 is a useful new preoperative diagnostic tool for evaluating lesions close to vital cortical and subcortical structures. Nine patients are presented in this paper to demonstrate how DT mapping further elucidates the complex relationships between a lesion and its surrounding tissue. Evidence of intact fiber bundles traversing areas of tumor invasion was apparent in two patients. In one patient who developed transient postoperative aphasia for a few days, the tumor resection was targeted in a limited area of the dominant frontal lobe, sparing tissue with evident white matter bundles. Limiting the extent of resection in this patient may have avoided a permanent neurological deficit.

Other patients demonstrated displacement of white matter fibers from their normal anatomical position. In one patient with a pilocytic astrocytoma located centrally within the left hemisphere, the lesion displaced the corticospinal tracts within the corona radiata medially and posteriorly. 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 frontal direction, allowing for aggressive resection at the frontal pole of the neoplasm while avoiding the posteriorly deviated motor fibers. This resulted in postoperative improvement of the patient's hemiparesis, presumably due to the elimination of pressure on the corticospinal tracts.

In one patient with a Grade 4 astrocytoma, the neoplasm invested the bulk of the anterior temporal lobe. Diffusion-tensor imaging maps indicated that most of the white matter pathways were obliterated by the tumor. The inferior lateral funiculus was not visible throughout most of its anterior course. The more medial optic radiations, however, demonstrated normal anisotropy, thus suggesting intact fibers. Although gross-total resection of the enhancing portion of the tumor was performed, resection of the surrounding fibers, which appeared abnormal on T_2-weighted images, was not attempted to preserve the intact white matter tracts. Postoperatively, the patient had no neurological deficit.

Conclusions

The effect of cerebral neoplasms on white matter pathways is not precisely understood with the aid of current diagnostic modalities. Diffusion-tensor imaging allowed for the identification of multiple viable white matter pathways within hemispheres involved by tumor. In this small cohort of patients the information provided by DT imaging further defined precise relationships between subcortical white matter structures and cerebral neoplasms. Involvement of white matter tracts may be important in surgical planning and in predicting the extent of 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. Whether resection of these involved fibers results in subtle postoperative neurological deficits requires further systematic study.

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