Role of diffusion tensor imaging in resection of thalamic juvenile pilocytic astrocytoma

Clinical article

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Object. The choice of surgical approach during resection of a thalamic juvenile pilocytic astrocytoma (JPA) is dictated by the location of the displaced normal thalamus and posterior limb of the internal capsule (PLIC). Diffusion tensor (DT) imaging and white matter tractography can identify the location of the PLIC in relation to the tumor and may be useful in planning the operative trajectory.

Methods. Diffusion tensor imaging was used to localize the PLIC on preoperative MR imaging in 6 children undergoing resection of thalamic JPAs. After review of the standard T2-weighted MR imaging sequences, the anticipated position of the PLIC was determined. This result was compared with the location of the PLIC determined by a blinded radiologist with the use of DT imaging. The utility of DT imaging in determining the surgical approach to a thalamic JPA, degree of resection, and neurological outcomes were all evaluated.

Results. Diffusion tensor imaging confirmed the expected location of the PLIC as approximated on conventional T2-weighted images in all 6 cases. In 1 patient in particular, unexpected medial deviation of the PLIC was identified, and this proved useful in tailoring the approach to a more lateral trajectory. Gross-total resection of all cystic and solid tumor components was confirmed on postoperative imaging in all cases. All patients experienced mild to moderate worsening of neurological status immediately following resection, but 4 of 6 patients were back to their preoperative baseline at 6-month follow-up.

Conclusions. Diffusion tensor imaging and white matter tractography successfully identified the white matter fibers emanating from the precentral gyrus within the PLIC in children with thalamic JPAs prior to surgery. Diffusion tensor imaging served as a valuable tool for stereotactic planning of operative approaches to thalamic JPAs. Localizing the position of the PLIC helped minimize potential neurological morbidity and facilitated gross-total resection.

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Key Words • brain neoplasm • diffusion tensor imaging • diencephalon • thalamus • microsurgery • juvenile pilocytic astrocytoma

Juvenile pilocytic astrocytoma is a benign tumor (WHO Grade I) most frequently observed in children and young adults, which has a predilection for deep midline structures including the thalamus, pineal, basal ganglia, hypothalamus, and optic pathways.4,6,9,13,21 Although the benefits of GTR for survival in patients with JPA have been described, concerns exist regarding postoperative neurological outcomes following surgery in the thalamus.2,8,13,18,35 The use of volumetric stereotactic resection techniques for resection of thalamic JPAs has decreased the incidence of postoperative deficits and has enabled complete resection and favorable long-term survival.24,25,27,28,32,34,35

Diffusion tensor imaging and white matter tractography are relatively new additions to MR imaging, which exploit the preferential movement of water protons within the brain along the axis of axons.30 The sensitivity of DT imaging to anisotropic movement of protons allows visualization of the larger white matter tracts on directionally encoded color maps and can provide quantitative measurements of the integrity of these tracts in disease states.10,11,20 Diffusion tensor imaging is a potentially valuable tool for operative planning, and the results of DT imaging have been shown to correlate with clinical out-
comes following supratentorial tumor surgery. In the setting of thalamic tumors, such information can potentially impact the operative plan to maximize tumor resection and minimize postoperative motor deficits from disruption of the corticospinal tracts in the PLIC.

Depending on the anatomical origin and extension of a thalamic tumor, there are a variety of transcortical approaches and approaches directed along the interhemispheric and transverse cerebral fissures that avoid disruption of the PLIC and minimize damage to the displaced normal thalamus. Anterior thalamic tumors generally displace normal thalamus posteriorly and the PLIC lateral to the tumor. Posteroventral thalamic tumors generally displace normal thalamus anteriorly and superiorly and the PLIC anteriorly. Posterocentral tumors usually displace normal thalamus anteriorly and superiorly and the PLIC anteriorly. The surgical approaches include transfrontal directed along the anterior limb of the internal capsule for anterior thalamic tumors, transparietal through the atrium of the lateral ventricle for posterodorsal thalamic tumors, transcoccipitotemporal along the sublenticular limb of the internal capsule for posterocentral thalamic tumors, interhemispheric transcallosal for medially located dorsally exophytic tumors, and occipitotransental for posteroventral tumors.

In all of these approaches, careful identification of the normal thalamus, internal capsule, and tumor extension into adjacent structures is paramount for planning the optimal stereotactic approach. This is particularly challenging in very large tumors that distort the normal anatomy. In this report we summarize our recent experience with DT imaging in children with thalamic JPAs who underwent stereotactic resection with particular emphasis on the tumor location, relationship to the internal capsule, and direction of approach.

**Methods**

**Clinical Material**

Between February of 2006 and November of 2008, eight children with thalamic JPAs underwent stereotactic tumor resection performed by the senior author (J.H.W.) at the New York University Medical Center. In 6 of these cases DT imaging was performed during the preoperative imaging database acquisition. Patients with JPAs originating in the basal ganglia, hypothalamus, pineal region, and rostral brainstem but extending into the thalamus were excluded from this series. All patients were 18 years of age or younger at the time of surgery and data collection and participation in the study was approved by the university institutional review board. Data were retrospectively collected, and office and inpatient records, pre- and postoperative and most recent follow-up MR imaging studies, and operative and pathology reports were reviewed. Patient characteristics, prior treatments, imaging features, extent of resection, other oncological treatments, and postoperative morbidity were recorded. The results of detailed preoperative and serial postoperative neurological examinations performed by the senior author, pediatric neurologists, and neuro-oncologists were obtained from office and inpatient charts.

The goal of each operation was the resection of the entire contrast-enhancing solid and cystic tumor mass identified on preoperative MR images. A neuroradiologist independently reviewed and compared the pre- and postoperative MR images to determine the extent of resection. Resection was classified as gross-total (GTR) when postoperative imaging studies documented complete removal of the entire imaging-defined tumor volume. The resection was considered to be subtotal (STR) in cases showing any residual enhancement or tumor mass on postoperative imaging. The neuroradiologist also performed the DT imaging and tractography analysis and was completely blinded to the pre- and postoperative neurological and clinical status of the patients.

Neurological examinations performed by the pediatric neurologist/neuro-oncologist preoperatively, on the first postoperative day, 1 week after surgery, 3 months after surgery and at most recent follow-up were reviewed. Postoperative neurological deficits were graded as mild (minimal deficit that is noticeable), moderate (deficit that interferes with function, but could be overcome), or severe (deficit that significantly disables function). Other complications, such as hemorrhage, infection, or need for shunt placement, were recorded.

**Magnetic Resonance Imaging, DT Imaging, and White Matter Tractography**

Preoperative imaging was performed on a 1.5-T system (Avanto, Siemens) by acquiring conventional MR images for diagnostic and anatomical purposes, including pre- and postcontrast T1-weighted images, T2-weighted images, and FLAIR sequences. In addition, a diffusion-weighted echo-planar sequence was obtained with the following parameters: TR/TE, 6100/78 msec; section thickness, 5.0 mm with no intersection gap; matrix, 128 × 128; field of view, 220 × 220 mm, and total imaging time, 1 minute 44 seconds. A total of 7 image sets were obtained: 6 with noncollinear diffusion-weighting gradients with a b value of 1000 seconds/mm² and 1 without diffusion weighting (b = 0 seconds/mm²).

The acquired raw data were then transferred to a workstation for postprocessing (Siemens Leonardo). Diffusion tensors were calculated using the Siemens Leonardo workstation toolbox software. Eigenvector maps, FA, and ADC maps were calculated. To aid in the visualization of eigenvector orientation and coherent white matter tracts, a color-assigned FA map was created. Per convention, left-to-right-oriented axonal fibers were designated as green, anterior-to-posterior fibers red, and superior-to-inferior fibers blue. Regions of interest were drawn in the bilateral PLICs and descending corticospinal tracts to obtain quantitative FA and ADC values. Three-dimensional DT imaging axonal tract models were then generated by placing seed points defined within ROIs, guided by known anatomy. The primary concern with resection of thalamic tumors and, thus, the ROI in this study were the pyramidal tracts. Given the significant distortion of the motor fibers within the midbrain, the precentral gyrus was used as the location for seed point placement. The tracts were then created bidirectionally from each seed point with internal constraints designed to filter out nonprincipal or divergent pathways.
All the patients in this study underwent preoperative imaging that demonstrated solitary intraaxial, parenchymal mass lesions involving the thalamus with variable midbrain and brainstem involvement. Each of the mass lesions demonstrated imaging characteristics of low-grade astrocytomas, including a well-circumscribed border, variable contrast enhancement and cystic change, and limited peritumoral edema. Preoperatively, the mass lesion was then determined to be in one of the following anatomical locations: anterior thalamus, posterodorsal thalamus, posteromedial thalamus, or posteromesial thalamus.

Surgical Approaches and Stereotactic Resection

Tumor resection was performed with the patient under general anesthesia and with use of intraoperative motor evoked potential and somatosensory evoked potential monitoring. Computer-assisted volumetric stereotactic systems (Compass Stereotactic System/Cygnus Frameless Stereotactic System, COMPASS International, Inc.) were used in all cases. Surgical procedures were planned in advance with the use of an imaging database that included stereotactic CT and MR imaging scans. In the cases in which head frames were used, the tumor volume in stereotactic space was calculated (using the stereotactic system) from the CT and MR imaging tumor outlines and then reformatted into slices perpendicular to the planned operative trajectory as described in other reports. When a frame-based stereotactic system was used, a 2-cm cylindrical stereotactic retractor/dilator was used for the transcortical approaches. The relationship of the retractor to the outlined tumor volume perpendicular to the surgical line of sight was displayed intraoperatively to maintain orientation during resection and to identify the imaging-defined boundaries of the tumor in the surgical field. With both frame-based and frameless tumor resection, a plane between tumor and surrounding normal parenchyma was microsurgically dissected. The entire volume of the tumor was usually dissected free from the surrounding parenchyma before being delivered from the resection cavity.

The surgical approach used during resection of a thalamic tumor was based upon the relationship of the tumor to uninvolved thalamic structures that were displaced by the tumor. In general, surgical trajectories were chosen to traverse noneloquent brain tissue, to run parallel to major white matter fiber tracts, and to maximally preserve displaced or compressed normal thalamic structures. The final surgical approach trajectory was adjusted to avoid any large cortical arteries and draining veins and the internal cerebral and basal veins.

Anterior thalamic tumors were approached with the patient in supine position by means of a frontal craniotomy and a posterior and medial trajectory extending through the anterior limb of the internal capsule. Posterodorsal thalamic tumors were exposed through a superior parietal craniotomy, with the patient’s head prone, utilizing an anterior trajectory through the superior parietal lobe and posterior body or atrium of the lateral ventricle. Posteromedial tumors were exposed through a temporo-occipital–junction craniotomy, with the patient’s head in an oblique position and utilizing an anterior and medial trajectory extending from a posterior temporal or lateral occipital incision and through the sublenticular portion of the internal capsule or through the posterior temporal horn to the posteroverentral thalamus. Posteromedial thalamic tumors were approached via an interhemispheric occipital transtentorial craniotomy with the patient positioned operative side down, utilizing gravity retraction of the interhemispheric corridor, a paramedian tentorial incision and working below the splenium of the corpus callosum and vein of Galen. Medially located dorsally exophytic thalamic tumors were approached via a parasagittal craniotomy with the patient positioned with the operative side down to allow for gravity retraction, and transcortical tumor resection was performed along the interhemispheric fissure.

Illustrative Cases

Case 1: Anterior Transcortical Approach

This 3-year-old boy presented with diminished right hand use and on neurological examination demonstrated a slight right hemiparesis. An MR imaging study revealed a heterogeneous tumor within the anterior left thalamus (Fig. 1). The tumor consisted of a nonenhancing cystic component with internal septations and an eccentric enhancing nodule. The anterior thalamic tumor extended ventrally into the midbrain to the crus cerebri with exophytic tumor growth abutting the posterior cerebral artery in front of the cerebral peduncle. The lesion displaced the normal thalamus posteriorly. The PLIC, which can be partially traced on the T2-weighted MR images, would be expected to be displaced laterally. Diffusion tensor imaging demonstrated the location of the displaced PLIC to be even more posterior than expected, making an anterior trajectory the most favorable.

He underwent a left-sided stereotactic craniotomy directed through the middle frontal gyrus and anterior limb of the internal capsule. Postoperative MR imaging confirmed GTR of the solid and cystic mass and pathology findings were consistent with JPA. After surgery he had transient worsening of his hemiparesis and a slight visual field deficit. His visual deficit and hemiparesis improved by the first postoperative week, when he was ambulating independently and had only slight residual arm weakness. On 6-month follow-up examination he only had slight clumsiness of the right hand.

Case 2: Interhemispheric Transcallosal Approach

This 10-year-old boy had a 3-year history of progressive right hand tremor and incoordination. Speech difficulties had also developed, leading to academic decline. On neurological examination, he had mild central facial weakness and moderate right hemiparesis. An MR imaging study revealed a well-circumscribed tumor with patchy, inhomogeneous enhancement in the left anterior and medial thalamus that reached the ependymal surface of the lateral ventricle (Fig. 2). The tumor extended into the midbrain and cerebral peduncle and pushed normal thalamus posteriorly and superiorly. The PLIC, which can be partly traced on the T2-weighted MR images, would be expected to be displaced laterally. Diffusion tensor im-
aging revealed that the PLIC was deviated laterally; however, a small component was also thinned out and draped over the anterolateral margin of the tumor. To avoid injury to this small anterior component, a transcallosal approach was used, which allowed access to the medial part of the tumor first through the floor of the lateral ventricle.

Postoperative MR imaging confirmed GTR of the solid and cystic mass and pathology was consistent with JPA. After surgery there was slight worsening of the preoperative hemiparesis and transient dysphasia. The dysphasia resolved rapidly during the first postoperative week. On 6-month follow-up examination he was ambulating and had considerable recovery in hemiparesis to his preoperative baseline.

**Case 3: Posteroinferior Subtemporal Approach**

This 7-year-old girl complained of worsening handwriting and on neurological examination had mild right hemiparesis, hemiparetic gait, and upper extremity tremor. Preoperative MR imaging revealed a well-circumscribed tumor, with a contrast-enhancing peripheral rim and a small central enhancing nodule, in the left posteroventral thalamus with extension into the subthalamus, midbrain, and cerebral peduncle (Fig. 3). The tumor displaced the normal thalamus superiority and anteriorly. The PLIC, which can be partly traced on the T2-weighted MR images, would be expected to be displaced anteriorly and laterally. Diffusion tensor imaging confirmed the expected location of the PLIC draped over the anterolateral aspect of the tumor margin, making a posterior approach most favorable. To avoid traversing the anteriorly and superiorly displaced normal thalamus, a posteroinferior approach was used.

She underwent a left-sided approach directed under the occipitotemporal junction and a basal temporal cortical incision and transchoroidal exposure of the tumor. Gross-total resection of the tumor was confirmed on postoperative MR imaging and pathological examination revealed a JPA. After surgery the patient had a transient increase in hemiparesis, which returned to the preoperative baseline over the next 2 days. However, on the 4th postoperative day she experienced acute development of hemiplegia and lethargy. A hematoma in the resection bed was identified on CT scan. Following emergent evacuation, the patient had mild dysphasia and hemiparesis. On 6-month follow-up she had regained strength nearly to her preoperative baseline and was ambulating independently, but her mild dysphasia and hand weakness persisted.
Case 4: Posteroinferior Transcortical Approach

This 7-year-old boy had a right thalamic tumor, which was discovered incidentally after a bicycle accident. He initially underwent a stereotactic biopsy that revealed JPA and was followed up conservatively. He then developed slight left-side weakness and lethargy secondary to marked tumor enlargement and was referred to our institution. An MR imaging study demonstrated a well-circumscribed contrast-enhancing tumor in the posteroveentral thalamus with extension inferiorly into the ventrolateral thalamus near the optic tract in the roof of the ambient cistern (Fig. 4). The tumor displaced normal thalamus anteriorly and superiorly. The PLIC, which can be partly traced on the T2-weighted MR images, would be expected to be displaced anteriorly and laterally. Diffusion tensor imaging revealed that, in contrast to what is found in most cases of posteroveentral tumors, the significant ventrolateral component of this tumor further displaced the PLIC in an anterior and even medial direction. Therefore, the usual posteroinferior approach could be modified to a more lateral approach that would still spare the motor fibers within the internal capsule.

He underwent a right-sided craniotomy directed through the posterior middle temporal gyrus and through the choroidal fissure for tumor resection. Postoperative MR imaging confirmed GTR of the contrast-enhancing mass and pathological findings were consistent with JPA. Immediately following surgery the patient had slight exacerbation of his left hemiparesis, which proved transient. On 3-month follow-up he only had mild fine motor dysfunction of the hand, was ambulating independently, and was in regular school.

Case 5: Posterosuperior Transcortical Approach

This 18-year-old asymptomatic and neurologically intact boy with a history of neurofibromatosis Type 1, underwent a surveillance MR imaging that initially revealed a small contrast-enhancing left thalamic tumor. A stereotactic biopsy revealed JPA. Over the following 3 months, the tumor doubled in size. Preoperative MR imaging demonstrated a well-circumscribed homogeneously enhancing tumor within and expanding the posterior thalamus and pulvinar region (Fig. 5). The posterodorsal thalamic tumor reached the ependymal surface of the atrium of the left lateral ventricle and displaced normal thalamus anteriorly. The PLIC, which can be partly traced on the T2-weighted MR images, would be expected to be displaced anteriorly and laterally. Diffusion tensor imaging
confirmed the anterior location of the internal capsule, which allowed a posterosuperior transcortical trajectory to excise the tumor.

He underwent a left-sided stereotactic craniotomy directed through the superior parietal lobule, entering the atrium of the lateral ventricle and encountering the ependymal surface of the tumor in the medial wall of the lateral ventricle. Postoperative MR imaging confirmed GTR, and pathological findings were consistent with JPA. The MIB-1 index, however, was 10% and the patient was treated with vincristine and carboplatin. Immediately after surgery, he had a right homonymous hemianopsia and Gerstmann syndrome. The Gerstmann syndrome completely resolved by the 1-week follow-up examination, but a visual field deficit remained. Shortly after surgery, he was able to resume college without difficulty.

**Case 6: Occipital Transtentorial Approach**

This 4-year-old boy had hydrocephalus secondary to a right thalamic lesion identified as a result of complaints of intermittent headaches that eventually progressed to severe nighttime headaches. He was otherwise neurologically intact and underwent an endoscopic third ventriculostomy and biopsy of the lesion at another hospital. An MR imaging study demonstrated a well-circumscribed contrast-enhancing tumor in the posterior medial thalamus, extending inferiorly into the upper part of the tegmentum with obstruction of the sylvian aqueduct (Fig. 6).

The tumor displaced normal thalamus and the PLIC, which was easily identified on the T2-weighted MR images, anteriorly and laterally. Diffusion tensor imaging confirmed the expected location of the PLIC displaced anteriorly and laterally along with and in front of the displaced normal thalamus. To avoid traversing the displaced normal thalamus and PLIC, an interhemispheric occipital transtentorial approach was used for this posterior and medial lesion. Postoperative MR imaging confirmed GTR of the contrast-enhancing mass, and pathological findings were consistent with JPA. Postoperatively, the patient had Parinaud syndrome, which had mostly resolved on 2-week follow-up examination, but was otherwise neurologically intact.

**Discussion**

Resection of deep-seated tumors such as those arising from the thalamus remains a neurosurgical challenge. With stereotactic techniques, some well-circumscribed le-
Diffusion tensor imaging and thalamic JPA resection

sions such as JPAs can be completely and safely removed from the thalamus in children.24,25,32,34,35 Juvenile pilocytic astrocytomas in particular are well suited for stereotactic resection because the contrast-enhancing margins on MR images correspond to histologically and surgically identifiable normal brain–tumor interface. Although a variety of operative trajectories exist for resection of thalamic tumors, careful identification of the normal thalamus, internal capsule, and tumor extension into adjacent structures is paramount for planning the optimal surgical strategy. This is particularly challenging in very large tumors that distort normal anatomy and obscure the location of the PLIC and the motor fibers therein.

In the present series, the operative plans for resection of thalamic JPAs were augmented with DT imaging to identify the actual location of the PLIC in relation to the tumor. Furthermore, tractography of the white matter fibers emanating from the precentral gyrus was particularly helpful in optimizing the planned approach trajectory before surgery. The operative plans were initially formulated with established anatomical/surgical principles of thalamic tumor resection and after careful study of routine MR imaging—particularly, the axial T2-weighted sequences.24,25,32,34,35 In some cases, the internal capsule could not be well visualized on standard MR images because of distortion from the large tumor size and extension into the midbrain. Prior to DT imaging, the location of the internal capsule in such cases was anatomically approximated based on the location of tumor growth within the thalamus (anterior vs posterior thalamus) and the subsequent expected deviation of the internal capsule. The cases in the present series allowed us to compare the anatomically expected position of the internal capsule with the actual visualized position on DT imaging. Not surprisingly, we have found the position of the internal capsule on DT imaging and tractography was generally congruous to the position a surgeon would anatomically predict. However, DT imaging analysis allowed for more accurate anatomical localization, fine tuning of the operative approach, and augmented surgeon confidence.

Confidently identifying the position of the internal capsule is important because it enables an aggressive attempt at GTR of thalamic JPAs. Complete resection of JPAs leads to long-term disease-free survival in the majority of patients and is currently unmatched by other treatments.2,13,16,17,35 Chemotherapy,14,33,36,38,39 conventional radiation therapy,12,15,19 and stereotactic radiosurgery5,41 may play a role for multiply recurrent tumors or residual disease; however, none of these options is superior to complete resection. Furthermore, the potential long-term adverse ef-

Fig. 4. Case 4. Posteroinferior transcortical approach. This patient had a right-side posteroverentral thalamic tumor that extended inferiorly into the ventrolateral thalamus near the optic tract and roof of the ambient cistern. Tumor resection was directed through the posterior middle temporal gyrus and choroidal fissure. A: Color-coded anisotropic maps revealing the anteriorly displaced fibers of the PLIC (black arrows). B and C: Preoperative contrast-enhanced sagittal and coronal (B) and axial (C) T1-weighted MR images revealing the contrast-enhancing tumor and the anteriorly and superiorly displaced normal thalamus (white arrows). D and E: Postoperative axial (D) and sagittal (E) contrast-enhanced T1-weighted MR images confirming GTR.
The techniques for stereotactic volumetric resection of JPAs located in the thalamus have been previously described with good functional neurological outcomes and long-term disease-free survival.\textsuperscript{24,25,32,34,35} With the aid of the preoperative imaging database, operative trajectories are planned that minimally disrupt normal eloquent brain tissue en route to the tumor. The anterior or posterior thalamic location of a JPA and the anterior or posterior location of displaced normal thalamus can usually be identified on sagittal MR images. The position of the internal capsule can also be identified on axial T2-weighted images in many patients with thalamic JPAs. Anterior thalamic tumors generally displace normal thalamus posteriorly, and the PLIC usually resides lateral to the tumor (therefore an anterior approach is optimal). Posterosuperior thalamic tumors generally displace normal thalamus anteriorly and inferiorly and displace the PLIC anteriorly. Posteroventral tumors usually displace normal thalamus anteriorly and superiorly and also displace the PLIC anteriorly.

Although the location of the tumor in the thalamus can usually be identified, visualizing the PLIC on MR images is sometimes difficult with large lesions that dis-
tort the surrounding anatomy. In such cases the position of the internal capsule is approximated based on the category of thalamic tumor (anterior thalamus, posterodorsal thalamus, posteroventral thalamus). While these approximations have been successfully used in cases in which the internal capsule cannot be clearly visualized on conventional MR images, it is of interest to directly identify the location of the PLIC using DT imaging and to compare it to the anatomically anticipated location.

Diffusion tensor imaging is a technology that has been recently introduced into the neurosurgical operating room to identify white matter fiber tracts. The generated images can also be incorporated into the stereotactic space, and DT imaging can even be performed after surgery to visualize repositioning of the white matter fibers after tumor removal. It can serve as a useful tool to validate the trajectories to thalamic tumors that have been previously developed using anatomical knowledge and clinical experience. Moreover, in cases of very large tumors, DT imaging and tractography can identify the location of the displaced precentral white matter tracts in relation to the tumor mass and minimize the risk of postoperative hemiparesis.

When selecting the optimal trajectory for resection of thalamic lesions, we use the 3 principles previously mentioned: 1) minimize injury to eloquent cortex en route to the lesion, 2) avoid disruption of the PLIC, and 3) minimize damage to displaced but normal thalamus. Following these principles, there are a variety of trajectories that can be used. Transcortical approaches, ideally suited for stereotactic volumetric resection through a cylindrical retractor, allow more variability in angle of approach, minimize retraction injury to the surrounding brain compared with conventional retractors, and allow direct targeting of the tumor brain interface. Approaches directed along interhemispheric and transverse cerebral fissures avoid a cortical incision but are more limited in angle of approach.

Tumors located in the anterior thalamus can be stereotactically resected through a white matter incision parallel to the direction of fibers in the anterior limb of the internal capsule. Tumors in the posterodorsal thalamus, especially on the language-dominant side, can be stereotactically resected through a superior parietal trajectory traversing the atrium of the lateral ventricle. Medially located tumors of the anterior or posterior thalamus that have dorsally exophytic components or abut the superior ependymal surface can be resected through anterior or posterior interhemispheric transcallosal approaches, respectively. Posteroventral thalamic tumors can be stereotactically resected through an inferiorly

Fig. 6. Case 6. Occipital-transtentorial approach. This patient had a right-side posteromedial thalamic tumor that extended inferiorly into the tectum. The tumor was resected via an occipital transtentorial approach directed along the interhemispheric fissure. A: Color-coded anisotropic maps revealing the anteriorly displaced fibers of the PLIC (black arrows). (The white arrows indicate displaced normal thalamus.) B–D: Preoperative contrast-enhanced coronal (B), axial (C), and sagittal (D) T1-weighted MR images revealing the contrast-enhancing tumor and the anteriorly and superiorly displaced normal thalamus (white arrows). E and F: Postoperative contrast-enhanced axial (E) and sagittal (F) T1-weighted MR images confirming GTR.
placed posterior temporal or lateral occipital cortical incision directed through the posterior temporal horn or the sublenticular internal capsule to the ventral thalamus.

Barring any large temporal draining veins, posteroventral thalamic tumors with a large midbrain component can also be exposed after elevation of the occipitotemporal junction combined with a tentorial incision if needed (lateral occipital transtentorial approach). Furthermore, posteromedial thalamic tumors that lie medial to the fornix within the transverse cerebral fissure can be removed with an interhemispheric occipital-transtentorial or an infratentorial supracerebellar approach, depending on the angle of the tentorium, location of the deep venous system, and comfort of the surgeon.

We generally advocate against using transsylvian approaches to thalamic tumors, because traversing the insula would eventually traverse the internal capsule and the perforating vessels supplying it. We also do not advocate resection of these lesions using a transsylvian approach and resection from the basal surface of the brain unless the lesion has a large ventral exophytic component adjacent to the midbrain. This route along the basal surface of the brain requires working between numerous perforators and is fraught with poor visualization.

Knowledge of the location of the PLIC (aided by DT imaging) and the location of the normal thalamus (on conventional MR imaging sequences) helped plan a safe approach trajectory. However, once the tumor was encountered, dissection proceeded along the surgically identified brain-tumor interface, which in the case of JPA corresponds to the contrast-enhancing lesion on MR imaging. Such dissection relies on conventional surgical techniques for tumor dissection, and the utility of DT imaging during the tumor dissection, after the approach has been selected and executed, is limited.

In this series of cases involving children with thalamic JPAs, DT imaging served as a useful adjunct to conventional T2-weighted images and confirmed the anticipated location of the PLIC. The information added by DT imaging and tractography can give confidence to surgeons of all levels of expertise in thalamic surgery. Furthermore, as specifically illustrated here in one case, it can allow further refinement of the operative approach based on the knowledge of the actual location of the PLIC. This gain of understanding of regional anatomy near such eloquent structures will undoubtedly provide improved disease control and limit neurological morbidity.

Conclusions

In this small series of children who had stereotactic resection of thalamic JPAs, DT imaging of the white matter tracts adjacent to the thalamus and tractography of the white matter fibers from the precentral gyrus provided information valuable for surgical planning. Diffusion tensor imaging successfully identified the motor fibers within the PLIC and helped prevent iatrogenic disruption during tumor removal by optimizing the approach to these deep-seated lesions. We found this technology helpful in minimizing potential neurological morbidity while improving the ability to attain complete resection.

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References


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