Transcortical surgery for lateral ventricular tumors

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Object. Tumors of the lateral ventricle can be removed via two major approaches: the transcallosal or the transcortical route. The purpose of this study is to discuss the techniques and outcomes in transcortical surgery of tumors located in the lateral ventricle.

Methods. An experience with 29 consecutive lateral ventricular tumors resected via the transcortical route, over a 5-year period, is presented. The risks, complications, and outcomes of this surgical series, as well as those reported in the literature, are discussed. Surgical approaches to all five regions of the lateral ventricle are described. Neuropsychological, functional, and neurosurgical outcomes are evaluated.

Conclusions. The transcortical technique makes it possible to resect lesions in each of the five regions of the lateral ventricle. It provides superior microsurgical working space and flexibility for maneuvering within the lateral ventricle. The key to a successful transcortical approach is an understanding of the functional anatomy of eloquent cortex to be resected, the location of the lesion, and its vascular supply. A clear understanding of the advantages and limitations of the transcortical approach makes performing this procedure for resection of large lesions in the ventricle both safe and effective. The majority of the patients in this series (86%) had a good outcome, returning to baseline functional status and suffering minimal morbidity. In the microsurgical era, transcortical surgery-related postoperative morbidity and outcome are dependent more on tumor histological type and site of origin than on approach.

KEY WORDS • lateral ventricle • transcortical approach • surgical approach • brain lesion

Abbreviations used in this paper: CSF = cerebrospinal fluid; CT = computerized tomography; ICP = intracranial pressure; MR = magnetic resonance; PCA = posterior cerebral artery.

Tumors of the lateral ventricle are rare lesions in a general neurosurgical practice. They account for less than 1% of intracranial tumors in most series of large brain tumors. Tumors in this location are generally slow growing and can become large before causing symptoms. Symptoms are produced only after there is obstruction of the normal CSF pathways, compression of the adjacent neural structures, or hydrocephalus induced by overproduction of CSF. Symptoms produced only after there is obstruction of the normal CSF pathways, compression of the adjacent neural structures, or hydrocephalus induced by overproduction of CSF.

Complete resection of many, but not all, of these lesions is possible via the transcortical or transcallosal route. The location of the lateral ventricles makes passing through cortical structures mandatory in all approaches to these lesions. The challenge to the surgeon is to develop a route to these deep lesions that will cause the least morbidity, provide adequate working space, and achieve a complete resection. This must be performed with minimal manipulation of the neural structures encircling the ventricles. In planning such an approach consideration is given to avoiding functional cortical areas, minimizing retraction, and acquiring early control of feeding vessels.

The transcortical route is preferred by some neurosurgeons for a variety of reasons. The transcallosal approach may decrease the risk of postoperative seizures and functional deficits. It is recognized that the transcallosal route to the ventricles can be safely performed to excise lesions in the ventricular body, anterior horn, and atrium. The transcortical approach to the lateral ventricles is a simple and attractive alternative to the transcallosal approach for many deep-seated tumors. It has the advantage of simplicity. The risks of an elegantly performed operation in the age of microsurgical techniques are far less significant than previously reported. In addition, tumors located in certain regions of the lateral ventricle, specifically the temporal horn or atrium, are often more safely and easily approached through a cortical incision. Last, the transcortical approach provides superior working space and more flexibility in traversing the lateral ventricle.

I use both the transcallosal and the transcortical routes for the excision of lateral ventricular masses. This article is based, in part, on my recent 5-year experience with excising mass lesions in the lateral ventricle via the transcortical route. The nature of my practice dictates that I report a strong bias toward pediatric tumors. This paper will also focus on the important transcortical approaches used to access lesions of all five sections of the lateral ventricles.
their indications, and the documented advantages and risks of each approach. My intention is not to claim that one procedure is superior; I will provide a realistic assessment of the challenges, complications, and outcomes of the transcortical approach to a mass lesion in the lateral ventricle.

CLINICAL MATERIAL AND METHODS

Twenty-nine tumors of the lateral ventricle were excised by the author via the transcortical approach from 1995 to 2000. From 1995 to 1997, the procedures were performed at Walter Reed Army Medical Center; from 1997 to 2000, the operations were performed at The Children’s Hospital and Regional Medical Center/The University of Washington. The patients ranged from 3 to 35 years of age. The majority (27) of the patients were younger than 16 years of age. Fifteen patients were male and 14 were female.

The distribution of tumor type is listed in Table 1. The majority of the tumors were astrocytoma, choroid plexus neoplasm, or ependymoma.

Patients generally develop symptoms late in the growth of the lesion, and the symptoms are often nonspecific in nature. These symptoms can include headache, imbalance, visual field deficits, memory difficulty, personality changes, cognitive impairment, weakness, and seizures. The signs and symptoms prior to diagnosis in this series were typical of patients with large-sized tumors located in the lateral ventricle. The majority of the patients were children who presented with signs of increased ICP. The specific symptoms included headache, vomiting, and general malaise. Nine of the patients presented with signs and symptoms of obstructive hydrocephalus; two children, younger than 3 years of age, presented with significantly worse by surgical intervention (poor outcome). Two of those patients died of complications from tumor progression over 1 year postsurgery despite undergoing aggressive adjuvant therapy for malignant tumors (anaplastic astrocytoma). All ependymoma, choroid plexus neoplasms, and other tumors were successfully excised.

The patient outcome analysis was simplified to three categories: good, fair, and poor. Patients with a good outcome (86%) experienced either no permanent deficits or minor deficits, which permitted them to return to school or work. Patients with postoperative deficits that prevented their return to school or work were classified as having a fair outcome (14% of cases). No patient was made significantly worse by surgical intervention (poor outcome).

The complications were carefully noted and are listed in Table 3. Two patients (6.9%) suffered a long-term seizure disorder. Three of the six patients in whom choroid plexus neoplasms were excised required permanent CSF diversion. Persistent subdural fluid collections were present in four patients, but only one required a burr hole to drain the fluid collection. Six patients suffered a visual field cut, which was related to the parietal or occipital approach to their tumor.

TABLE 1
Lateral ventricular masses grouped by pathological diagnosis

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>central neurocytoma</td>
<td>1</td>
</tr>
<tr>
<td>subependymoma</td>
<td>2</td>
</tr>
<tr>
<td>oligodendroglioma</td>
<td>2</td>
</tr>
<tr>
<td>primitive neuroectodermal tumor</td>
<td>1</td>
</tr>
<tr>
<td>pilocytic astrocytoma</td>
<td>4</td>
</tr>
<tr>
<td>malignant glioma</td>
<td>5</td>
</tr>
<tr>
<td>cavernous hemangioma</td>
<td>1</td>
</tr>
<tr>
<td>choroid plexus tumor</td>
<td>6</td>
</tr>
<tr>
<td>supratentorial ependymoma</td>
<td>7</td>
</tr>
<tr>
<td>total</td>
<td>29</td>
</tr>
</tbody>
</table>

DISCUSSION

Relevant Surgical Anatomy

An appreciation of the relevant anatomy is extremely helpful when performing transcortical approaches to the lateral ventricles. A more detailed analysis of the pertinent anatomy can be found in the elegant monographs produced in Rhoton’s laboratory.

The lateral ventricles are paired C-shaped structures that wrap around the ipsilateral thalamus. Each ventricle is divided into five sections: anterior horn, body, temporal horn, atrium, and occipital horn. Each of these five sections has a roof, a floor, and a medial and lateral wall.

The walls of the lateral ventricles are formed by the thalamus, septum pellucidum, corpus callosum and its radiations, caudate nucleus, and the fornix. The caudate nucleus is also an almond-shaped structure that forms the lateral wall of the body, anterior lateral wall of the atrium, and roof of the temporal horn. The fornix starts as the fimbria of the hippocampi in the medial temporal horn and runs along the thalamus in the anterior wall of the atrium. After giving off commissural fibers, it continues in the inferior medial wall of the body. Finally, it forms the superior and anterior borders of the foramen of Monro.

RESULTS

A summary of the relationship of the surgical approach to the outcome and complications is shown in Table 2. There were no deaths in this series. Six (20.7%) of the 29 patients underwent a subtotal resection of their tumor. The remaining patients underwent gross-total excision of their tumor. All incompletely resected tumors were astrocytoma, which arose from deep structures and grew into the ventricle. Five tumors involving the thalamus were judged to be incompletely resected based on their invasive nature, although three demonstrated no enhancement after gado-linium administration postresection. These patients not only had an incomplete tumor resection but also suffered the worst functional outcomes. Two of those patients died of complications from tumor progression over 1 year postsurgery despite undergoing aggressive adjuvant therapy for malignant tumors (anaplastic astrocytoma). All ependymoma, choroid plexus neoplasms, and other tumors were successfully excised.

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The thalamus, which is in the center of the lateral ventricle, is seen in the floor of the body, interior wall of the atrium, and medial roof of the temporal horn. The choroidal fissure is an important surgical landmark defined by the groove between the thalamus and the fornix where the tela choroidea gives rise to the choroid plexus. The septum pellucidum is a thin, diaphanous wall which separates the frontal horns and body in the midline. The genu of the internal capsule lies in the lateral wall between the caudate and thalamus at the level of the foramen of Monro. The remainder of the lateral ventricular surfaces is formed by the corpus callosum and its radiations. The posterior choroidal arteries are grouped into lateral and medial divisions. The lateral posterior choroidal artery is comprised of one to six branches, which arise in the ambient and quadrigeminal cisterns from the PCA. These branches then pierce the ventricle and pass around the pulvinar and through the choroidal fissure at the level of the crus of the fornix to supply the choroid plexus in the posterior temporal horn, atrium, and body of the ventricles. The medial posterior choroidal arteries arise as one to three branches from the PCA in the interpeduncular and crural cisterns. These arteries circumnavigate the midbrain and move to the pineal gland to enter the roof of the third ventricle. This vessel then passes in the velum interpositum, between the thalami, adjacent to the internal cerebral veins. The medial posterior choroidal arteries travel through the velum interpositum (tela choroidea), sending inconstant branches to the lateral ventricle through the choroidal fissure and foramen of Monro. The medial posterior choroidal artery supplies the choroid plexus in the roof of the third ventricle and sometimes the choroid plexus of the lateral ventricle.

The veins are useful as landmarks to direct the surgeon to the foramen of Monro, especially in cases in which hydrocephalus is present. There are many important veins...
and angiography. A review of 47 lateral ventricle tumors determined by CT scanning, MR imaging, MR angiography, and angiography. On MR imaging, they may possess heterogeneous signal characteristics caused by necrosis and calcification and are isodense to brain on T1-weighted images and brightly enhanced with gadolinium administration. Outside the trigone, tumors in older patients are often either a primary or metastatic malignancy.

In adults older than 30 years of age, tumors in the atrium and trigone are most commonly meningiomas. They are isodense to brain on T1-weighted images and brightly enhance with gadolinium administration. Outside the trigone, tumors in older patients are often either a primary or metastatic malignancy.

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Table 4: Transcortical approaches for lateral ventricular tumors

<table>
<thead>
<tr>
<th>Approach</th>
<th>Indication</th>
<th>Potential Complication</th>
</tr>
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<tbody>
<tr>
<td>middle frontal gyrus</td>
<td>ipsilateral frontal horn or anterior body lesions &amp; anterior body of fornix</td>
<td>attention deficits in either hemisphere (rare);</td>
</tr>
<tr>
<td></td>
<td>3rd ventricle, especially for subchoroidal approaches &amp; unilateral interhemispheric approach</td>
<td>speech apraxia or abulia in dominant hemisphere;</td>
</tr>
<tr>
<td></td>
<td>lesion in posterior temporal horn, ambient &amp; temporal horn, especially a large one, &amp; surgery for epilepsy</td>
<td>subdural hygromas after removal of large lesions w/ hydrocephalus;</td>
</tr>
<tr>
<td></td>
<td>occipital horn drain into the basal internal cerebral veins</td>
<td>language deficits in dominant hemisphere, hemiparesis;</td>
</tr>
<tr>
<td></td>
<td>through the ambient cistern.</td>
<td>safer in nondominant hemisphere, spatial neglect &amp; visual field deficit in the nondominant hemisphere</td>
</tr>
<tr>
<td></td>
<td>from the lateral wall of the body of the ventricle through the cerebral veins</td>
<td>homonymous field deficit; vascular supply is deep to</td>
</tr>
<tr>
<td></td>
<td>as it travels in the roof of the third ventricle within the velum interpositum</td>
<td>tumor; risk of hemorrhage</td>
</tr>
<tr>
<td></td>
<td>Veins from the atrium and occipital horn drain into the basal internal cerebral veins as well as the vein of Galen.48</td>
<td></td>
</tr>
<tr>
<td>Pathological Entities</td>
<td></td>
<td>in all parts of the ventricle and frequently will arise from the thalamus, where, based on MR documentation, they can appear to infiltrate. Ependymoma, when supratentorial, can be intraventricular as well as intraparenchymal.20 In this series, I report on ependymomas that originate in the ventricle.</td>
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</tbody>
</table>

Currently, the differential diagnosis of tumors in the lateral ventricle depends on the age of the patient, location of the tumor, and specific radiological characteristics as determined by CT scanning, MR imaging, MR angiography, and angiography.20,51 A review of 47 lateral ventricle tumors examined by radiologists at the Armed Forces Institute of Pathology was performed using CT and/or MR imaging studies, and the authors found that tumors seemed to occur in age-related groupings.20 Tumors found in the lateral ventricle of children younger than 5 years of age were often choroid plexus tumors, whereas in older children they tended to be glioma. Choroid plexus tumors are often quite vascular and demonstrate a tumor blush on MR angiography and angiography. On MR imaging, they may possess heterogeneous signal characteristics caused by necrosis and calcification and are isodense to hypodense on T1-weighted images relative to the white matter. The most common hypo- or isodense, nonenhancing tumor in the body or foramen of Monro is subependymoma. In children with tuberous sclerosis, they are often giant cell astrocytoma. In this location, they often reach a large size before being diagnosed.24,31,40 Astrocytoma can be found in all parts of the ventricle and frequently will arise from the thalamus, where, based on MR documentation, they can appear to infiltrate. Ependymoma, when supratentorial, can be intraventricular as well as intraparenchymal.20 In this series, I report on ependymomas that originate in the ventricle.

In adults older than 30 years of age, tumors in the atrium and trigone are most commonly meningiomas. They are isodense to brain on T1-weighted images and brightly enhance with gadolinium administration. Outside the trigone, tumors in older patients are often either a primary or metastatic malignancy.20 Intraventricular homogeneous masses, which are revealed to engulf the choroid glomus on CT scanning and which are demonstrated to have a significant choroidal artery supply on angiography, are usually benign.27,42

Central neurocytomas, which occur mostly in adults in the second to fourth decade of life, tend to adhere to septum pellucidum and possess a characteristic CT and MR imaging appearance. On CT and MR imaging, the tumors tend to be primarily solid with some cystic regions, and contain calcifications and signal voids that represent tumor vessels.5 These tumors can be quite large on presentation. Although the natural history and long-term prognosis of these lesions are not completely understood, excision appears to be curative. Significant blood loss and a dense connection to the septum pellucidum and structures adjacent to the foramen of Monro, however, may complicate the resection.

Other nonneoplastic processes such as cysts, sarcoidosis, xanthogranulomas (which appear to be dense on CT scans with flecks of calcification), arteriovenous malformations, cavernous hemangiomas, and cysticercosis lesions are also found in the lateral ventricle with varying frequency.15

Preoperative Planning and Special Surgical Considerations

A CT session is often the first radiological study pa-
patients undergo. Subsequently they undergo MR imaging with and without gadolinium, which reveals the precise location and extent of the lesion within the ventricle and, thus, helps guide the surgical approach. If increased vascularity of the tumor is noted by the radiologist, MR angiography may be performed while the patient is in the imaging system. Magnetic resonance angiography or traditional cerebral angiography is useful for identifying major feeding vessels in vascular lesions such as meningioma, choroid plexus tumors, and central neurocytoma, and such studies guide the surgical approach because early proximal control of a choroidal feeding vessel may be warranted. Furthermore, when possible our interventional neuroradiologists will perform an embolization procedure to decrease the blood flow. In cases of successfully preoperatively embolized tumors, the excisions have been made markedly easier, with far less blood loss occurring. We have performed embolization of choroidal vessels in children as young as 3 years of age. Because large blood losses in small children can cause shock quickly or cause the surgeon to halt or stage an operation, I favor preoperative embolization whenever it is technically feasible.

Preoperative visual field testing, a neuroophthalmological examination, and neuropsychological evaluations are performed for all patients who are well enough to tolerate them in our clinic. These examinations often delineate subtle deficits not appreciated on baseline neurological evaluations. The comprehensive neuropsychological examination consists of a thorough assessment of intellectual, academic, sensorimotor, language, spatial, memory, attention, and executive skills. The examination is repeated postoperatively at various intervals to provide data for a more objective assessment of outcomes.

Stereotaxy is occasionally used to guide the approach in cases of smaller lesions. Intraoperative ultrasonography can also be used to help guide the subcortical dissection. The evolution of frameless stereotactic techniques with real-time interactive localization has made surgery in the lateral ventricle safer and more predictable at our institution, as well as at others.\(^{6,52}\) It can provide guidance during the approach, improve trajectory toward the vascular supply, and assist in the complete resection of all lesions.

Ventricular communication after tumor resection is an important goal. Cyst walls need to be removed. In selected patients, an endoscope is inserted to ensure the absence of blood clot or residual tumor and that intraventricular communication has been achieved. Whenever possible, I fenestrate the septum pellucidum to allow bilateral ventricular communication.

Although instruments are no substitute for judgment and experience, it is useful to have access to intraoperative ultrasonography or a frameless stereotactic guidance system, cavitron, endoscope, and irrigating nonstick bipolar electrocautery as well as to standard microinstruments. Cottonoids placed around the mass as it is being removed may limit blood spillage into the ventricle. A saline warmed filled with saline or lactated Ringer solution is used to ensure physiological conditions are maintained during the intraventricular irrigation.

Patients in whom a cortical incision is made receive a 15- to 18-mg/kg fosphenytoin loading dose preoperatively. They are maintained on prophylactic anticonvulsant therapy for at least 1 to 3 months after the procedure, depending on their presenting status and postoperative condition.

After resection of a ventricular tumor, a standard external ventricular catheter or reservoir-equipped ventricular catheter is placed in the ventricle and run outside the dura through one of the burr holes. This provides external drainage of proteinaceous material and blood products from the surgery and serves as a convenient ICP monitor.

**Surgical Approaches**

The complex anatomy of the lateral ventricle permits a wide variety of surgical approaches (Fig. 1 and Table 4). The location and size of the lesion, hemispheric dominance, preoperative deficits, associated hydrocephalus, vascularity of the lesion, and experience of the surgeon all contribute to the ultimate selection of surgical approach. Occasionally, a combination of approaches is required to achieve a gross-total resection of the lesion and to cause minimal morbidity. Although I describe ideal cortical incisions, flexibility is required based on functional mapping or individual variations in cortical topography. I will concentrate on transcortical approaches as they apply to different locations within the ventricular system.

**Craniotomy Flap and Cortical Incisions.** I have used a variety of incisions for transcortical operations, including linear, bicoronal, horseshoe-, question mark–, and serpentine-shaped incisions. Incisions are all performed behind the hairline. Linear incisions, which heal well, seem to cause slightly less morbidity and do not compromise surgical exposure. Regardless of the type of incision, the goal is to provide adequate exposure for a craniotomy that will minimize cortical retraction. For a frontal approach, the bone flap will have its medial border adjacent to but not over the midline and its anterior border above the floor of the anterior fossa; a unicoronal or modified bicoronal incision will best achieve this goal. For the occipital approaches, the border of the craniotomy should be adjacent to the sagittal and transverse sinuses; linear, serpentine-, and horseshoe-shaped incisions are all satisfactory. For middle fossa approaches, the craniotomy should be based on the floor of the middle fossa and extend high enough

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![Fig. 1. Lateral diagram illustrating the various transcortical approaches for removing masses in the lateral ventricle.](image-url)
so that all three temporal gyri can be visualized; a standard question mark– or a T-shaped incision is sufficient.

The size and method of making the cortical incision are important. The site is chosen based on the topography of the sulci and gyri or location of eloquent cortex based on mapping findings or directed by ultrasonography and/or stereotaxis. Some surgeons prefer to enter the sulcus to limit the cortical incision. Although I have used the sulcus incision for the removal of small subcortical tumors or arteriovenous malformations, this incision is too limiting for the removal of large intraventricular tumors.

In 1951, McKissock \(^{29}\) recommended that colloid cysts of the third ventricle be exposed via a frontal transcortical approach through an opening made by removing a conical block of cerebral tissue. Since that report, a similar technique has been used to excise lateral ventricular tumors. \(^{19}\) This technique provided visibility and maneuverability before the advent of the neurosurgical microscope, but it is unnecessary in the microsurgical age. Some of the early discouraging transcortical approach–related results may be partially due to the undesirable sequelae (seizures, cerebral clefts) that can result from this technique. Although the incidence of epilepsy in McKissock’s follow-up series published in 1965 is not high, the linear cortical incision is less destructive. \(^{28}\)

An irrigating nonstick bipolar device is helpful for electrocautery. I prefer the technique of placing a ventricular catheter or Cone brain needle, by using ultrasonographic guidance, frameless stereotactic guidance, or a freehand pass. Once the trajectory to the ventricle is achieved, a small cortical incision is made and followed down to the ventricle. The ependyma is broached with bipolar electrocautery, and the ventricle is entered. A cortical aperture is made using flat microinstruments or microsuction to develop a subcortical path to the lesion. Very little of the subcortical white matter is removed, and two opposing flat malleable brain retractors are placed to increase visibility. The use of Greenberg retractors, which release tension at regular intervals, limits the risks associated with retraction. The goal is not necessarily to make the smallest cortical incision but the most appropriate. Transcortical surgery has the advantages of wide avenues and a more maneuverable microsurgical field. \(^{30}\) When necessary, making a larger cortical incision to remove an extremely large tumor is wise. Hemorrhage can be more effectively controlled without manipulating the neural structures lining the ventricle.

**Frontal Lobe Approaches.** In this series, the tumors in the frontal region were primarily astrocytoma, subependymoma, and ependymoma. Tumors of the frontal horn can become very large and cause obstruction of the foramen of Monro with ventricular dilation. The transcortical middle frontal gyrus approach is an excellent route for the excision of tumors in the ipsilateral anterior horn of the lateral ventricle, the anterior body of the lateral ventricle, and the anterior or superior third ventricle (Fig. 2). This is the approach I use most frequently to excise tumors of the frontal horn. That most neurosurgeons are comfortable with passing a catheter into the frontal horn of the lateral ventricle probably accounts for the relative ease of this approach; it is simply an extension of that common neurosurgical maneuver. Tumors that extend inferiorly from the lateral ventricle into the third ventricle and require subchoroidal exposure for removal are better visualized when using a transcortical than a transcallosal approach. \(^{39}\)

In cases with small ventricles, tumor in both lateral ventricles, and tumor in the body of the lateral ventricle, surgery may be better performed via a transcortical route or a combination of approaches. After the floor of the lateral ventricle is visualized, regardless of the approach, the anatomy is similar.

The patient is placed in the supine position with the head at a 30° angle. The free 4 × 5–cm bone flap is placed over the central portion of the middle frontal gyrus and must be large enough to permit retraction of the middle frontal gyrus in two directions. The flap is based on the coronal suture, with the medial border 2 cm off the midline and the posterior border 2 cm behind the coronal suture. For shunt implantation, a ventricular catheter is placed into the frontal horn of the lateral ventricle through the middle frontal gyrus by using standard landmarks. The
landmarks are the ipsilateral canthus, a plane perpendicular to the skull, and a plane anterior and parallel to the internal auditory meatus. Ultrasonography or stereotactic guidance is helpful, especially if the extent of the resection is going to be intraoperatively gauged using these tools. A 2- to 2.5-cm cortical incision is made parallel to the sulcus in the middle frontal gyrus.

Bipolar electrocautery and microsuction or blunt dissection with a microinstrument is used to follow the catheter to the depths of the white matter toward the ipsilateral foramen of Monro. Two malleable brain retractors are placed to the depth of the ependyma. The microscope is brought in to broach the ependymal lining. After the ependyma is opened, the tumor is located and resected.

Raimondi and Gutierrez\(^{38}\) have reported that the removal of dominant-hemisphere intraventricular lesions via a transcortical middle frontal gyrus approach can cause speech and facial apraxia in patients. Forniceal damage, an important concern, can cause neuropsychological deficits regardless of whether the fornices are approached transcortically or transcallosally.

In the nine consecutive transcortical frontal approaches I have performed in the last 5 years, major permanent neuropsychological deficits have been avoided. The complications associated with this approach have been related to the histological type and site of origin of the primary lesion and not the approach. Only one patient has required long-term anticonvulsant agents for seizure control.

**Approach to the Temporal Horn.** The transcortical approach to the temporal horn is the primary method with which to remove tumors in this region. Early control of the anterior choroidal vessels can be obtained, making tumor excision slightly less challenging. Because meningioma is the most common tumor found in this ventricle, any branch of the choroidal artery can feed the tumor. Unfortunately, posterior choroidal artery branches feeding the tumor are not normally exposed until the bulk of the tumor is removed. No solitary middle fossa approach will permit early control of both anterior and posterior choroidal arteries, initially.\(^{21}\) Anatomically, the structures that must be respected during removal of temporal horn tumors include the medial structures such as the hippocampus and its projections, temporal stem, PCA, anterior choroidal artery, and brainstem. Superiorly, one must avoid the optic tract, the Meyer–Archambault loop, and arcuate fasciculus. The temporal horn, however, is the least likely of the five ventricular regions to harbor a tumor.\(^{36,43}\) There are three cortical incisions that provide access to the temporal horn of the lateral ventricle: the middle temporal gyrus, the lateral temporoparietal junction, and the trans-temporal horn occipitotemporal incision, with or without a modified temporal lobectomy.

**Lateral Temporoparietal Junction Approach.** The lateral temporoparietal junction approach is used in cases in which the angular and supramarginal gyrus are flattened by a large tumor in the nondominant atrium that lies directly beneath them. In such a case, this is the shortest and most direct route to the tumor. The advantage of this approach is that a small portion of brain needs to be traversed from the cortex to the tumor. The disadvantage of this approach, which has discouraged its use, is the significant neuropsychological sequelae reported when traversing the angular gyrus. I have successfully used this approach four times in the last 5 years. I find it useful for very large tumors with attenuated cortex. As shown in the images in Fig. 3, a very large choroid plexus carcinoma was removed via this route. Furthermore, this approach provides superior access to the posterior lateral choroidal feeding vessels in a large tumor, compared with a trans-temporal horn approach. In the latter approach, the anterior or choroidal vessels are normally encountered first. In the case depicted in Fig. 3, an intraventricular choroid plexus carcinoma was successfully removed via this route, and there was no evidence postoperatively of neuropsychological deficit. Regardless of hemisphere, a cortical incision in the temporoparietal junction can result in a visual field deficit caused by the interruption of the optic radiations.\(^{12}\) The patient whose imaging studies are shown in Fig. 3, however, experienced an improvement in a preoperative visual field cut. A cortical incision through the angular gyrus in the dominant hemisphere can also cause right–left confusion, digital agnosia, agraphia, and acalculia (that is, Gerstmann syndrome).\(^{14}\) In the nondominant hemisphere, visual memory loss and neglect can result, which are also potentially disabling.\(^{12}\) In my experience these complications have not been associated with this approach.

**Middle Temporal Gyrus Approach.** The middle temporal gyrus provides a direct route to most middle fossa ventricular lesions. In the nondominant hemisphere, this is a very acceptable route, causing minimal morbidity. In the dominant hemisphere, the danger posed to language cortex becomes an issue and requires refinement in technique. Ojemann\(^{33}\) has meticulously detailed the individual variability of language localization to include language encoding in some individuals within 3.5 cm of the temporal tip and in gyri other than the superior temporal gyrus.

*Fig. 3. Left: Preoperative CT scan obtained in a 3-year-old boy harboring a very large choroid plexus carcinoma in the atrium of the lateral ventricle; he presented with hemiparesis, megacephaly, and malaise. The child required embolization of his posterior lateral choroidal feeding vessels prior to surgery. He then underwent a successful lateral temporoparietal approach for gross-total resection of tumor. The embolization was invaluable, rendering this tumor less vascular than most choroid plexus tumors. Right: The patient has received postoperative chemotherapy and is tumor free 2 years later. He is neurologically well, without hemiparesis.*
Thus, in dominant hemisphere lesions, the risk of causing language deficit is most effectively prevented by cortical stimulation and mapping. Facial apraxia has also been reported in the dominant hemisphere.\(^{31}\) I performed this approach in three patients. One patient experienced a temporary hemiparesis and speech deficit while an extremely large middle fossa tumor was being removed. The patient made a full recovery within 3 months. The patient whose imaging studies are featured in Fig. 4 underwent a middle fossa approach and no morbidity was caused. The patient, a 14-year-old girl, presented with deteriorating mental status, hemiparesis, and visual field loss. She underwent successful removal of her intraventricular primitive neuroectodermal tumor. There was no evidence of a visual field cut or speech loss despite the occurrence of intratumoral hemorrhage that necessitated an emergency tumor resection.

The patient undergoing a middle temporal gyrus approach is placed in a supine position with the head rotated 60 to 90\(^\circ\) to the contralateral side, and the vertex is tilted 5 to 10\(^\circ\) down. A shoulder roll is applied under the ipsilateral shoulder to secure this position without excessive rotation of the neck. The frontotemporal craniotomy is performed through a T- or question mark–shaped incision, starting at the base of the zygoma, 0.5 cm in front of the tragus, with a 3- to 4-cm posterior bend just superior to the ear. The craniotomy should be configured to ensure visualization of the superior, middle, and inferior temporal gyri and should be located posterior enough to provide access to the posterior tumor limits. The pterion and greater wing of the sphenoid may be removed to allow anterior or visualization of the tumor and control of the anterior choroidal artery as it exists from the carotid artery. The normal temporal horn is 3.5 cm from the anterior temporal tip, but pathological relationships can alter this measurement. A standard horizontal cortical incision is placed 3.5 to 4 cm posterior to the temporal tip and parallel to the superior temporal sulcus, and the superior temporal gyrus is preserved. Intraoperative ultrasonography can help to identify the temporal horn when the tumor is small.

**Transtemporal Horn Occipitotemporal Gyrus Approach.** The occipitotemporal gyrus incision used to reach the temporal horn is applicable to lesions in the atrium and temporal horn. A large incision is made in the occipitotemporal gyrus and the inferior surface of the temporal lobe. This incision was described by Spencer and Collins\(^{34}\) in 1982 and was first used in the surgical treatment of epilepsy. It was designed to remove the hippocampus and associated structures and is therefore familiar to many neurosurgeons specializing in the treatment of epilepsy. Although I have used this incision in procedures to remove small and laterally placed tumors, the approach is also extremely useful for removing large lesions in either hemisphere. It was used in two patients, and the postoperative results were satisfactory. Once a very dilated ventricle has been entered, one is able to work and to reach as far as the anterior and posterior lateral ventricle. The modified anterior temporal lobectomy approach is useful in cases of large tumors located in the anterior temporal horn, especially those that appear to involve portions of the anterior temporal cortex. It can also be used to reach tumors as far posteriorly as the occipital horn, especially if there is an associated trapped and dilated temporal horn.

The incision used in the occipitotemporal gyrus approach can be extended into a modified anterior temporal lobectomy. By performing this extensive cortical incision, early access to the choroidal fissure is achieved. Little brain retraction is required, and visibility and maneuverability around the lesion are significantly enhanced. The vein of Labbé is identified and carefully preserved by avoiding extensive manipulation or retraction. By opening the temporal horn inferiorly, the choroidal fissure is exposed and some of the branches of the anterior and lateral posterior choroidal arteries may be observed entering the undersurface of the tumor. Resection of the parahippocampal gyrus and/or hippocampus will expose branches of the PCA, ambient and crural cisterns, and the vessels feeding the medial wall of the tumor.

Damage to the Meyer–Archambault loop results in a quadrantanopia. Language cortex can be injured if portions of the dominant temporal lobe encoding it are disrupted, as previously described.\(^{33}\) Furthermore, temporary alexia has been described after interruption of the fibers inferior to the occipital horn or trigone.\(^{37}\)

In this operation scalp incision and craniotomy are similar to those described for the middle temporal gyrus approach. The incision begins less than 3.5 cm from the temporal tip. In cases of dominant hemisphere lesions, the resection begins less than 3 cm from the temporal tip, preserving most of the superior temporal gyrus. In this approach, it is important to preserve the sylvian vascular tree, which is accomplished by leaving the arachnoid intact over that gyrus. The inferior temporal gyrus is removed in a more generous fashion to provide inferior access to the choroidal fissure and the inferior aspect of the tumor.

Luders and coworkers\(^{25,26}\) have described a basal language region in the inferior temporal lobe that is best...
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evoked by cortical stimulation. Its removal does not uniformly lead to a language deficit because it presumably represents ancillary language cortex. Our experience is similar to that of Luders and coworkers. We have also mapped this language area in several patients but have yet to record a postoperative language deficit following its excision.

**Superior Parietal Incision.** The superior parietal route is one of the best approaches for reaching the collateral trigone the posterior part of the body, atrium, and the glo- mus of the choroid plexus. It has been used to reach vascular malformations in the trigone, as well as tumors. I have effectively used this approach to resect tumors that extend into the atrium or posterior body from the thalamus. In one case, a 15-year-old boy underwent an aggressive resection of an intraventricular anaplastic astrocytoma that originated in the thalamus (Fig. 5). He experienced improvement in his premorbid neurological status and neuropsychological function.

Postoperative cortical damage manifested by a visual field cut can occur if the medial wall of the atrium adjacent to the calcarine cortex is injured; however, the cortical incision is high enough to avoid the optic radiations in most cases (Fig. 5 lower right). The superior parietal transcortical approach is more risky in the dominant hemisphere. The risks include apraxia, acalculia, visual spatial distortion, and Gerstmann syndrome. Because the vascular supply to the tumor is deep, circumnavigating the tumor may require retraction that can be deleterious to the superior parietal lobule. This operation can be performed safely in the dominant hemisphere when performed using minimal retraction of a relatively avascular tumor. Sugita and Hongo have reported using the parietal transcortical approach to remove 43 third ventricle tumors without causing Gerstmann syndrome or any other significant neuropsychological deficits; 20 of these operations were performed in the dominant hemisphere.

The patient is placed in the three-quarter prone position with the parietal boss in the most superior position and the face turned toward the floor. The cortical incision is performed on the long axis of the superior parietal lobule with the trajectory directed toward the atrium; it is made high enough to avoid the optic radiations and posterior enough to avoid language encoded at the junction of the partial and temporal lobes. The lateral posterior choroidal artery, which can be uncovered in the choroidal fissure between the pulvinar and the crus of the fornix, must be isolated and secured.

**Occipital Incision or Lobectomy.** This approach is best suited for tumors found in the posterior medial aspect of the atrium, in the region of the choroidal fissure between the crus of the fornix and pulvinar, or in the bulb of the corpus callosum. It is also appropriate to expose large tumors for which an occipital lobectomy will be required. This is not a good approach for removal of tumors situated in the temporal horn or frontal horn. In the last 5 years, I used this approach once to remove a metastatic ependymoma that arose from the posterior horn of the lateral ventricle and left tumor nodules in several locations within the occipital lobe. To achieve local control, I removed the occipital lobe filled with tumor, which simultaneously provided access to the posterior horn of the lateral ventri-
The true incidence of cortical incision–related postoperative epilepsy is hard to determine because there are many factors that can contribute to a seizure disorder, including the tumor histological type, presence of preoperative seizures, presence of residual tumor, subdural hygroma, and electrolyte imbalance. Any patient who undergoes a craniotomy or has his/her cortex broached is at risk for postoperative seizures. Rates of postoperative seizures have been noted to be as low as 19% in a recent study and as high as 75% in a study reported in the premicrosurgical age. It is difficult to isolate surgical technique accurately in the various studies and arrive at an incidence of transcortical incision–induced postoperative epilepsy. In our recent series at 1-year follow up, we found an incidence of 6.8% of persistent postoperative epilepsy that required medication.

Postoperative neurological deficits include hemiparesis and language deficits. A mild to moderate hemiparesis is not uncommon when a large trigone or ventricle body tumor is excised via a middle fossa transcortical approach. Most weakness is presumably the result of retraction pressure and will resolve; however, the incidence of permanent motor loss has been reported to be as high as 30% in some series. Language impairment is a possibility when the tumor is based in the dominant hemisphere. In such cases approximately 10 to 30% of patients will suffer a new speech deficit or worsening of their preoperative deficit. Cognitive deficits and personality disorders are much more difficult to quantitate, especially if preoperative neuropsychological studies are not conducted. It is wise to leave tumor, especially if it is attached to critical structures such as the basal ganglia or fornices, and particularly if the lesions is benign. Incomplete mass lesion removal occurred in 19 to 50% of patients in published series and in 20.7% in this series. It is clear in this series and previous ones that the incomplete resections are a result of the tumor histological type and its site of origin, as opposed to the surgical approach.

Subdural hygroma formation is a well-recognized problem, especially in patients in whom an enormous tumor is associated with ventriculomegaly. This is especially true in pediatric series in which large choroid plexus neoplasms and hydrocephalus are treated. The cortical surface may fall or pull away from the dura and create a hematoma or hygroma, which may eventually require the placement of a shunt. In their 1989 series of transcortical approaches to intra- and periventricular tumors in 38 patients, Tanaka, et al., found that persistent subdural fluid accumulations developed in 24% of the patients; 11% required surgical treatment. Patients with preoperative hydrocephalus and those who underwent a transfrontal approach were at greatest risk. Filling the ventricles with sterile saline or lactated Ringer solution before the completion of the surgery and leaving both subdural and intraventricular catheters in place may reduce the incidence of hygroma and hydrocephalus. In a report published in 2000, the authors demonstrated that placement of fibrin glue over the cortical surface significantly decreased the rate of subdural fluid collections. In addition, I position the patient with his/her operated side down for the first 8 hours to lessen the chance that a greater amount of cortex will pull away from the dura and skull. Postoperative ventriculomegaly is common. Not all patients will require placement of a shunt, however, because the ICP measured by ventricular catheter may be normal or even low after a large tumor is excised. The number of
patients requiring a shunt will vary based on different factors. Approximately 10 to 50% of patients will ultimately require CSF diversion.\textsuperscript{9,13,37} In this series, the majority of the patients who needed CSF diversion harbored a choroid plexus carcinoma. A total of 50% of the patients with choroid plexus carcinoma required CSF diversion, but only 10.3% of the overall patients in this series required placement of a shunt.

All patients may suffer some form of meningeal irritation caused by the presence of blood products in the CSF. This type of chemical meningitis can be treated by administering analgesic agents and a tapered course of steroid medication. In most series the authors report rates of infection of less than 5%.\textsuperscript{37}

Mortality rates associated with the removal of lateral ventricle tumors vary depending on the period in which the surgery was conducted. Prior to the advent of microsurgical techniques, the mortality and morbidity rates were higher than those of the present day.\textsuperscript{16} In early studies the authors reported mortality rates as high as 75%, mostly because result of intraoperative hemorrhage or cerebral edema. Exsanguination probably contributed to the poor outcome and high mortality rate in early series of children in whom choroid plexus tumors were excised.\textsuperscript{38} In the more modern series the authors have recorded mortality rates far lower than 10%. The deaths in the microsurgical era are usually secondary to catastrophic postoperative hemorrhage or pulmonary embolus.\textsuperscript{1,10,18,19,30,31,34,37,40} Nonetheless, even with our current technology a flexible surgical approach is important. A staged removal of a very large, vascular lesion via combined approaches is preferable to a single, long, difficult procedure.

**Complication Avoidance**

Many maneuvers can be easily used to try to avoid complications when removing these deep-seated tumors. The operative time for excision of tumors in the lateral ventricle can be long and the procedure can be tedious; therefore, patient positioning is important. All dependent parts should be padded, meticulously avoiding nerve stretch or compression injuries. The pneumatic sequential pressure hose or similar antiembolic precautions should be used. Although these operations do not require placement of the patient in the sitting position, air embolus can occur in both the prone and supine position, especially because the head may be elevated to decrease ICP and improve venous drainage.\textsuperscript{45}

Cortical incisions are made in the gyri and not the sulci, except in isolated cases when the latter is more appropriate. They should be sufficiently sized to allow removal of large tumors in a piecemeal fashion and to control bleeding at the edges of the tumor margin. Excessive retraction is avoided by working only within the field of view, moving the microscope to avoid manipulating important neural elements, and periodically releasing the retractor tension. In general, it is best to secure the vascular supply early.

As a general principle, the number of veins sacrificed during a transcortical approach should be kept to a minimum. Sacrifice of both deep and superficial veins can cause inconstant deficits, which have been reported as severe by some surgeons and inconsequential by others. This is a controversial neurosurgical issue. The variation in outcome may be the result of differences in individual anatomy. Dandy\textsuperscript{8} claimed that one internal cerebral vein can be sacrificed without effect, and, occasionally, even the great vein of Galen has been ligated without causing death. Other surgeons have found this observation to be incorrect. I make every effort to avoid sacrificing any vein unless it clearly compromises access to the ventricular mass. In my experience flow in one internal cerebral vein was inadvertently lost when removing large tumors from the third ventricle; however, the patient suffered no catastrophic neurological event. I coagulate and divide some superficial cortical veins during approaches to the lateral ventricle, but major draining structures such as the vein of Labbé and large bridging veins are maintained to avoid venous infarcts.

All patients should be monitored in an intensive care setting for at least 24 hours and should undergo MR imaging or contrast-enhanced and noncontrast CT scanning within 72 hours to assess ventricular size and tumor residual. Repeating the neuroimaging study in a week is useful for assessing the presence of extracerebral fluid collections. It is useful to remove the external catheters/drains as soon as possible and to mobilize the patient. Patients with persistent ventriculomegaly or subdural hygroma are monitored longer and receive antibiotic therapy for as long as a drain is in place. Adequate levels of anticonvulsant agents are monitored at regular intervals and electrolyte imbalance is aggressively treated.

**CONCLUSIONS**

The potential for complications in the operative treatment of lateral ventricular tumors is relatively high regardless of the surgical approach. Nevertheless, the potential for maximal tumor resection and a good outcome is equally high with that of a transcortical approach. Because callosal sectioning is not associated with postoperative neuropsychological sequelae or seizure disorders, this route is both attractive and appropriate for many patients.\textsuperscript{3,41} Tumors in the lateral ventricle, however, cannot be reached without some form of cortical incision.

In the microsurgical era, the sequelae of a cortical incision are minimal for most patients. The true frequency of postoperative complications must be gauged in the context of the preoperative condition and the surgical alternatives. The transcortical approach is a powerful alternative that permits access to all five regions of the lateral ventricle via one or a combination of approaches (Table 4). The field of view in these operations can be quite extensive compared with those provided by transcalsoscal operations. The informed selection and judicious application of each approach will provide a very favorable risk–benefit ratio. A flexible surgical approach is important; a staged removal of a large vascular lesion by performing a combination of techniques and approaches is preferable to a long, difficult single procedure.

The application of ultrasonography, endoscopy, and evolving stereotactic and intraoperative imaging technology has certainly contributed to the success of the transcortical removal of tumors in the lateral ventricle. Improved understanding of retraction pressure, micro-
surgical technique, cortical function, epilepsy mediation, and neuropsychological sequelae of surgery have made this approach safer.

In general, the transcortical approach to deep-seated lesions is an elegant alternative and effective way to approach lesions in the lateral ventricles. In selected circumstances, such as in patients who harbor a tumor in association with significant hydrocephalus, a mass in the temporal horn, atium, or underthinned cortex, a transcortical approach is the most appropriate route and should therefore be in every neurosurgeon’s armamentarium.

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