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Surgical approaches to tumors of the lateral ventricle

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Tumors of the lateral ventricle comprise between 0.8% and 1.6% of all brain tumors and occur more commonly in children [1–3]. They are considered "primary" intraventricular tumors when they develop from the ventricular lining (ie, the ependyma and subependymal glia), from the epithelium of the choroid plexus and its arachnoid supporting tissue, or from misplaced tissue. They are "secondary" or paraventricular tumors when they develop from the brain parenchyma and more than two thirds of their surface bulges into the lateral ventricle [3]. The most frequent lateral ventricular tumors are ependymoma, astrocytoma, choroid plexus papilloma, and meningioma. Less common tumors in this location are subependymal giant cell astrocytoma, oligodendroglioma, subependymoma, pilocytic astrocytoma, neurocytoma, choroid plexus carcinoma, teratoma, choroid plexus cyst, xanthogranuloma, hemangioblastoma, cavernous malformation, epidermoid, metastatic carcinoma, and primary melanoma [2]. Although malignant tumors are encountered occasionally, most tumors of the lateral ventricle are histologically benign or have slow growth potential [1].

The clinical manifestations of lateral ventricular tumors are most often a consequence of the hydrocephalus they produce, either by obstruction of the normal pathways of cerebrospinal fluid (CSF) flow or by its overproduction rather than from compression of eloquent or autonomic regions of the brain [1]. Because they often grow to a considerable size before they reach clinical attention, the best treatment option for these tumors is invariably surgery [3].

Any one or a combination of surgical approaches can be used for lateral ventricular tumors. Because a variety of eloquent structures surround the lateral ventricles, surgical approaches to tumors in this region must address their relatively deep location in the brain, appropriate pathways through the surrounding neural structures, the large size of the tumors, their vascular supply and drainage, and the presence or absence of hydrocephalus. Historically, the transcortical approaches have been favored over the interhemispheric routes by many surgeons [1–3]. More recently, however, the interhemispheric transcallosal approaches have become more popular in that no cortical brain tissue has to be violated to provide direct access to the ventricular system [4–6]. In general, for tumors in the anterior portion of the lateral ventricles, either an anterior interhemispheric transcallosal approach or a frontal transcortical approach is used. Approaches to more posterior intraventricular tumors include the transcortical temporal or superior parietal lobule approach and the posterior interhemispheric transcallosal approach.

Common clinical presentations

Overall, intraventricular tumors are more common in children than in adults, accounting for approximately 3% of adult brain tumors and 16% of childhood and adolescent brain tumors [7]. Half of the intraventricular tumors in adults and one quarter of the intraventricular tumors in

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children are found in the lateral ventricles [3]. Although tumors in the lateral ventricle present in either gender at any age, there is a slight male predilection and a definite trend toward the younger population, with the average patient age at presentation typically between 20 and 30 years [1–3].

Because of their location and their often benign character, tumors of the lateral ventricle tend to grow quite large before they become clinically apparent. As these tumors grow slowly within the ventricular space, they either obstruct normal CSF flow, leading to hydrocephalus and resulting signs and symptoms of increased intracranial pressure (ICP), or they compress the adjacent structures, causing a focal neurologic deficit. The most frequently seen clinical symptoms and signs are papilledema (42.9%), headache (35.7%), motor disturbance (25%), sensory disturbance (25%), nausea and vomiting (22.3%), visual field deficit (17.8%), loss of vision (17.8%), and mental status changes (17.8%) [2,3]. Mass effect, either directly from the tumor or indirectly from hydrocephalus, often impairs the fornices and leads to short-term memory loss. Infrequently, intraventricular tumors may bleed spontaneously, leading to acute clinical deterioration. Because of the variable location of these tumors within the ventricular system, however, no stereotypic neurologic or behavioral signs or symptoms can be expected.

Tumors of the lateral ventricles: differential diagnosis

In one of the largest reported series of patients with lateral ventricular tumors (112 patients), the most common pathologic diagnoses were ependymoma (25%), astrocytoma (21.4%), oligodendroglioma (7.1%), choroid plexus papilloma (6.3%), meningioma (5.3%), and subependymal giant cell astrocytoma (5.3%) [2]. These tumors were located throughout the lateral ventricles with the following distribution: frontal horn and foramen of Monro (42.8%), body and septum pellucidum (22.3%), atrium or trigone (19.7%), temporal horn (8.9%), and occipital horn (6.3%). This series is slightly atypical, however, in that several other authors have reported the atrium as the most common location for tumors of the lateral ventricle [1,3,8,9].

The diagnosis of lateral ventricular lesions varies significantly with age and location within the ventricle (Fig. 1). In young children, lateral ventricular neoplasms are most often choroid plexus papillomas or carcinomas, and they typically arise in the trigonal region [10]. If arising from the body of the ventricle in this age group, a primitive neuroectodermal tumor (PNET) must also be considered. Tumors arising in the frontal horn or body of the ventricle in older children are typically low-grade gliomas, including subependymal giant cell astrocytomas, pilocytic astrocytomas, and ependymomas [3,10]. In adults, the most common pathologic diagnoses and locations are central neurocytomas and malignant astrocytomas, both of which localize to the frontal horn or body of the lateral ventricle, and meningiomas, which typically occur in the atrium [3]. The temporal and occipital horns are the least common sites for tumor occurrence within the lateral ventricles [8]. More commonly, the temporal and occipital horns become trapped and encysted by growing neoplasms in the atrium or adjacent brain parenchyma.

Relevant regional anatomy

The lateral ventricles are paired C-shaped structures, each subdivided into the frontal horn, body, atrium (trigone), occipital horn, and temporal horn. Anteriorly, the lateral ventricles communicate with the third ventricle by way of the foramina of Monro; posteriorly, they curve around the thalami and diverge from the midline. In the absence of hydrocephalus, each lateral ventricle has a volume of approximately 8 mL [8].

Each lateral ventricle extends anteriorly from the foramen of Monro into the frontal lobe as the frontal horn (cornu anterius) and extends posteriorly from the foramen over the thalamus as the body of the ventricle (cella media). Once behind the thalamus, the ventricles curve in a lateral and inferior direction and then anteriorly into the temporal lobe as the temporal horn (cornu inferius). The occipital horn (cornu posterius) extends posteriorly from the junction of the body and temporal horn. The triangular expansion of the ventricle between the occipital and temporal horns is known as the trigone or atrium. The atrium thus opens anteriorly above the thalamus into the body of the lateral ventricle, anteriorly below the thalamus into the temporal horn, and posteriorly into the occipital horn [11].

In normal-sized ventricles, the average length of the frontal horn is around 3.2 cm, with approximately 3 to 4 cm of frontal cortex lying anterior to it. The body of the lateral ventricle

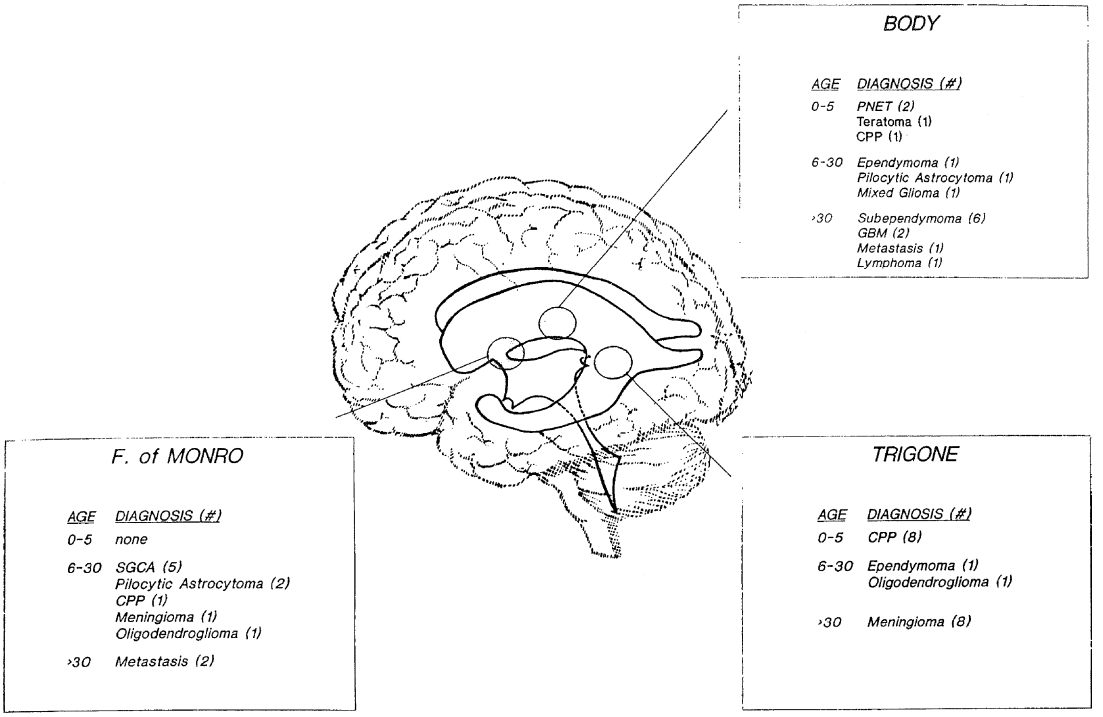

Fig. 1. Anatomic locations and tumor pathology by age group. PNET, primitive neuroectodermal tumor; CPP, choroid plexus papilloma; GBM, glioblastoma multiforme; F, foramen; SGCA, subependymal giant cell astrocytoma. (*From* Jelinek J, Smirniotopoulos JG, Parisi JE, Kanzer M. Lateral ventricular neoplasms of the brain: differential diagnosis based on clinical, CT, and MR findings [Fig. 1]. AJNR Am J Neuroradiol 1990;11(3):567–74; with permission.)

from the foramen of Monro to the trigone spans nearly 4.0 cm, and the anterior-posterior diameter of the trigone adds another 2.1 cm to the overall length of the ventricle. The length of the temporal horn from the trigone averages 4.0 cm, leaving about 2.5 cm of temporal cortex anterior to the ventricle. The occipital horn is the most variable, ranging in size from 0 to 3.4 cm [8].

The septum pellucidum, thalamus, corpus callosum, caudate nucleus, and fornix form the walls of each of the lateral ventricles (Fig. 2). The frontal horns and bodies of the lateral ventricle are separated by the septum pellucidum, a thin, translucent, triangular membrane consisting of two glial laminae with a potential space (cavum) in between [12]. The inferior leaflets of the septum hold the bodies of the fornices, another set of paired C-shaped structures. The fornices originate in the hippocampus on the floor of the temporal horn, pass posteriorly around the thalamus along the anterior wall of the atrium, curve superomedially to travel in the medial wall of the body of the lateral ventricle, and finally separate into two columns that form the anterior and superior margins of the foramen of Monro in their course toward the mamillary bodies.

The head of the caudate nucleus forms the lateral wall of the frontal horn of the lateral ventricle, and the rostrum of the corpus callosum forms the floor medial to the caudate. The medial wall is formed by the septum pellucidum, and the roof is formed by the body and genu of the corpus callosum. At the foramen of Monro, the head of the caudate nucleus is situated laterally, whereas the columns of the fornix curve ventrally and inferiorly to outline the medial and anterior borders of the foramen [11].

The caudate nucleus courses posteriorly to form the lateral wall of the body of the ventricle, and the superior surface of the thalamus forms the floor. The roof of the body of the lateral ventricle is formed by the corpus callosum, and the medial wall is formed by the septum pellucidum above and the body of the fornix below.

The atrium and occipital horn together form a triangular cavity with the apex posteriorly in the

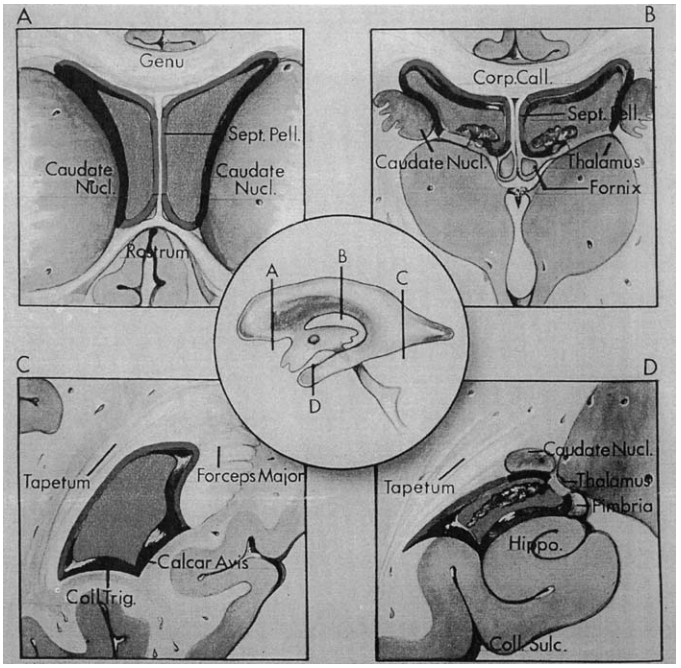

Fig. 2. Structures in the walls of the lateral ventricles. The central diagram shows the level of the cross-sections through the frontal horn (*A*), body (*B*), atrium (*C*), and temporal horn (*D*). (*A*) Frontal horn. The genu of the corpus callosum is in the roof, the caudate nucleus is in the lateral wall, the rostrum of the corpus callosum is in the floor, and the septum pellucidum is in the medial wall. (*B*) Body of the lateral ventricle. The body of the corpus callosum is in the roof, the caudate nucleus is in the lateral wall, the thalamus is in the floor, and the septum pellucidum and fornix are in the medial wall. The choroidal fissure, the site of the attachment of the choroid plexus in the lateral ventricle, is situated between the fornix and the thalamus. (*C*) Atrium. The lateral wall and roof are formed by the tapetum of the corpus callosum, and the floor is formed by the collateral trigone, which overlies the collateral sulcus. The inferior part of the medial wall is formed by the calcar avis, the prominence that overlies the deep end of the calcarine sulcus, and the superior part of the medial wall is formed by the bulb of the corpus callosum, which overlies the forceps major. (*D*) Temporal horn. The medial part of the floor of the temporal horn is formed by the prominence overlying the hippocampal formation, and the lateral part of the floor is formed by the prominence called the collateral eminence, which overlies the deep end of the collateral sulcus. The roof is formed by the caudate nucleus and the tapetum of the corpus callosum, the lateral wall is formed by the tapetum of the corpus callosum, and the medial wall of the temporal horn is little more than the cleft between the fimbria of the fornix and the inferolateral aspect of the thalamus. Call., callosum; Coll., collateral; Corp., corpus; Hippo., hippocampus; Nucl., nucleus; Pell., pellucidum; Sept., septum; Sulc., sulcus; Trig., trigone. (*From* Rhoton AL, Jr. The lateral and third ventricles [Fig. 5.4]. Neurosurgery 2002;51(4 Suppl 1):S207–71; with permission.)

occipital lobe and the base anteriorly on the posterior thalamus [13]. The lateral wall and roof of the atrium are formed by the body, splenium, and tapetum of the corpus callosum, and the floor is formed by the collateral trigone, which overlies the collateral sulcus. The medial wall is formed by a combination of the calcar avis inferiorly and the forceps major superiorly.

The superior and lateral walls of the temporal horn are formed primarily from the tail of the caudate nucleus and the tapetum of the corpus callosum. The bulge of the hippocampus lies in the floor of the temporal horn, and the only structure in the medial wall is the choroidal fissure.

Once the lateral ventricle has been entered, certain landmarks are usually visible and should be identified if not obstructed by tumor (Figs. 3 and 4). The characteristic white smooth ependymal surface is lined with veins that serve as guidelines for the surgeon's orientation. The thalamostriate vein, coursing in a groove separating the caudate nucleus from the thalamus, joins the septal vein to form the internal cerebral vein just proximal to the foramen of Monro beneath the choroid plexus. The choroid plexus lying within the choroidal

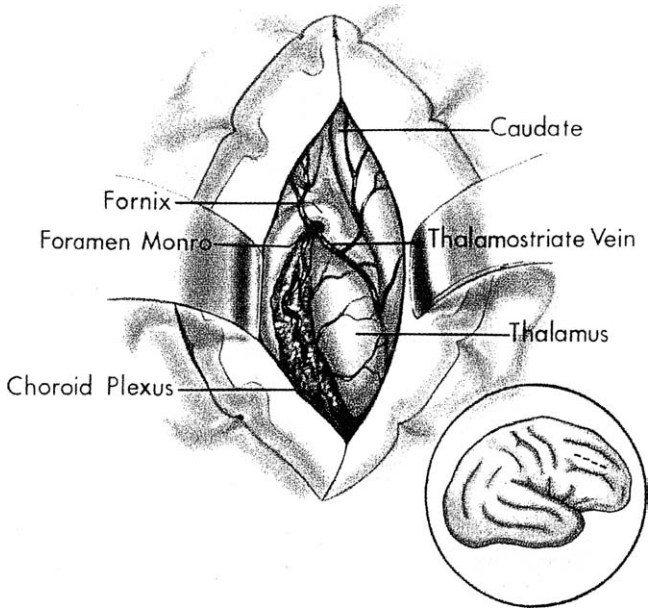

Fig. 3. Frontal transcortical approach into the right lateral ventricle. This opening exposes the caudate nucleus, fornix, foramen of Monro, thalamus, thalamostriate vein, and choroid plexus. The inset on the lower right shows the site of the cortical incision. (*From* Rhoton AL, Jr. The lateral and third ventricles [Fig. 5.25]. Neurosurgery 2002;51(4 Suppl 1): S207–71; with permission.)

fissure is arguably the single most valuable intraventricular landmark for the neurosurgeon.

The choroid plexus runs parallel and lateral to the fornix and is attached by the taenia at the choroidal fissure, which lies between the fornix and the thalamus. The choroid plexus is thus found in the medial aspect of the body, atrium, and temporal horns of the lateral ventricles. It courses anterior and inferior through the foramina of Monro to lie in the roof of the third ventricle. The glomus is a prominent tuft of choroid plexus found in the atrium. From the atrium, the choroid plexus extends forward and inferior into the temporal horn, where it terminates immediately posterior to the amygdala. The arterial supply to the choroid plexus derives from the anterior and posterior choroidal arteries, which, in turn, arise from the internal carotid and posterior cerebral arteries, respectively. The choroidal arteries enter into the choroid plexus through the choroidal fissure.

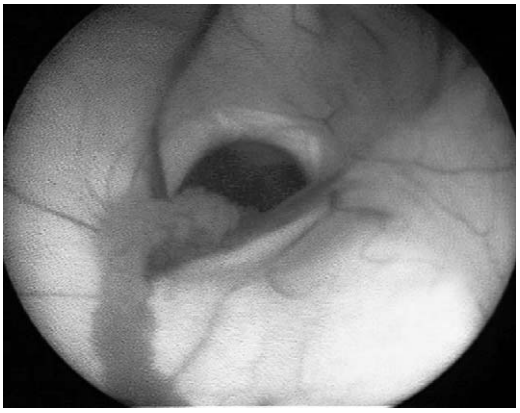

Fig. 4. Intraoperative photograph exposing the right lateral ventricle with the caudate nucleus, fornix, foramen of Monro, thalamus, thalamostriate vein, septal vein, and choroid plexus.

The venous drainage of the ventricular system consists of the symmetric, midline, bilateral, internal cerebral veins formed by the thalamostriate and septal veins on each side. The internal cerebral veins help to define the floor of the lateral ventricles and roof of the third ventricle as they course from anterior to posterior to join and form the vein of Galen.

Most lateral ventricular tumors receive their blood supply from the anterior and posterior choroidal arteries. Tumors situated in the body of the lateral ventricles derive most of their blood supply from the posterior lateral choroidal arteries.

Tumors of the temporal horn are supplied primarily by the anterior choroidal artery, and tumors of the atrium usually derive their supply from both branches. In addition, supply from the lenticulostriate arteries or from penetrating branches can occur in tumors originating from the floor or wall of the lateral ventricle. Most ventricular tumors have venous drainage toward the deep cerebral veins via dilated subependymal branches [2].

Operative intervention

Preoperative considerations

MRI is the preferred modality for preoperative evaluation because it provides the best three-dimensional images of the tumor and the surrounding neurovascular structures. It can also give clues regarding the vascularity of the tumor. CT provides reasonable detail when MRI is contraindicated, and areas of calcification or hemorrhage are more easily seen with CT. In select cases of large intraventricular tumors, angiography may be helpful to provide more detailed information about the vascular supply of the lesion [3] and to provide the opportunity for preoperative embolization. The absence of either large dural feeding vessels or dedicated tumor vessels often makes superselective embolization impossible, however, and risks injury to the anterior and posterior choroidal arteries supplying eloquent areas of the brain.

A number of adjuncts for preoperative and intraoperative planning that have facilitated removal of intraventricular lesions previously thought to be resectable only with considerable morbidity have become available during the last several years [14,15]. Frameless stereotactic guidance systems allow precise localization of the tumor, which permits the surgeon to choose an approach to the lesion that minimizes manipulation of functionally critical cortex, targets vascular pedicles, and potentially increases the safety of aggressive tumor removal. Critics of these systems argue that the accuracy and resolution of tumor position and size are compromised if the brain is retracted, diuretics are used, or the brain shifts with tumor removal. The ventricular system, however, is deep, based on the midline, and less likely to shift than other areas of the cortex [14,15]. Moreover, technical developments linking stereotactic systems with real-time intraoperative ultrasound may improve accuracy and curtail these limitations. Regardless, these stereotactic systems are helpful not only in determining the margins of otherwise poorly defined tumors but in aiding the planning of surgical approaches, designing limited craniotomies, and avoiding eloquent cortex or vascular structures.

It is important to consider the operative position of the patient at the time of the localizing study, because "standard" fiducial placement can lead to difficulty in perioperative registration and poor intraoperative accuracy. If the prone or lateral position is to be used, for example, standard fiducial markers across the front of the head often cannot be seen by the navigation camera, which leads to increased registration time, fiducial marker omission, and decreased accuracy. Furthermore, fiducials placed on the back of the head are more mobile and are often distorted when the patient lies supine in the headholder at MRI, also leading to decreased accuracy. Careful preoperative placement of fiducials across the vertex or appropriate side of the head, however, usually leads to quicker registration and increased intraoperative accuracy. It is often necessary to shave small areas of hair for fiducial placement, and we always mark the center and edges of the fiducials with a marker in case they move before coregistration. Of note, the appropriate side of the head may not always be the operative side of the head; if an interhemispheric approach is used and the patient is positioned lateral with the tumor side down and the head angled 45° to the floor so that the falx holds up the cortex, optimal fiducial placement may be on the side of the head contralateral to the tumor.

As previously mentioned, ultrasound is another tool that is becoming more useful during surgery. Ultrasound provides real-time feedback on the location of the lesion, which avoids problems with intraoperative brain movements that limit the accuracy of stereotactic techniques after the tumor resection has been initiated. Other intraoperative techniques that are increasingly popular with temporal approaches include cortical stimulation and functional language mapping.

Intraoperative considerations

Common features of the surgical preparation include insertion of a urinary drainage catheter, an arterial line, and in cases where significant blood loss is anticipated, a central line and sizable peripheral intravenous lines to facilitate expeditious replacement of blood and clotting factors if

needed. Mild hyperventilation (to a pCO_2 of 30–35) is used if increased ICP is a concern. Prophylactic antibiotics are administered 30 minutes before skin incision and repeated every 4 to 6 hours during the procedure. Corticosteroids and anticonvulsants are also given during surgery and continued after surgery.

The positioning used for resection of lateral ventricular tumors is commonly supine or lateral decubitus, depending on the operative trajectory. Occasionally, the prone position is used for posteriorly located lesions. A three-pinhead fixation device is generally used for adults and children older than 2 years, whereas a horseshoe headrest is commonly used in younger patients. Care must be taken to avoid excessive tightening of the headholder, because this can lead to iatrogenic skull fractures and CSF leaks in younger children. Attention must also be given to padding all potential pressure points and avoiding extremes of neck rotation or flexion, which may place traction on the brachial plexus or cause compression of the jugular veins.

If frameless stereotactic guidance is to be used, the device is registered to the patient's craniofacial surface anatomy and any fiducial markers that may have been placed during preoperative MRI. Stereotactic guidance allows the skin incision and craniotomy to be tailored to the specific approach.

To avoid shaving large areas of the head, we routinely shave 1- to 2-cm wide strips of hair along the planned incision line. The incision line is marked, and routine skin preparation is conducted, including a 5-minute prescrub with an antibacterial soap and formal povidone iodine (Betadine) preparation. The skin incision is determined by the location of the lesion and is discussed in the section on specific operative approaches. After formal draping, 0.5% local anesthetic with 1:100,000 epinephrine is infiltrated along the incision line. If operating on a small child, the local anesthetic can be diluted accordingly (maximum dose is 1 mL/kg of 0.5% anesthetic). Although not necessary in the adult population, we perform the incision in layers in children, using a number 15 blade to incise the skin and a needle tip cautery to incise the dermis, galea, and periosteum. Although care must be taken to avoid thermal injury to the skin, this approach facilitates scalp exposure with minimal blood loss, and skin clips are rarely required. The scalp flap is then reflected subperiosteally. To achieve low-profile scalp retraction, we commonly set up the Greenberg retractor system and use skin hooks with rubber bands affixed to the bars to retract the skin edges. The craniotomy site is determined by the location of the tumor and is discussed with specific approaches elsewhere in this article. Burr holes are made, and the underlying dura is carefully stripped using a ball-ended or other blunt dissecting instrument. The burr holes are then connected using a small craniotome bit (eg, Midas Rex B5 drill bit, Medtronic, Fortworth, TX), and the bone flap is removed. Bone edges are waxed, and epidural bleeding is controlled with surgical and 4-0 tenting sutures if needed.

If the dura is tense, mannitol (up to 1 g/kg) can be used to help reduce ICP and prevent brain herniation on dural opening. In young children, we prefer to use boluses of thiopental (starting at 5 mg/kg up to a maximum of 10 mg/kg) rather than mannitol to reduce perioperative fluid and electrolyte shifts and to minimize the reduction in brain volume after resection of large tumors. Dural opening depends on the location of the craniotomy and is discussed with each specific operative approach elsewhere in this article. When possible, we prefer to use linear dural openings to reduce the chances of outward brain herniation in the setting of increased ICP and to facilitate dural opening and closing. The dural edges are reflected using 4-0 silk sutures attached to hanging mosquito clamps, and the brain surface is protected using Surgicel (Johnson and Johnson, New Brunswick, NJ), Telfa (Kendall, Lynn, MA), or cottonoids.

For intraventricular tumors, the most direct trajectory to the lesion is usually appropriate. At this stage, stereotactic or ultrasonic localization can be helpful to guide the cortical incision. Once the entry site has been selected, a 3- to 4-cm pial surface is coagulated and incised. Although some surgeons prefer a transsulcal approach, we generally enter the cortex through a gyrus to avoid injury to sulcal vessels. The corticectomy is deepened through the gray and white matter until the ventricle is reached. It should be possible to identify the ependyma without rupturing it. It will appear darker and more blue than the adjacent white matter. Careful dissection of the white matter overlying it should be continued with the sucker until the ependyma is exposed over the full length of the cortical incision. Before incising the ependyma and entering the ventricle, all bleeding points on the walls of the cortical incision are controlled with cautery and the walls are protected with Surgicel and cottonoid strips. In many cases, the cortical mantle is stretched quite thin from chronic ventriculomegaly and the ventricle

is entered quickly. The length of the cortical exposure is extended as needed, and self-retaining retractors are placed to provide adequate exposure of the tumor.

Familiarity with multiple-arm self-retaining retractor systems is essential. We routinely use the Greenberg retractor system because of its independently functioning components. We have found that at least three separate retractors are needed to expose deep intraventricular lesions optimally. The retractor blades are placed just within the ventricle using a curve at the tip of the blade to lift the brain from its collapsed position. The retractors should be adjusted so that the brain is simply being supported and not forcibly retracted.

After ventricular entry, cottonoids are placed behind the tumor over the dependent portion of the ventricle to avoid letting blood or tumor fragments travel into the remaining ventricular system. For highly vascular intraventricular tumors, it is important to avoid attempts at resecting the tumor until the arterial supply has been coagulated and divided. If the large size of the tumor precludes early control of the vascular pedicle, we routinely use bipolar cautery along the capsule to devascularize progressively and shrink the tumor until it can be mobilized away from its feeding vessels. Tumors can then be debulked using cautery and microscissors, removing the tumor in lobules or with an ultrasonic aspirator. The tumor should be gently delivered by piecemeal dissection, allowing complete removal through a small cortical incision. En bloc tumor removal increases the surgical morbidity [2]; piecemeal removal reduces the tumor in size so that it can be mobilized to expose the vascular supply and removed. Frozen specimens are sent to the pathologist for preliminary identification of tumor type.

After the tumor has been resected and preliminary hemostasis has been achieved, the ventricle should be gently filled with saline and emptied several times to seek any bleeding vessels from the walls of the ventricular system. Furthermore, a Valsalva maneuver can be performed to confirm that the field is dry. Minor bleeding from the walls can often be controlled with serial packing of cotton balls or cottonoids. The remainder of the ventricular system is then inspected to be certain that large blood clots or tumor fragments have not accumulated in remote sites. The cavity can be lined with Surgicel if needed. Because Surgicel not only complicates postoperative imaging studies but can also potentially become dislodged and obstruct CSF flow, it is avoided if possible. The resection cavity is filled with saline to prevent collapse of the brain after the retractors have been removed.

In most cases, we perform a septal fenestration and leave a ventricular drain in place to drain postoperative blood and debris and allow for emergent CSF diversion in case of hydrocephalus. After exiting thorough a lateral burr hole, the drain is tunneled subcutaneously away from the skin incision and secured to the skin with multiple 2-0 silk sutures. The subdural space should be inspected and irrigated thoroughly to be sure no bridging veins have been torn by collapse of the cortex. The dura is then closed with 4-0 silk sutures or approximated and covered with pericranium or another dural substitute. The bone flap is secured using either titanium plates and screws or 2-0 absorbable sutures if the bone is too thin to accommodate 3-mm screws. The scalp is then closed in layers with absorbable galeal sutures and either staples, nylons, or a running plain gut suture to approximate the skin edges. A sterile dressing and head wrap are applied, usually with a chin strap in children to prevent immediate removal of the head wrap by an agitated child. The ventricular catheter is connected to a drainage bag with a volurimeter.

Postoperative considerations

Patients are monitored in the intensive care unit the night of surgery. Antibiotics are continued for 24 hours after surgery, and corticosteroids are gradually tapered over 10 to 14 days. Antiepileptic medications are continued for at least 1 week after surgery and are then discontinued according to the individual surgeon's preference. Externalized ventricular drainage is weaned over 3 to 5 days by elevating and clamping the drain. After clamping the drain and verifying patient tolerance, head CT is usually done to document the absence of severe hydrocephalus. Although most patients tolerate removal of the ventricular drain, either an endoscopic third ventriculostomy or a shunting procedure may eventually be required to control hydrocephalus. Further postoperative imaging generally consists of MRI within 48 hours to confirm the extent of tumor resection.

Selective surgical approaches

The choice of approach to the lateral ventricle depends on several factors, including (1) localization of the tumor within the ventricle, (2) presence

or absence of hydrocephalus, (3) whether the hemisphere involved is dominant, (4) size of the tumor, (5) origin of the blood vessels supplying the tumor, and (6) histopathologic features. Ideally, the approach chosen should ensure sufficient exposure to permit piecemeal removal of the tumor, allow rapid identification of the supplying vessels so they can be divided promptly, avoid excessive brain retraction, and limit damage to functional cortex. It is impossible to reach a lateral ventricular tumor without opening some neural structures, but some important structures must be preserved during surgery. At the least, these include the Rolandic area, the language area, the fornix at least on one side, the internal cerebral veins, and the vein of Galen [2]. The anterior approaches are the anterior transcallosal, anterior transcortical, and anterior frontal. The posterior approaches are the posterior transcallosal, posterior transcortical, and occipital. The inferior approaches are the temporal and posterior frontotemporal (Fig. 5) [11,13]. Because they are used more commonly, this report focuses on the following approaches: anterior, temporal, and parietal transcortical approaches and anterior and posterior interhemispheric approaches. As with many areas of tumor surgery, the choice of approach has much to do with a particular surgeon's experience with a given approach.

Transcortical approaches

Frontal transcortical (middle frontal gyrus) approach

The frontal transcortical corridor can be used to access large tumors of the frontal horn and the anterior portion of the body of one lateral ventricle (Fig. 6). This approach is also effective for tumors originating in the anterior third ventricle and extending up into one lateral ventricle

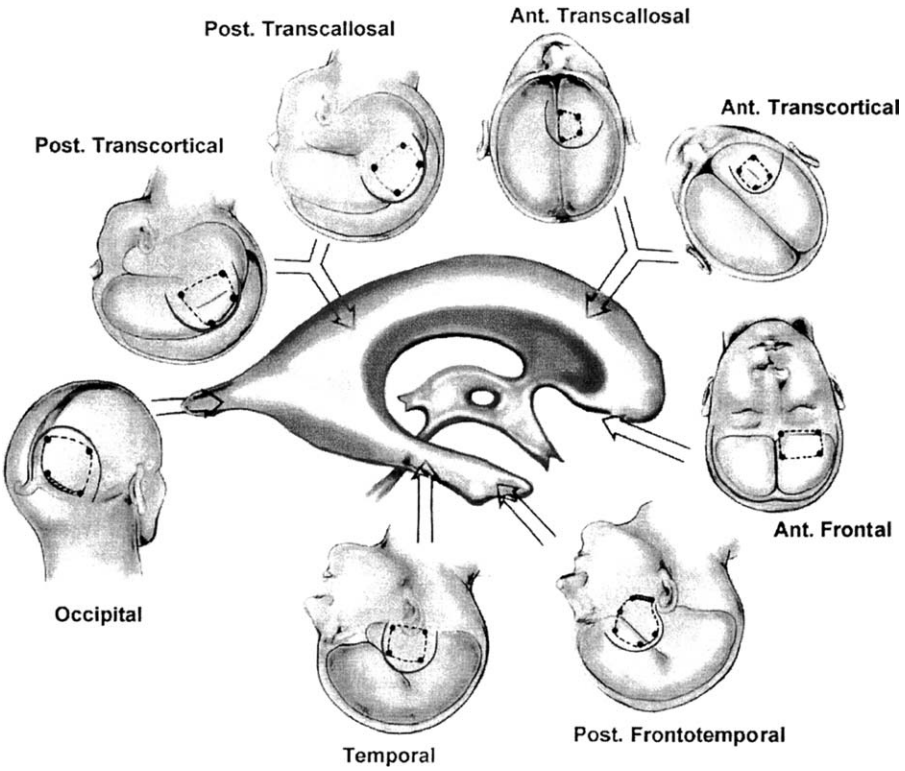

Fig. 5. Surgical approaches to the lateral ventricles. The site of the skin incision (*solid line*) and the bone flap (*broken line*) are shown for each approach. The anterior part of the lateral ventricle may be reached by the anterior transcallosal, anterior transcortical, and frontal approaches. The posterior routes to the lateral ventricle are the posterior transcallosal, posterior transcortical, and occipital approaches. The inferior part of the lateral ventricle can be reached using the frontotemporal and temporal approaches. Ant., anterior; Post., posterior. (*From* Rhoton AL, Jr. The lateral and third ventricles [Fig. 5.21]. Neurosurgery 2002;51(4 Suppl 1):S207–71; with permission.)

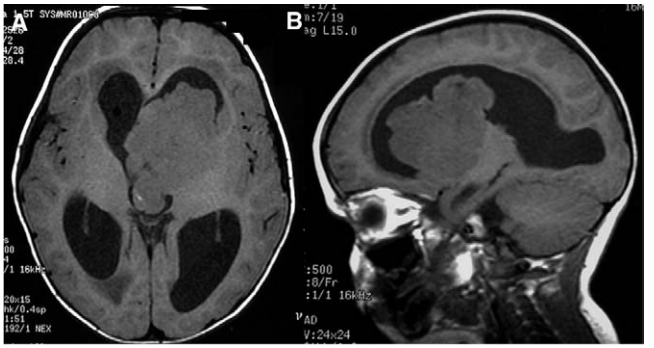

Fig. 6. T1-weighted axial (*A*) and sagittal (*B*) MRI without contrast demonstrates a large mass in the left lateral ventricle that was resected via a frontal transcortical approach.

through the foramen of Monro. This approach is greatly facilitated if there is hydrocephalus or the involved ventricle has been partially obstructed and is enlarged. The primary advantage of this approach is that with large tumors, transcortical exposure provides better access to the tumor than a transcallosal route [3]. Compared with a transcallosal approach, disadvantages of the transcortical approach are that (1) it is more difficult to expose the lateral ventricle on the opposite side and (2) the incidence of postoperative epilepsy after any transcortical approach is higher than after a transcallosal approach [2].

Because the lateral ventricles cannot be entered from a transcortical approach without an incision through the overlying cortex, functional cortex may be injured during the approach. Although a middle frontal gyrus entry is least likely to cause noticeable neurologic injury, transient postoperative attention deficits can result from an incision in the middle frontal gyrus of either hemisphere. A more posteriorly located incision in the supplemental motor or premotor area in either hemisphere can cause transient hemiparesis, and if an incision is made in the dominant hemisphere, transient speech difficulties can occur. A frontal transcortical approach is contraindicated for tumors of the midventricular body because it would involve making a lesion in motor or sensory cortex.

The patient is positioned supine with gentle neck flexion. Either a bicoronal or unilateral curvilinear skin incision is most often employed, and a free bone flap is fashioned. The bone flap is designed with its center slightly anterior to the coronal suture and overlying the middle frontal gyrus, allowing a familiar trajectory to the foramen of Monro. The dura is then opened in a linear, cruciate, or U-shaped fashion with the base medial.

A 3- to 4-cm cortical incision is made along the long axis of the middle frontal gyrus anterior to the coronal suture and well anterior to the premotor gyrus. If available, stereotactic guidance or intraoperative ultrasound can be used to direct the angle of transit to the site of the tumor. Deepening of the corticectomy and placement of retractors are as previously described. Once the medial, lateral, and inferior intraventricular anatomic landmarks have been identified, resection of the tumor can proceed with confidence. The extent of inferior and inferolateral resection of these tumors should be tempered by the knowledge that the subependymal white matter immediately lateral to the foramen of Monro overlies the genu of the internal capsule [13].

Temporal transcortical (middle temporal gyrus) approach

Although the temporal horn and trigonal regions can be approached from the posterior frontotemporal, temporal, or subtemporal route, the approach through the posterior portion of the middle temporal gyrus is preferred by many surgeons, especially for choroidal tumors. Occasionally, an approach through the inferior temporal gyrus is possible if the lesion is small and located primarily in the temporal horn of the lateral ventricle. A temporal transcortical approach is advantageous, because the anterior choroidal vessels can be identified early, coagulated, and divided before internal decompression of the tumor. It offers poor visualization, however, of the posterior choroidal artery. This approach also has the advantage of providing a short trajectory to the lesion. As with all transcortical approaches, the temporal transcortical approach

is greatly facilitated in the presence of hydrocephalus or a trapped dilated temporal horn.

The most common complications associated with a transcortical entry through the middle temporal gyrus are visual field loss from injury to the optic radiations and speech dysfunction, especially if approaching through the dominant hemisphere [9,16]. Despite extreme variability, Haglund and colleagues [17] demonstrated no language localizations below the middle temporal gyrus. Nevertheless, some surgeons use cortical mapping when operating in the dominant temporal lobe, and others argue that these complications can be reduced if an incision through the inferior temporal gyrus is used instead [9]. In addition, choroidal artery territory infarcts can occur if the artery is taken too proximally.

The patient's head is set in the lateral position. An inverted U-shaped incision above the ear or a reverse question mark incision is made, and a temporal craniotomy is performed. The craniotomy should be low enough to expose the floor of the middle fossa, with its posterior extent above the asterion to minimize inadvertent injury to the transverse sinus. The dura is opened in a U-shaped fashion with its base inferiorly or linearly along the middle temporal gyrus. A cortical incision is made in the middle temporal gyrus anterior to the optic radiations. The middle temporal gyrus is then traversed to expose the ventricle and tumor. Some authors advocate a transsulcal incision between the middle and inferior temporal gyri because it reduced hemianoptic complications, with preservation of the superior quadrant fibers, as well as the risk of inducing speech disturbances [9].

Parietal transcortical (superior parietal lobule) approach

The parietal transcortical approach may be used for removal of tumors in the trigonal region or for tumors of the posterior body of the lateral ventricle (Fig. 7). The shortest distance between a trigonal lesion and the surgeon is often transcortical in the parietal cortex. This approach is particularly well-suited for large masses in these regions with associated ventricular dilatation. Compared with the middle temporal gyrus approach, the parietal transcortical approach may be associated with a reduced incidence of language impairment, although this approach does not provide for access to supplying anterior choroidal arteries before tumor removal. The primary limitation of this approach is delayed visualization of the afferent vessels, which can only be controlled once the tumor has been debulked, because they often lie underneath the lesion [9].

Possible complications of the superior parietal lobule approach are permanent visual field impairment; although the cortical incision is performed away from the optic radiations running lateral and inferior to the trigonal region, large tumors may destroy the ventricular ependyma and infiltrate the white matter so that the optic radiations are damaged during dissection [9]. Furthermore, apraxia and acalculia or a complete Gerstmann syndrome can occur when the lesion arises in the dominant hemisphere [18]. Only rarely, however, is this approach complicated by neurologic deficits [2].

The patient may be positioned prone or lateral decubitus. A linear or U-shaped incision is made, and a bone flap centered over the superior parietal

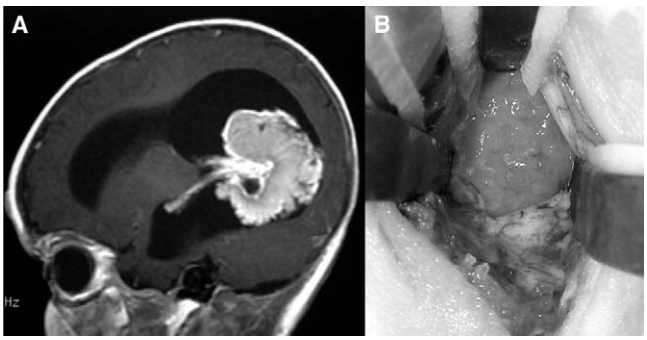

Fig. 7. (*A*) T1-weighted sagittal MRI with contrast demonstrates an enhancing mass in the posterior lateral ventricle that was resected via a parietal transcortical approach. (*B*) Intraoperative photomicrograph demonstrating the surgeon's view of the exposed lateral ventricle and tumor. Note the use of three self-retaining retractors for optimal exposure.

lobule is removed above the lambdoid suture. A dural opening is made, followed by a cortical incision through the superior parietal lobule into the ventricle. The corticectomy is made medial enough to avoid the optic radiations and anterior enough to allow access to the floor of the body of the lateral ventricle but well behind the sensorimotor cortex. Self-retaining retractors are then placed to maintain operative exposure.

Interhemispheric approaches

Anterior transcallosal approach

The anterior transcallosal approach may be used to approach tumors of the midbody or anterior horn of the lateral ventricle (Fig. 8) [5]. This approach is preferred if the tumor is small, located near the midline, and does not require excessive hemispheric retraction. Many authors advocate this approach for tumors located in the midbody of the ventricle, because a transcortical approach through the Rolandic area is contraindicated [9]. With small tumors, this approach may be chosen from the opposite site if the tumor lies in the dominant hemisphere [19,20]. Compared with a transcortical route, it offers the advantages of (1) easy access to both lateral ventricles (which may be difficult to achieve using the frontal transcortical route) and (2) the absence of a cortical incision, reducing the incidence of postoperative seizures. Furthermore, the transcallosal approach is easier to perform than the transcortical approach if the ventricles are of normal size or only minimally enlarged [2,20,21]. If entry into the third ventricle is required, although a transcortical approach allows only a transchoroidal entry, a transcallosal approach allows either an interforniceal trajectory or a transchoroidal entry.

The complications of interhemispheric transcallosal approaches to the ventricles are well reported and include hemiparesis, aphasia, mutism, confabulation, memory deficits, astereognosis, and alexia without agraphia [5,6,20,22]. Entry into the lateral ventricles through an interhemispheric approach cannot be achieved without a callosal resection. There is substantial evidence from the study of patients with sections of their cerebral commissures that the tracts of the corpus callosum have an essential role in the transfer of sensory information from one cerebral hemisphere to the other [16]. Extensive neuropsychiatric testing has shown that after sectioning of the corpus callosum, patients do exhibit significant deficits in tests designed to demonstrate interhemispheric transfer of tactile information [23]. Even when callosal sections have involved the entire body of the corpus callosum, with preservation of the genu and rostrum, the immediate and long-term effects of surgery have not been disconcerting, however [23]. There is no change in the patient's ordinary behavior, and the patients do not appear to suffer any inconvenience from this subtle incapacity [23]. Furthermore, when dividing only the anterior third of the body of the corpus callosum, no significant clinical deficits could be demonstrated [5]. The interhemispheric dissection may also result in injury to the bridging veins. The issue of venous drainage is an important one, because excessive venous compromise can lead to venous hypertension and infarction of the basal ganglia and internal capsule [6]. Although we and others have sacrificed bridging veins anterior to the coronal suture without adverse effects [20], we try to preserve all bridging veins whenever possible.

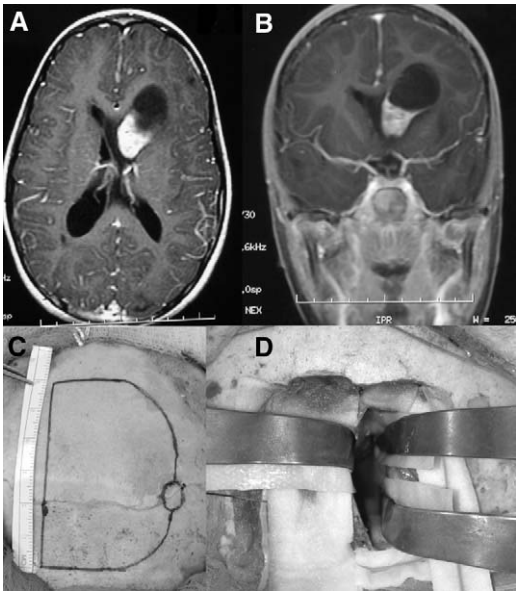

Fig. 8. T1-weighted axial (*A*) and coronal (*B*) MRI with contrast demonstrates an enhancing mass in the left lateral ventricle that was resected via an anterior transcallosal approach. (*C*) Intraoperative photograph demonstrating the size and position of the bone flap for this approach. (*D*) Intraoperative photograph showing the use of three self-retaining retractors (two laterally and one medially) to establish the interhemispheric corridor.

The patient is positioned supine with the head straight and the neck gently flexed. Either a C-shaped or bicoronal incision is made. Burr holes are made over the midline at the anterior and posterior limits of the craniotomy. An additional burr hole is made over the coronal suture laterally to facilitate dissection of the underlying dura. We commonly make a bone flap that is 3 cm wide and approximately 6 cm in anterior-posterior length, situated two thirds anterior and one third posterior to the coronal suture. This provides a familiar trajectory to the lateral ventricle and foramen of Monro and minimizes the risk of venous infarction from interruption of draining veins from the cortex. A rectangular-, trapezoid-, or half-elliptic–shaped bone flap is then removed. In the pediatric population, we prefer to make the medial cut of the bone flap at the edge of the sagittal sinus to minimize potential occlusion or injury during medial retraction. In the adult population, however, the thicker bone often makes it necessary to cross the midline and expose the entire sinus for an adequate operative corridor. The dura is opened in a U-shaped fashion with its base toward the sinus, taking care not to injure bridging veins in the subdural space. Although we attempt to preserve all medially draining veins, at least one anterior vein occasionally must be sacrificed to allow adequate access to the interhemispheric fissure. The falx-cortical interface is identified, and the interhemispheric plane is developed. Telfa or cottonoid strips are laid down medially and laterally, followed by placement and progressive advancement of self-retaining retractors. We find it optimal to use one retractor blade medially and two laterally to establish an uncluttered operative corridor and prevent excessive retraction on the hemisphere laterally. With the medial retractor blade, a gentle hook is placed at the tip to ensure that the sagittal sinus is not occluded. After the retractors are in place, the operating microscope is used to help identify the glistening white corpus callosum and its associated pericallosal arteries. It is easy to mistake the cingulate gyrus for the corpus callosum, but the former has the typical brown-gray appearance of the cortical-pial surface, whereas the callosum is strikingly white. Once the callosum is identified, cotton balls or rolled cottonoids can be placed at the deep anterior and posterior poles to help maintain hemispheric retraction. The callosum is then traversed over a length of approximately 2.0 to 2.5 cm to allow entry into the ventricular system. To limit the potential for functional injury, the callosal section is performed in the anterior third of the body, sparing the genu [5]. Depending on the location of the callosal incision, the surgeon may enter into the left or right lateral ventricle or into a cavum septum pellucidum. If the anatomy is not excessively distorted from the tumor, orientation can be achieved by identifying the major anatomic landmarks within the ventricle: the choroid plexus, the thalamostriate vein, and the septal vein [5]. Entry into a cavum septum pellucidum may be confusing until the surgeon realizes that no intraventricular structures are present. Regardless of the side of initial ventricular entry, it is generally possible to achieve adequate biventricular exposure by extending the callosotomy or fenestrating the septum pellucidum. Both maneuvers are often needed for lateral ventricular tumors that extend bilaterally via the foramen of Monro. If needed, additional exposure of tumor in the third ventricle can be obtained using either a transchoroidal or interforniceal exposure.

Posterior transcallosal approach

A posterior interhemispheric transcallosal approach may be used to approach tumors of the trigone or posterior body of the lateral ventricle (Figs. 9 and 10). The primary motor and sensory gyri are situated on the cortical surface overlying the body of the lateral ventricle, precluding a transcortical approach. Medially positioned tumors or tumors with blood supply primarily from the posterior choroidal arteries are preferably approached from a posterior interhemispheric approach [3]. Larger tumors of the trigone are not suitable for transcallosal removal, because the tumor itself prevents the hemispheric retraction that is required to effect tumor removal. Some authors insist that in patients with a preexisting hemianopsia, a transcallosal approach must be avoided, because a lesion of the splenium of the corpus callosum can lead to alexia and a syndrome of verbal-visual disconnection (inability to name objects situated in the left half of the visual field) [18,24]. Additional complications of an interhemispheric transcallosal approach have been described previously.

The patient is placed in the lateral decubitus position with the tumor side down and the head elevated 45°. With this method, gravity causes the hemisphere to fall away from the falx once the dura is opened, thus minimizing brain retraction. Alternatively, the prone position can be used,

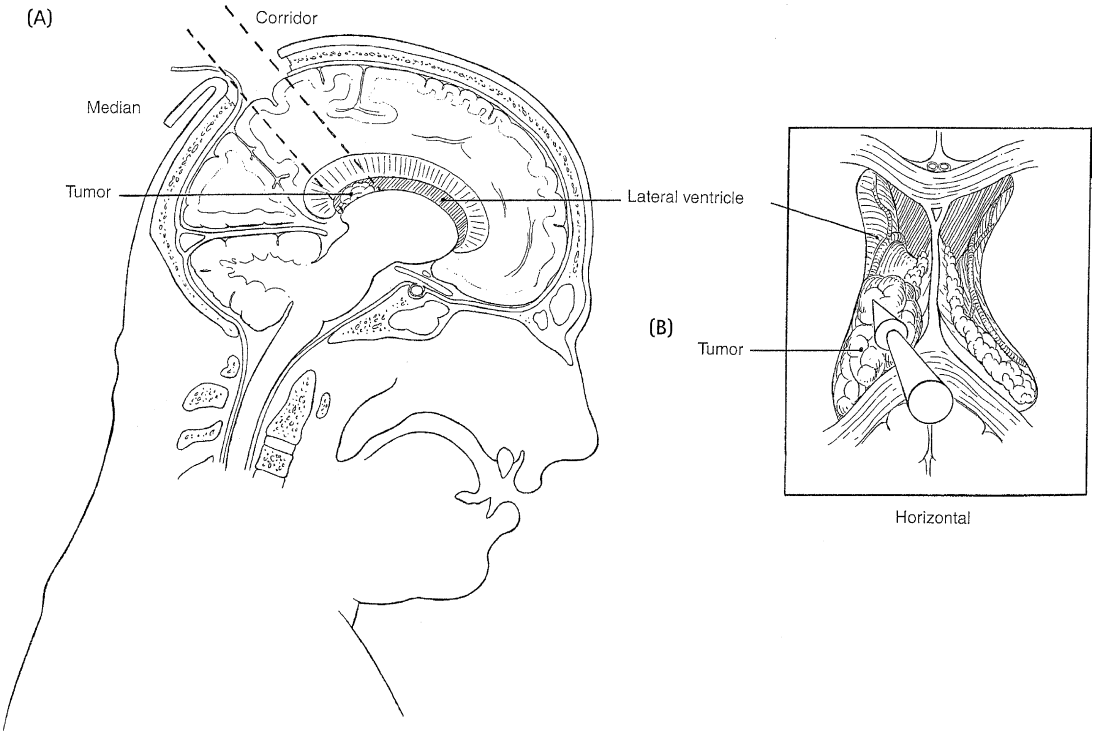

Fig. 9. Illustration of the posterior transcallosal approach. (*A*) The sagittal view depicts the corridor of approach to the posterior corpus callosum. (*B*) View into the lateral ventricle, showing route of entry. (*From* Abosch A, McDermott MW, Wilson CB. Lateral ventricular tumors [Fig. 64.4]. In: Kaye AH, Black P, editors. Operative neurosurgery. London: Churchill Livingstone; 2000. p. 799–812; with permission.)

preserving the orientation to the midline. The incision and bone flap are performed as previously described. The posterior portion of the corpus callosum is resected, but the splenium is preserved to minimize the potential for functional injury [2]. Tumor resection and closure are then performed as previously described.

Outcome and complications

The risks of intraventricular surgery are potentially catastrophic. The relative rarity of these lesions has precluded large series examining postoperative complication rates and the prognosis for recovery. Postoperative complication rates

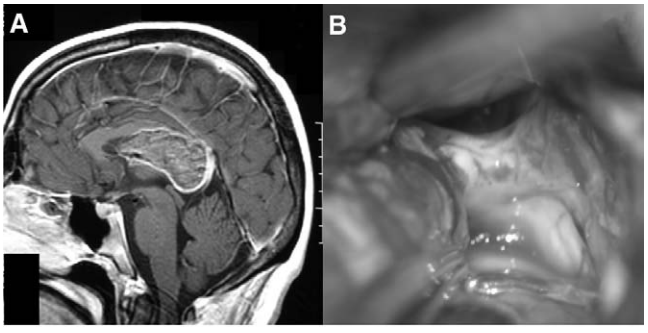

Fig. 10. (*A*) T1-weighted sagittal MRI with contrast demonstrates a large cavernous malformation throughout the body and atrium of the lateral ventricle that was resected via a posterior transcallosal approach with the patient in the prone position. (*B*) Intraoperative photomicrograph showing the surgeon's view into the lateral ventricles from this approach. Both ventricles were widely opened, and the septum was resected with the mass.

vary, but they typically approach 20% [2]. Surgical mortality has decreased tremendously with advancements in microsurgery, falling from 35% in older series [25] to 6% to 10% in more recent series [1–3]. The most common complications are severe brain edema, intraventricular hemorrhage, subdural hematoma, epidural hematoma, and additional neurologic deficits [2]. A review by Piepmeier and colleagues [26] reported rates of occurrence for specific postoperative deficits. The most commonly reported neurologic complications include visual field deficits (20%–64%), hemiparesis (8%–30%), speech deficit (8%–36%), subdural hematoma (11%), seizures (29%–70%), persistent hydrocephalus (12%–33%), and death (12%–75%). As with all craniotomies, the particular postoperative neurologic deficit risked depends on the surgical approach selected (Fig. 11). As previously mentioned, the risk of postoperative seizures has been noted to be higher with transcortical routes than with transcallosal approaches [18], especially in children [23].

Tumors of the lateral ventricles may lead to functional forniceal lesions either directly or as a result of increased ICP. Furthermore, the fornices are often manipulated to some degree with intraventricular surgery. As a result, some patients experience severe memory difficulties [6,27]. Fortunately, this problem is usually transient [16,23]. When the effects on memory were compared between transcortical and transcallosal removal of intraventricular tumors, it was concluded that transcallosal approaches did not seem to be responsible for any increased memory deficits [16].

Because of the deep-seated nature of these tumors, the proximity of eloquent cortex, and the histologic nature of some lesions, gross total removal of lateral ventricular tumors is not always

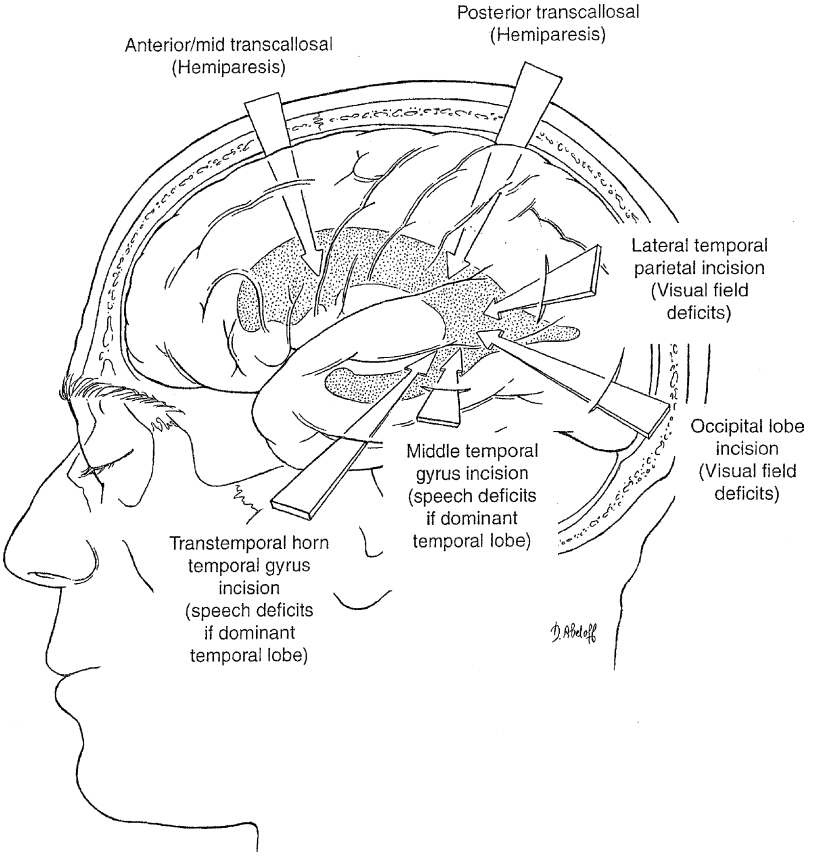

Fig. 11. Illustration summarizing approaches to tumors of the lateral ventricles and some of the potential attendant neurologic deficits. (*From* Abosch A, McDermott MW, Wilson CB. Lateral ventricular tumors [Fig. 64.4]. In: Kaye AH, Black P, editors. Operative neurosurgery. London: Churchill Livingstone; 2000. p. 799–812; with permission.)

possible without unacceptable morbidity. In a large series, total removal was accomplished in 38.4% of lesions, subtotal removal in 56.2%, and biopsy in 2.7% [2]. Fortunately, most intraventricular lesions are benign or of low malignancy, and a complete or even subtotal resection leads to a cure or long survival in most cases [1].

Summary

Lateral ventricular tumors are rare lesions of the central nervous system, and because most tumors are benign or low grade, permanent cure can be achieved with complete removal. After adequate preoperative imaging discloses a lateral ventricular mass, the neurosurgeon has several options to choose from when determining the ideal surgical approach to the tumor. The surgical approach cannot be standardized, because the specific location, size, and vascularization of these deep-seated tumors are fundamental elements influencing the choice of surgical approach. Although access to the lateral ventricles may require additional preoperative considerations and planning, the combination of proper knowledge of the cortical and intraventricular anatomy with the familiarity and selection of an appropriate surgical approach will optimize the surgical outcome.

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