13 Neuroendoscopic and Keyhole Approaches to the Pineal Region

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Abbreviations

CSF	Cerebrospinal fluid
CT	Computed tomography
ETV	Endoscopic third ventriculostomy
FLAIR	Fluid-attenuated inversion recovery
hCG	Human chorionic gonadotropin
MRI	Magnetic resonance imaging
SCIT	Supracerebellar-infratentorial

13.1 Introduction

The pineal region is located deep within the brain and cranial vault, and it is surrounded by a variety of important neurovascular structures. It is bordered by the splenium of the corpus callosum superiorly, the quadrigeminal plate of the rostral brainstem anteriorly and inferiorly, and the pulvinar on either side. The pineal gland is a small neuroendocrine gland and, along with the pituitary stalk, is one of the only midline intracranial structures that is unpaired. It is comprised of pinealocytes, whose primary function is to secrete melatonin directly into the systemic blood circulation [1]. Retinal neurons send information regarding ambient light to the suprachiasmatic nucleus of the hypothalamus; this information is relayed to the superior cervical ganglion of the sympathetic plexus and ultimately to the pineal gland, which regulates day–night cycles and moderates hormonal secretion. Primary disorders of pineal gland endocrine function are extremely rare. However, the region is host to a wide variety of tumors of various pathologies, which brings it to the attention of the neurosurgeon.

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13.2 Rationale

Various approaches to lesions in the pineal region have been extensively described [2–4], each with its own set of advantages and limitations. Historically, the pineal region was most often addressed either with stereotactic biopsy or via open posterior approaches. Most open approaches are achieved with the aid of microscopic visualization. During the past two decades, the endoscope has taken a preeminent role in many areas in neurosurgery, especially in skull base surgery. The endoscope improves illumination and visualization within a deep and narrow surgical corridor, which decreases approach-related morbidity. In the past few years, several groups have described [3, 5] endoscopic posterior approaches to the pineal region. With increased surgeon experience with this novel mode of visualization, the use of endoscopic approaches to the pineal region has transitioned from simple cyst fenestrations and tumor biopsies to large tumor resections and removal of vascular lesions. Because lesions in this area are located deep in the brain, a keyhole approach can offer an exposure that is as good as most traditional approaches. In this chapter, we describe the anatomy of the pineal region, the common pathologies encountered within this space, and the traditional open surgical approaches. We then contrast open approaches with our experience with endoscopic keyhole approaches to the pineal region.

13.3 Patient Selection

Any mass in the pineal region that causes symptoms should be considered for resection. Even a germinoma, which tends to respond well to radiation, can be considered for resection if morbidity can be kept low. Any lesion that has been demonstrated to grow should also be considered for resection, regardless of symptoms. Any pineal region lesion that can be removed through a traditional open suboccipital transtentorial or supracerebellar-infratentorial (SCIT) craniotomy can be also removed through an endoscopic keyhole approach.

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For the SCIT approach, a sitting-slouch position is preferred. However, this position is contraindicated in a patient with a patent foramen ovale in the heart because this condition carries a risk that air emboli will transit the septal defect and embolize to the brain.

Pineal Region Pathology

Among all intracranial tumors, pineal region tumors account for 0.1–1% of lesions in the adult population and for 9% in the pediatric population [6]. Tumors arising from the pineal gland tissue are known as pinealomas, with numerous subtypes depending on the cell of origin. Tumors arising from pinealocytes can give rise to pineocytomas or pineoblastomas. Those arising from glial cells can result in astrocytomas, oligodendrogliomas, or glioblastomas. More commonly, those arising from sequestered embryonic germ cells can give rise to germ cell tumors, including germinomas, embryonal carcinomas, lipomas, choriocarcinomas, teratomas, and yolk sac carcinomas. In addition to primary tumors of pineal origin, other lesions can be found in this location and must be included in the differential diagnosis. Other lesions include metastatic disease, cavernomas, pineal cysts, aneurysms, and meningiomas. Nearly 40% of all asymptomatic adults develop idiopathic calcification of the pineal gland, which can be misidentified as a tumor [6]. Pineal pathologies that can be accessed using an endoscopic keyhole approach include the following:

- Primary pineal tumors (pineocytoma, pineal tumor of intermediate differentiation, pineoblastoma)
- Germ cell tumors (germinomas, embryonal carcinomas, lipomas, choriocarcinomas, teratomas, or yolk sac carcinomas)
- Glial tumors (astrocytomas, oligodendrogliomas, or glioblastomas)
- Lipomas
- Meningiomas
- Pineal cysts

The most commonly encountered pineal region pathology in adults is the pineal region cyst, with some reports indicating an incidence as high as 23% [7]. Often, patients with these lesions are asymptomatic, and the lesion appears stable on repeat imaging. Although it can be tempting to treat these lesions, most patients should be followed with serial imaging. In some cases, a large cyst can result in a mass effect on surrounding pineal region structures, such as the superior colliculi or cerebral aqueduct. At our institution, surgical intervention is offered only when neurological findings, such as obstructive hydrocephalus or Parinaud syndrome, are attributable to the pineal region cyst.

The most commonly encountered pineal region tumors are germ cell tumors, which account for 50–75% of all cases [6]. These lesions occur more frequently in males and are often diagnosed during puberty. Among germ cell tumor subtypes, germinomas are the most common, accounting for 50% of germ cell tumors. Germinomas are often exquisitely sensitive to chemotherapy and radiotherapy. Prior to the availability of safe surgical options, many pineal region tumors were treated with chemoradiation with a presumptive diagnosis of germinoma without tissue confirmation, but this practice is not common today. Patients with nongerminomatous germ cell tumors have less favorable outcomes because these lesions often metastasize early in the course of their growth [8].

Pineocytomas account for 11–28% of primary pineal tumors [9] and have varying degrees of aggressive behavior. Grade 2 pineocytomas are often less aggressive and well circumscribed, with minimal invasion into normal surrounding brain tissue. Conversely, grade 4 pineoblastomas often shed tumor cells within the cerebrospinal fluid (CSF) pathway, and patients may present with distant metastases in the central nervous system. For this reason, patients with pineoblastomas require craniospinal radiation treatment, with close radiological follow-up for assessment of possible distant metastases.

Clinical Presentation and Diagnosis

Clinical features associated with pineal region lesions can vary depending on the endocrine functional status of the tumor, as well as its vascularity, size, and configuration. Large tumors or cysts often present secondary to mass effect on surrounding neurovascular structures. Progressive compression of the rostral interstitial nucleus of the medial longitudinal fasciculus of the midbrain can result in Parinaud syndrome, which is characterized by impaired vertical gaze, eyelid retraction, and pseudo-Argyll Robertson pupils. Cerebral aqueduct stenosis can result in obstructive hydrocephalus, with concomitant gait instability, confusion, and urinary incontinence. Patients with acute hydrocephalus can present with more ominous findings, such as brain herniation, obtundation, and acute loss of consciousness, and they may require emergent lateral ventricular CSF drainage. Patients with friable and vascular lesions can present with secondary extralesional hemorrhage that causes damage to surrounding neurological structures, or they can present with intraventricular hemorrhage and subsequent hydrocephalus. Germ cell tumors can produce human chorionic gonadotropin (hCG), which manifests as precocious puberty in young boys and secondary amenorrhea in young girls.

Radiographic imaging is instrumental not only in constructing a differential diagnosis of pineal region masses but also in planning surgical approaches to the lesion. Basic computed tomography (CT) scans are often the first-line diagnostic study used by general practitioners, and CT scans can provide valuable information on the calcification of pineal region masses, peritumoral hemorrhage, and early obstructive hydrocephalus. Germinomas are often hyperdense to the brain and engulf the native pineal calcification; conversely, pineoblastomas are hyperdense lesions that have peripheral or "exploded" calcifications. Mixed-density lesions are often indicative of teratomas, and gliomas of the tectal region are often hypodense or isodense without calcifications [10].

Magnetic resonance imaging (MRI) is the preferred imaging modality in the identification of pineal region masses, and it is useful in assessing the relationship of the mass to surrounding neurovascular structures. MRI provides poor information for assessing the calcification of the lesion but can provide detailed information to differentiate between primary pineal tumors and para-pineal masses [11]. The pineal gland is a circumventricular organ, and it thus takes up gadolinium avidly; similarly, lesions that arise from pineal gland parenchyma also often demonstrate avid gadolinium contrast enhancement on MRI. Germ cell tumors are often hypointense on T1-weighted imaging and hyperintense on T2-weighted imaging. Teratomas are heterogenous lesions characterized by marked hyperintensity on T1-weighted imaging and several calcified nodules. Pineoblastomas often demonstrate a greater degree of surrounding brain invasion, with irregular or indistinguishable borders as compared to pineocytomas, which are often well demarcated from the surrounding brain tissue [11]. Pineal region cysts are characterized on MRI as round masses with smooth surfaces that are isointense to CSF on T1- and T2-weighted images [12] with minimal edema to surrounding brain tissue on fluid-attenuated inversion recovery (FLAIR) sequences. Vascular lesions can be distinguished from other pineal region masses by using dedicated vascular imaging, with particular attention paid to the venous phase to assess for vein of Galen malformations in young children.

Serum and CSF tumor markers are a valuable component of preoperative evaluation of patients with suspected pineal region tumors. Similar to radiographic studies, these markers can only be suggestive of certain tumor subtypes, but occasionally they provide the clinician with diagnostic information. Germ cell tumors often retain expression of their primordial lineage, and they can express hCG and alpha fetoprotein in both CSF and serum. Although not diagnostic, elevated hCG and alpha fetoprotein can be indicative of an aggressive germ cell tumor, with an elevated CSF-to-serum gradient suggestive of an intracranial lesion. These markers may be most helpful in determining the anticipated response to surgery or radiotherapy or chemotherapy; however, active debate remains in the medical literature about the utility of these diagnostic studies. Ultimately, histopathology remains the gold-standard modality in the diagnosis of pineal region tumors.

13.4 Surgical Anatomy

The pineal region lies at the back of the third ventricle; it is bounded above by the junction of the velum interpositum, with the paired internal cerebral arteries in the roof of the third ventricle, immediately laterally by the posterior and habenular commissures, and further laterally by the pulvinar of the thalamus. The pineal gland rests on the tectum, immediately above the superior colliculi. Dorsally, the vein of Galen and, more posteriorly, the culmen of the vermis of the cerebellum bound the space. For anterior transventricular approaches, the relevant anatomy that must be considered is the foramen of Monro. For the anterior interhemispheric approach, the anatomy of the interhemispheric fissure and of the choroid plexus in the lateral ventricle must be considered. A subchoroidal approach will open into the posterior ventricle. The dominant surgical anatomy for the purpose of an endoscopic keyhole approach as emphasized in this chapter is the posterior paramedian SCIT region. The line between the inion and the root of the zygoma describes the approximate level of the transverse sinus. Under the transverse sinus, the intradural space is relatively open, except for occasional bridging veins between the superior cerebellar hemispheric surface and the tentorium. Beyond this, the cerebellum slopes up to the pineal region. In the midline, the culmen rides high and the precentral cerebellar vein tethers the cerebellum (Fig. 13.1). However, there is rarely any obstruction to a paramedian trajectory (Fig. 13.2a, b).

13.5 Surgical Technique

Anterior Endoscopic Approach

Histopathological analysis is imperative in the diagnosis and planning of adjuvant therapy for patients with pineal region disease. In patients with lesions that are large enough to result in obstructive hydrocephalus, anterior endoscopic keyhole approaches to the lateral ventricles can allow for both tissue diagnosis and CSF diversion. These approaches minimize approach-related morbidity compared to that with open microsurgical approaches, and they are often used by surgeons as a first-line treatment [13]. Endoscopic third ventriculostomy (ETV) is one such minimally invasive approach. It consists of guiding an endoscope transcortically into the lateral ventricles and fenestrating the tuber cinereum, which bypasses a block of CSF from lesions in the posterior third ventricle and aqueduct. The alternative route for CSF to flow

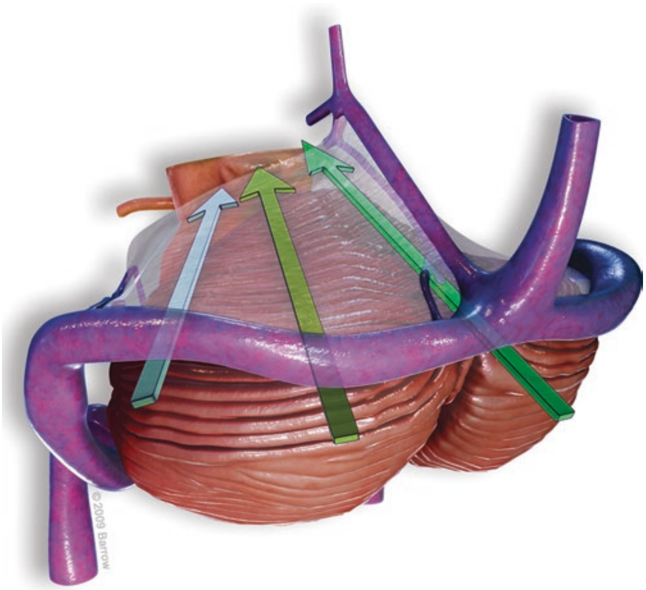

Fig. 13.1 The entire corridor from the retrosigmoid to the midline supracerebellar is available between the tentorium, which lies above the target area, and the superior surface of the cerebellum, which lies below the target area. The paramedian approach (*center arrow*) is the most advantageous for accessing the pineal region (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

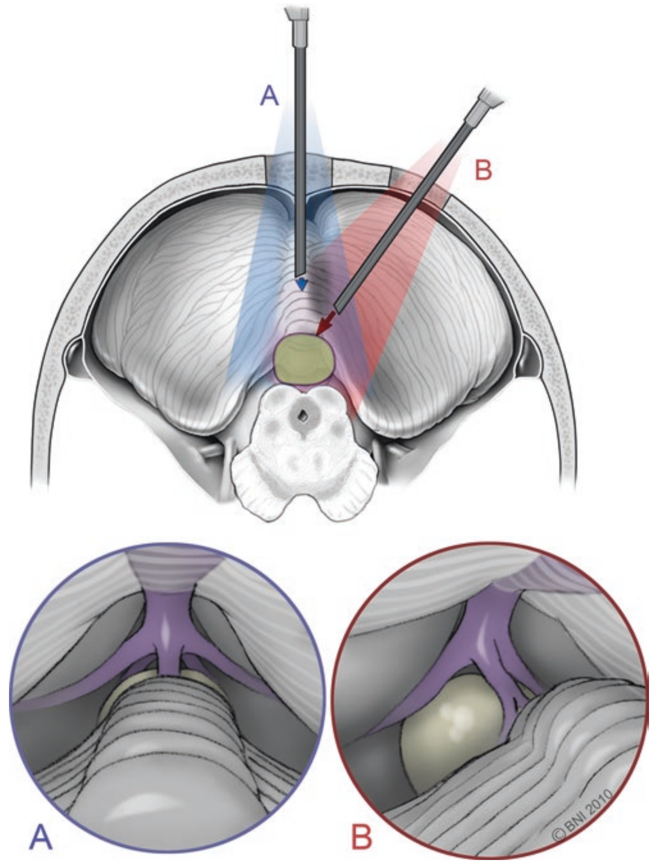

Fig. 13.2 Midline (**a**) and paramedian (**b**) approaches to the pineal region. The paramedian approach avoids obstruction by both the vermis and the bridging veins, and yet it still allows an excellent approach to both sides (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

into the basal subarachnoid space relieves hydrocephalus, such that a shunt is seldom required. This procedure is ideal for patients who have relatively recent-onset hydrocephalus from a pineal region mass because the natural CSF resorption pathways via the arachnoid granulations are intact. For patients with long-term obstruction, success in relieving hydrocephalus can often be variable [14].

The endoscopic unit used in an ETV consists of the endoscope with either a single port or dual ports to allow for placement of various tools, including a probe to make the initial ostomy and balloon catheters to expand the fenestration. The endoscope video output is projected onto a video monitor that is placed at eye level of the primary surgeon for comfort. An assistant also monitors and controls an irrigating pump that allows for clearing of debris and blood products within the lateral ventricles, which may otherwise obstruct the surgeon's view [15]. The procedure is performed by first planning a 1.5–2 cm incision located approximately 13–15 cm posterior to the nasion and approximately 2.5 cm lateral to the midline (Fig. 13.3). Image guidance is highly recommended because the trajectory varies substantially among individual patients. Special attention is placed on the location of this entry point with respect to the coronal suture in order to avoid injury to the motor cortex that would be caused by placing the entry too far behind the coronal suture. Stereotactic neuronavigation should be used to tailor the exact entry point as follows: the trajectory is derived by planning backward from the targeted site in the tuber cinereum, backward through the foramen of Monro, and projecting up to the cortex. Avoiding impact on the fornices is the most important consideration. A burr hole is then created after incising the skin, and a peel-away sheath is inserted into the ipsilateral lateral ventricle. After the lateral ventricles have been successfully catheterized by confirming the egress of CSF, the endoscope is advanced through the cannula, and the ventricular anatomy is identified including the foramen of Monro, column of the fornix, thalamostriate and septal veins, and thalamus. A detailed understanding of the ventricular anatomy is imperative to successfully and safely perform this operation because it is easy to become disoriented, especially if anatomy is distorted in patients with long-standing hydrocephalus. Once the surgeon is oriented, the endoscope is carefully advanced into the foramen of Monro to visualize the third ventricular floor. It is imperative to avoid sweeping motions when in the ventricle in order to avoid shear injury and to prevent vascular injury or excessive traction of the fornix, which is particularly sensitive to manipulation. Anatomical understanding of the third ventricle is also important when performing the next few steps. The floor of

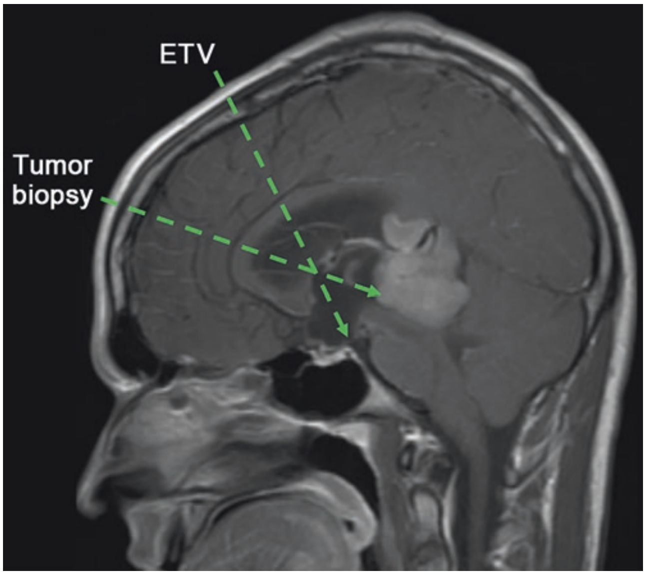

Fig. 13.3 In many patients, the ideal trajectory for access to the pineal region via the transventricular-transforaminal approach is very anterior compared to that preferred for an ETV. Often, separate burr holes are required for each approach (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

the third ventricle contains the cerebral aqueduct, which connects the third ventricle to the fourth ventricle and can be obstructed by pineal region lesions. When the endoscope is within the third ventricle, the mammillary bodies and infundibular recess, anterior commissure, dorsum sella, and membrane of Liliequist are identified. A region approximately two-thirds the distance between these two points is identified, and ports within the endoscope are commonly used as an ideal point of fenestration of the membrane of Liliequist. Often, the membrane of Liliequist is thin and translucent, with the basilar artery visible in the basal cisterns. At our institution, we often place the point of fenestration as far away from the basilar artery as possible to avoid iatrogenic injury to this structure, typically identifying the dorsum sella and working immediately posterior to the dorsum sella to perform the fenestration.

Endoscopic Pineal Region Biopsy

An ETV is often performed in combination with an endoscopic pineal region biopsy. Used in conjunction, these two procedures allow for the relief of hydrocephalus and provide tissue for histopathological diagnosis of pineal region tumors. However, a full resection of most lesions cannot be safely performed using this approach. In this procedure, the entry point required to access the posterior third ventricle necessitates an incision approximately 2 inches anterior to that performed for an ETV (Fig. 13.3). A more anterior entry point allows for more "in-line" access to the pineal region while minimizing traction on the fornix with a rigid endoscope. Often, two separate incisions and burr holes are used to perform a biopsy and ETV using rigid endoscopes. Alternatively, the same incision and burr hole can be used to perform both procedures when using a flexible, steerable endoscope because this tool does not require the lesion and surgical trajectory to be in-line. However, flexible endoscopes can often be difficult for inexperienced surgeons to use because the projected images can be disorienting and resolution is not as high as that of rigid endoscopes. Nevertheless, the flexible endoscope allows for greater access to more challenging lesions [16].

Posterior Endoscopic Keyhole Approaches

Several posterior approaches to the pineal region have been well described in the surgical literature [2–4], and they are used for a variety of lesions. These approaches include (1) the SCIT approach, (2) the supratentorial-transtentorial approach, and (3) the posterior interhemispheric approach. The use of any approach largely depends on the configuration of the tumor and its relationship to the deep venous structures. For lesions that push the vein of Galen posteriorly, more anterior approaches (e.g., the anterior interhemispheric approach or the posterior interhemispheric approach) are ideal. For lesions that push the vein of Galen anteriorly, the SCIT approach or the supratentorial-transtentorial approach is ideal. Each approach is associated with its own set of advantages and disadvantages.

Walter Dandy first described the posterior interhemispheric approach, which necessitates exposure of the superior sagittal sinus and interhemispheric space adjacent to the central sulcus [17]. A confluence of major interhemispheric draining veins can severely limit this approach. More posterior craniotomies adjacent to the occipital lobes, such as that used with the supratentorial-transtentorial approach, can place the primary visual cortex at risk for injury. The posterior interhemispheric approaches for pineal region tumors necessitate either fixed or intermittent retraction of the occipital lobes; thus, they are used less commonly at our institution. When posterior interhemispheric approaches are used, surgeons often rely on endoscopic assistance, with placement of endoscopes in the resection cavity after initially using microscopic visualization; [18] thus, this is not a purely endoscopic keyhole approach.

The use of endoscopy for pineal region tumors has been well described for anterior transventricular approaches, which are used mainly for tissue biopsy and hydrocephalus management [13–15]. As the use of the endoscope by skull base surgeons has increased for a range of anterior skull base pathologies, many of the endoscopic principles learned have been slowly used for posterior approaches to the pineal region. During the past decade, several different groups have described fully endoscopic keyhole SCIT approaches for pineal region pathology [19, 20]. These relatively novel approaches have steadily gained popularity, and their indications have expanded drastically from simple pineal cyst fenestration to complete resection of germinal or parenchymal tumors. The endoscopic keyhole approach allows for improved panoramic visualization of pineal region pathology and increased illumination within a narrow and deep surgical corridor, all the while decreasing approach-related morbidity with smaller incisions and craniotomies.

The SCIT route is a powerful method to access lesions of the pineal region, but the long and deep surgical corridor necessitates large exposures and significant cerebellar traction on the cerebellum when microscopic visualization is used. Microscopic surgeons often advocate exposure of the transverse sinus and/or the torcula to provide upward mobilization of the sinuses and tentorium cerebelli [21]. Because the light source is located outside of the cranial vault, increasing the upward mobilization of the tentorium allows for greater light penetration deep into the surgical cavity. However, this exposure increases the potential for iatrogenic injury to the sinuses, either during the craniotomy or with thrombosis of the vessels during prolonged exposure to the light microscope. Furthermore, microscopic surgeons often use fixed retraction of the cerebellum to increase the surgical working corridor and to decrease instrument obstruction of the surgeon's microscopic view. This increases the risk for retraction-related injury to the normal cerebellum. Lastly, the surgeon's microscopic view of the pineal region is limited to what is available within the line of sight. Manipulation of critical neurovascular structures outside the line of sight necessitates "blind" manipulation, further increasing the risk of inadvertent iatrogenic injury. Conversely, when endoscopic visualization is used, both the camera and light source are inserted into the cranial vault which decreases the need for large exposures to allow for light penetration and magnification of the surgical corridor. Furthermore, angled endoscopes and instruments permit the direct visualization of structures outside the surgical line of sight. The endoscopic SCIT approach may be safer than open microsurgical approaches because of the advantages afforded by the endoscope.

Operative Setup, Instrumentation, and Technique

When using an endoscopic keyhole SCIT approach to the pineal region, we prefer the sitting-slouch position for the patient unless the patient has a patent foramen ovale, in which case the patient should be positioned laterally (Fig. 13.4).

Fig. 13.4 The patient is placed in rigid fixation in the sitting-slouch position, with the back of the bed at the level of the patient's mid-shoulder blade or lower to keep the bed from obstructing the surgeon's hands (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

Several technical considerations must be taken into account when performing this procedure. The operating room setup is different than that used during microscopic procedures. The video monitor is placed directly in front of the primary surgeon who will be performing the bimodal intracranial dissection. A slave projector is placed adjacent to the primary screen to allow the assistant who is holding the endoscope to directly visualize a monitor without having to tilt his or her head; this improves surgeon comfort and decreases surgeon fatigue. We do not routinely employ irrigating sheaths, which are commonly used for endonasal procedures. The endoscope should be trialed and tested before the surgical pause to ensure its usability; replacement endoscopes and a replacement microscope should be available in the operating room should there be a technical issue with the primary equipment. The remaining surgical dissection tools are identical to those used in open microsurgical approaches, and no additional tools are necessary.

The surgical working corridor is optimized for the endoscope by expanding the infratentorial working space using various methods that obviate the need for fixed retraction. These methods include a generous dissection of arachnoid adhesions to permit CSF drainage early in the course of the procedure, the intravenous administration of mannitol, and occasionally the use of lumbar drainage. Furthermore, all patients undergoing endoscopic SCIT approaches at our institution are placed in the sitting-slouch position, unless contraindicated by a patent foramen ovale [3, 22]. This position has several advantages. First, it permits the use of gravity retraction of the cerebellar hemispheres, which further increases the size of the working corridor without the need for fixed retractors. Second, the sitting-slouch position is ergonomically advantageous for the endoscopic surgeon and the assistant, as the surgeon's hands are placed in a comfortable mid-body position for the duration of the procedure. This setup is in stark contrast to that of open microsurgical approaches for which the patient is in a sitting position; with these approaches, the surgeon's hands are elevated in midair for several hours which increases the risk for surgeon fatigue. Third, the sitting-slouch position allows for greater venous outflow and lower venous pressures, which decreases bleeding from the resection cavity during the procedure, and it allows for any blood that is spilled to freely drain away from the surgical field without obscuring the view. The sitting-slouch position also has several disadvantages of which the surgeon should be aware. First and foremost, it increases the risk of venous air embolism. Thus, all patients must undergo preoperative echocardiographic bubble studies to ensure that a patent foramen ovale is not present and to prevent the incidence of paradoxical air emboli. During the course of the procedure, all patients require precordial Doppler monitoring, as well as a central line in the right atrium to detect and treat venous air embolism. Furthermore, should there be a need for emergent conversion to open craniotomy during the course of an endoscopic approach, the sitting-slouch position can become quite uncomfortable for the microsurgeon.

At our institution, we use off-midline SCIT approaches. Midline approaches are avoided because of the larger number of bridging veins from the tentorium to the cerebellum located in this region, as well as obstruction of the pineal region by the high-riding culmen of the cerebellum in the midline [23]. All patients undergo a preoperative MRI with 1-mm cuts that are loaded into a navigation system and registered to the patient using surface contours. Stereotactic navigation techniques allow us to mark a 4-cm incision approximately 12 mm off midline, starting at the level of the transverse sinus and pointing down (Fig. 13.5) [3]. A 25-mm wide and 18-mm high keyhole craniotomy is then performed, exposing the inferior edge of the transverse sinus and dura overlying the upper cerebellum, lateral to the torcula. For lesions that are largely midline, we prefer a left-sided craniotomy when the primary surgeon is right handed to improve ergonomics [24]. Unlike in open microsurgical approaches, the relatively small craniotomy used in endoscopic approaches does not compromise the degree of visualization of the surgical corridor because the light source and camera are located within the cranial vault. However, the smaller the craniotomy, the greater the risk of instrument conflict [25, 26]. Hence, a craniotomy smaller than 20 mm wide may impede progress, and 25 mm is recommended. An inverted U-shaped incision in the dura is then performed up to the level of the transverse sinus, with or without the use of the endoscope, and the dura is retracted superiorly.

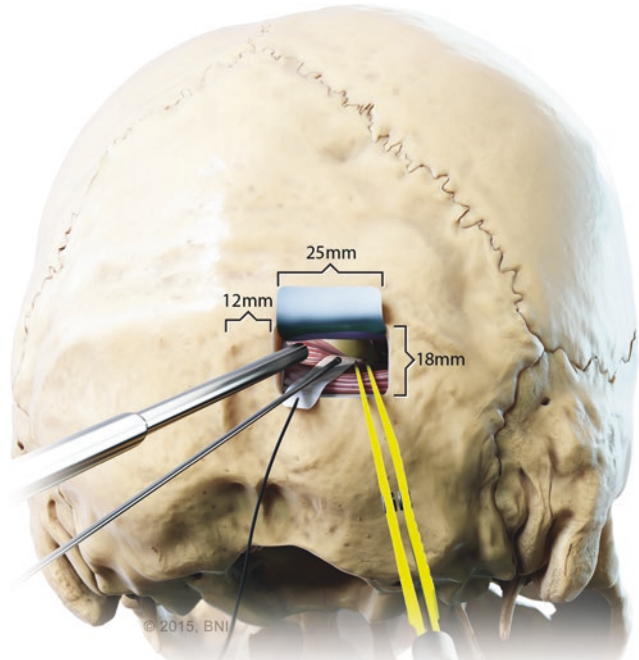

Fig. 13.5 The usual location of the paramedian opening is 12 mm from the midline at the level of the underside of the transverse sinus, and the craniotomy is 25 mm wide and 18 mm high. The endoscope is parked in one of the two upper corners of the craniotomy (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

The endoscope is advanced and wide; generous arachnoid dissection is performed progressively to increase the potential working space and to increase CSF drainage until the pineal region is visualized. Usually, veins can be avoided; in all cases, every attempt is made to preserve veins. When the trajectory is maintained parallel to the tentorium, the vein of Galen can be directly viewed; a slightly inferior trajectory can allow visualization of the pineal region (Fig. 13.6a–e). Larger tumors will have created their own space and the tumor will usually be obvious. If the tumor is not identifiable, it may be necessary to open the thick white arachnoid that often drapes this region. Surgeon knowledge of anatomy is key to navigating the depths of the supracerebellar corridor, especially when normal structures are distorted by tumors in this region. Adapters can be connected to the endoscope that allow for precise triangulation of the endoscopic tip using the neuronavigation platform [24]. During the intracranial segment of the procedure, general endoscopic principles are used for safe and effective surgery. These principles include constant visualization of the tip of instruments when they are introduced into the cranial vault. Such visualization helps to avoid iatrogenic injury to structures outside the line of sight. The endoscope should never be swept side to side because doing so can lead to catastrophic neurovascular injury outside the line of sight. The assistant holding the endoscope should be an active participant in the surgical procedure, frequently advancing and retracting the endoscope

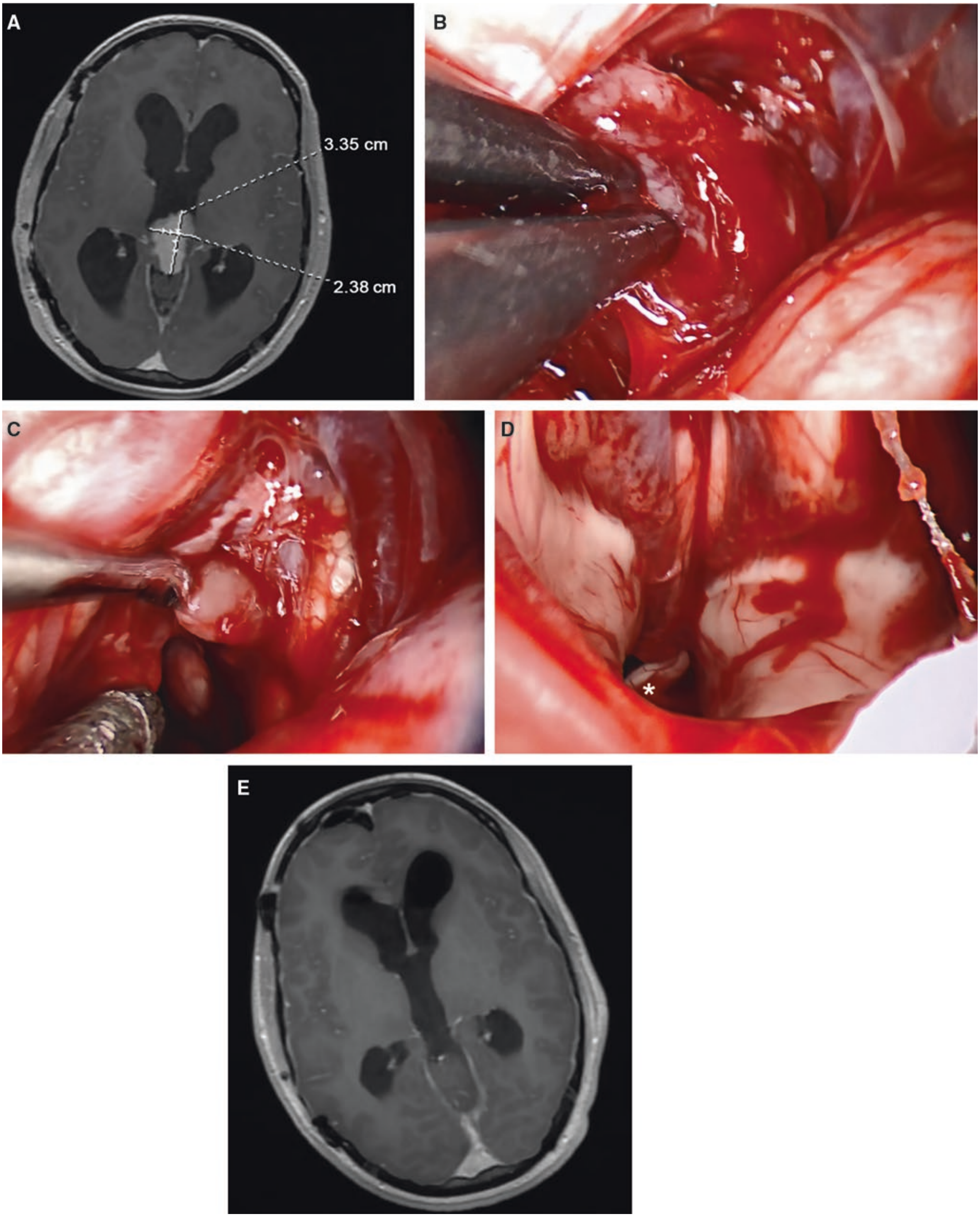

Fig. 13.6 (**a**) Preoperative axial gadolinium-enhanced magnetic resonance image (MRI) demonstrates a medium-sized enhancing pineal tumor. (**b**) Intraoperative view through a three-dimensional endoscope showing the tentorium to the upper left, the vermis to the lower right, and the instruments working on the tumor in the center. (**c**) The main bulk of the tumor has been removed, and a small nodule of residual tumor underneath the internal cerebral veins is removed with a dissector. (**d**) After tumor removal, the roof and anterior superior third ventricle are seen, along with both foramina of Monro (*asterisk*) and the choroid plexus in the roof of the third ventricle. (**e**) Postoperative axial gadolinium-enhanced MRI confirms gross-total removal of the enhancing mass (Used with permission from Barrow Neurological Institute, Phoenix, AZ, USA)

as the primary surgeon is moving instruments in and out of the intracranial vault. Excellent and precise sharp and blunt two-handed microneurosurgical technique should be used throughout. After the surgical resection of the tumor is completed, it is imperative that a watertight dural closure be performed to prevent a pseudomeningocele or CSF leaks.

13.6 Postoperative Care and Complications

Postoperatively, neurological assessment is of paramount importance. Any patient with loss of neurological function or slow emergence from sedation is taken immediately for a CT scan to assess for postoperative surgical bed hematoma or hydrocephalus. The presence of these pathologies should be treated accordingly, either with return to the operating room or placement of a bedside external ventricular drain. At our institution, negative imaging in the presence of neurological dysfunction prompts an MRI in addition to vascular imaging (CT angiography or MR angiography) to assess for a cerebrovascular accident. Patients with stable neurological function postoperatively will undergo a delayed gadolinium contrast-enhanced MRI to assess for residual disease and future treatment planning. All patients who undergo such a surgical procedure are placed in the neurological intensive care unit with continuous cardiac and neurological monitoring. We typically place patients with the head of the bed elevated for 2–3 days to reduce the probability of a pseudomeningocele. We rarely place a preoperative lumbar drain. When additional CSF diversion procedures are performed, they are typically discontinued on postoperative day 1 or 2, depending on the quality of dural closure as assessed intraoperatively. In the absence of known coagulopathy disorders, non-ambulatory patients are also prophylactically treated with sequential compression devices as well as pharmacological prophylactic-dose low-molecular-weight heparin.

13.7 Surgical Pearls

- Virtually all pineal region masses are advantageously approached from a supracerebellar-infratentorial approach.
- A sitting-slouch position uses gravity to create working space between the cerebellum and tentorium. A lumbar drain can be a useful adjunct.
- A preoperative echocardiogram with bubble study to assess for a patent foramen ovale and intraoperative Doppler studies for air embolism are essential.
- A combination of straight and angled endoscopes can be used with two-handed sharp microsurgical techniques to effect removal of a pineal region lesion.

13.8 Conclusion

Neuroendoscopic keyhole approaches to the pineal region are effective and safe methods to address a variety of pathologies. Anterior approaches are primarily used for tissue biopsy and for CSF diversion for lesions obstructing the cerebral aqueduct or third ventricle. Should the anatomical configuration of the lesion permit, posterior SCIT approaches can be used to resect pineal region tumors or cysts. These approaches provide better illumination and magnification of the pineal region than traditional approaches. Endoscopic keyhole approaches are associated with a steep learning curve and require a team-based approach as well as an intimate understanding of the important neurovascular structures of the pineal region.

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