Pineal region tumors are challenging to access due in large part to their central location within the calvaria and critical surrounding neurovascular structures. Harvey Cushing performed pineal region surgery only for palliative measures, noting "personally, I have never succeeded in exposing a pineal region tumor sufficiently well to justify an attempt to remove it." Numerous tumors can occupy this area, including tumors originating in the pineal body (pineoblastoma/pineocytomas, teratoma, and germinomas), splenium of the corpus callosum (intrinsic glial tumors), velum interpositum (meningiomas), or fornix. The surgical approaches to pineal region pathology are intimately related to the complex anatomical relationship of the surgical target to surrounding structures, location of feeding blood supply, anatomical variations, and extent of resection goals. Numerous approaches to this region have been described, and they can be tailored to the morphology of the target lesion. These approaches include the supracerebellar infratentorial approach, occipital interhemispheric approach, parietooccipital interhemispheric/transcallosal approach, posterior transcortical approach via the angular gyrus/lateral ventricle, posterior subtemporal approach, and combined supratentorial/infratentorial transtentorial approaches. In the present study, we describe a novel approach to the pineal region for superiorly projecting lesions, the anterior interhemispheric transsplenial approach.

Anterior interhemispheric transsplenial approach to pineal region tumors: anatomical study and illustrative case

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Pineal region tumors are challenging to access because they are centrally located within the calvaria and surrounded by critical neurovascular structures. The goal of this work is to describe a new surgical trajectory, the anterior interhemispheric transsplenial approach, to the pineal region and falcotentorial junction area. To demonstrate this approach, the authors examined 7 adult formalin-fixed silicone-injected cadaveric heads and 2 fresh human brain specimens. One representative case of falcotentorial meningioma treated through an anterior interhemispheric transsplenial approach is also described. Among the interhemispheric approaches to the pineal region, the anterior interhemispheric transsplenial approach has several advantages. 1) There are few or no bridging veins at the level of the pericoronal suture. 2) The parietal and occipital lobes are not retracted, which reduces the chances of approach-related morbidity, especially in the dominant hemisphere. 3) The risk of damage to the deep venous structures is low because the tumor surface reached first is relatively vein free. 4) The internal cerebral veins can be manipulated and dissected away laterally through the anterior interhemispheric route but not via the posterior interhemispheric route. 5) Early control of medial posterior choroidal arteries is obtained. The anterior interhemispheric transsplenial approach provides a safe and effective surgical corridor for patients with supratentorial pineal region tumors that 1) extend superiorly, involve the splenium of the corpus callosum, and push the deep venous system in a posterosuperior or anteroinferior direction; 2) are tentorial and displace the deep venous system inferiorly; or 3) originate from the splenium of the corpus callosum.

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transsplenial approach. Sano described a frontal transcallosal approach for large pineal tumors extending into the third ventricle. In a more current description, a frontal craniotomy and interhemispheric dissection is performed, and the splenium of the corpus callosum is sectioned. To the best of our knowledge, the anterior interhemispheric transsplenial approach has not been described to address pineal region pathology.

**Methods**

Seven adult, formalin-fixed, silicone-injected, human cadaveric heads and 2 human brain specimens without any known intracranial, extracranial, or sinonasal pathologies were examined (Figs. 1–3). Specimens were fixed in a supine position using a Mayfield head holder, and stepwise dissections were performed under 6x to 40x magnification using a Zeiss Surgical microscope (Carl Zeiss AG). Dissections were performed using standard straight and curved surgical instruments. On the basis of these anatomical dissections, the anterior interhemispheric transsplenial approach to the pineal region and falcotentorial junction area is described.

**Results**

**Surgical Technique**

The patient is placed supine with the sagittal plane of the head parallel to the floor, allowing the surgeon’s hands to work naturally from side to side (Fig. 4). The side of the head with the lesion is placed superiorly in the surgeon’s view, and the nonlesion side is placed inferiorly. If the tumor is located exactly in the midline and is not eccentric to one side, the right hemisphere (nondominant) is positioned down, and the left hemisphere (dominant) is placed up to reduce iatrogenic approach-related injury to the dominant lobe. The head is elevated 45° to both decrease the venous pressure and to allow for gravity retraction of the frontal lobe. In this manner, we avoid using fixed retraction. A linear skin incision is made pre-coronally as it crosses the midline and perpendicularly to the midline. One-third of the skin incision is made on the upper side (tumor side) and two-thirds on the lower side (nonlesion side). After the skin is incised, the galeal flap is retracted, and 2 bur holes placed over the superior sagittal sinus in the midline and 2 bur holes are placed 3 cm off midline. In such a manner, we avoid having to cross the sinus with a craniotome. We place bur holes directly over the superior sagittal sinus and create a 4 × 3-cm craniotomy flap. Venous oozing from the superior sagittal sinus is controlled with Surgicel (Ethicon, Inc.), and we avoid using FloSeal (Baxter International, Inc.) in this area to prevent sinus thrombosis. The inner edge of the bone is removed using a fine Kerrison rongeur to enhance the visualization. The dura is opened in a “U” shape and reflected over the superior sagittal sinus, and the dural leaflet is tacked up and out of the field.

We carefully plan the craniotomy preoperatively by discerning an area free of bridging veins using Stealth-Station neuronavigation (Medtronic, plc). Typically, there are few bridging veins in the pericoronal suture area. The aforementioned head position allows gravity retraction of the brain hemisphere away from the falx cerebri. The interhemispheric fissure is accessed and easily opened with sharp dissection of a few adhesions between the falx and cingulate gyrus, without the need for fixed retractors. As one proceeds deeper into the interhemispheric fissure, the inferior sagittal sinus, distal segment of the anterior cerebral artery, and body of the corpus callosum are observed. The small bridging veins of the inferior sagittal sinus can be coagulated to create a good exposure of the corpus callosum. Thereafter, access gradually proceeds posteriorly to reach the splenium of the corpus callosum. The distal segment of the anterior cerebral (pericallosal) arteries and postsplenial segments of the posterior cerebral arteries are exposed. If these are located directly over the splenium of the corpus callosum, they are circumferentially dissected and retracted to either side. The falx cerebri slopes toward the splenium of the corpus callosum. If there is a narrow corridor to the splenium, the falx cerebri is cut longitudinally from the point where the falx touches the corpus callosum to the level of the junction of the inferior sagittal sinus and straight sinus. The longitudinal (anteroposterior direction) incision is made over the splenium of the corpus callosum. The vertical splenial incision should not exceed 2 cm to avoid disconnection syndrome. Tumors that develop superiorly or those originating from the splenium of the corpus callosum thin the splenium, thereby simplifying the incision into the splenium.

At this stage, neuronavigation is used to begin debulking the tumor along its long axis. One should always be cognizant of the body and crura of the fornix, as well as the internal cerebral veins, which may be draped over the tumor. If the internal cerebral veins are seen first, they usually can be dissected, retracted laterally, and preserved. If these veins are damaged, temporary clips should be placed and a direct repair should be attempted using 9-0 nylon or 7-0 polypropylene sutures. These veins should not be sacrificed as this may result in a delayed severe venous infarct. Once the tumor is entered and debulked, cleavage planes between the tumor and surrounding structures are exploited to protect critical neurovascular structures. After resection of the tumor, meticulous hemostasis is performed, and if the working area is dry, there is no need to place an external ventricular drain. The dura mater is sutured watertight, and the bone flap is reattached to the skull using titanium plates. The scalp flap is then sutured.

**Uses and Benefits of the Anterior Interhemispheric Transsplenial Approach**

The anterior interhemispheric transsplenial approach might be preferred to treat tumors that 1) extend superiorly, involve the splenium of the corpus callosum, and push the deep venous system in a posterior or lateral direction (Fig. 5); 2) are tentorial (meningiomas, hemangiopericytomas) and displace the deep venous system inferiorly; or 3) originate from the splenium of the corpus callosum. The anterior interhemispheric transsplenial approach has several advantages over other interhemispheric approaches to the pineal region. There are few or no bridging veins at the level of the pericoronal suture. Since retraction of the parietal and occipital lobes is unnecessary, the likelihood of approach-related morbidity is reduced, especially in...
the dominant hemisphere. The risk of damage to the deep venous structures is lessened because the tumor surface reached first is relatively free of veins. The internal cerebral veins can be manipulated and dissected away laterally through the anterior interhemispheric route, but not from the posterior interhemispheric route. Also, early control of the medial posterior choroidal arteries is achieved with this approach.
FIG. 2. A: Superior view of a different specimen from that shown in Fig. 1. The right hemisphere has been dissected to expose the corpus callosum and the parts of the lateral ventricle. The anterior interhemispheric transsplenial trajectory (green arrow) from the frontal craniotomy to the splenium of the corpus callosum is accessed between the falx and the medial side of the hemisphere. B: Posterior view. The falx cerebri and tentorium come together at the falcotentorial junction, just behind the splenium of the corpus callosum in the midline. The pineal region is hidden by the junction of the falx cerebri and tentorium. C: Superior view. The removal of the body of the corpus callosum exposes parts of the lateral ventricle, septum pellucidum, and body of the fornix, and the splenium of the corpus callosum. FIG. 2. (continued)→
Illustrative Case

A 52-year-old woman presented with progressive fatigue and poor balance, as well as confusion and memory difficulties over the previous 3 years. Diagnostic imaging revealed a 5 × 5 × 5–cm falciotentorial meningioma in the pineal region that displaced the splenium of the corpus callosum anteriorly and inferiorly and that rose above the pineal region that displaced the splenium of the corpus callosum anteriorly (Fig. 6). The patient underwent a right anterior parasagittal craniotomy and interhemispheric approach to expose the lesion in the midline (Video 1).

VIDEO 1. A right anterior parasagittal craniotomy and interhemispheric approach to expose a falciotentorial junction meningioma. Used with permission from Barrow Neurological Institute, Phoenix, Arizona. Click here to view.

The surgical approach to the lesion was performed as previously described. Due to the large size of the lesion, it was immediately apparent upon completion of the interhemispheric dissection that the splenium of the corpus callosum was displaced forward and downward by the tumor. First, we continued the exposure over the top of the tumor mass protrusion into the interhemispheric space. We retracted down gently on the splenium, mobilizing it from the tumor to expose the more anterior aspect of the tumor in the subpenial and deep pineal area. We radically debulked the tumor from within using microinstruments, curettage, microsuction, and an ultrasonic aspirator. In this manner, we resected the lesion down to a stub that lay directly on the top of the deep cerebral veins. The tumor capsule here was grossly adherent, creating a significant risk to the venous complex if the tumor capsule was aggressively resected. The postoperative period was uneventful. Radiotherapy was administered to the patient to treat the remaining tumor capsule over the internal cerebral veins. At long-term follow-up, the patient was asymptomatic without regrowth of the lesion.

Discussion

The parietooccipital interhemispheric transcallosal approach has typically been used for supratentorial-extending pineal region tumors. However, a shortcoming of this approach is the possibility of damaging or dividing bridging veins, which can cause mild contralateral hemiparesis or contralateral asterognosis due to a serious venous infarct. More than one bridging vein should not be sacrificed. Craniotomy placement is flexible and should be based on the presence of the bridging veins in the surgical trajectory. However, in the anterior interhemispheric route with the craniotomy site placed two-thirds in front of and one-third behind the coronal suture, there is a relative scarcity of bridging veins, thus allowing for greater surgical maneuverability without risking iatrogenic injury to these important veins. The segment of the superior sagittal sinus in the frontal region above the genu of the corpus callosum has fewer bridging veins than any other area except the 4–6 cm proximal to the torcular herophili. The veins from each cortical area joining the superior sagittal sinus have a characteristic configuration: the veins enter the superior sagittal sinus from anterior to posterior, with decreasing angles as they join the sinus. The mean angles are 85° for the middle frontal vein, 65° for the posterior frontal vein, 25° for the anterior parietal vein, and 25° for the posterior parietal vein. The lacunae, the enlarged venous spaces, are largest and most constant in the parietal and posterior frontal areas. The lacunae in the anterior frontal and occipital areas are smaller. Thus, the anterior interhemispheric approach is a potential alternative to the parietooccipital interhemispheric approach. The guiding principle in selecting this approach is to use a trajectory that avoids major traversing veins and deep venous structures that would otherwise be encountered via a parietooccipital craniotomy.

The parietooccipital interhemispheric and occipital interhemispheric approaches with sectioning of the tentorium provide excellent exposure of the quadrigeminal plate and subtentorial area in inferiorly developed pineal region tumors (Fig. 7A and B). However, cutting the tentorium entails some risk of damage to the deep venous structures because of the close relationship of the tentorium and deep veins, in particular the straight sinus, superior cerebellar veins, precentral cerebellar vein, and vein of Galen. In the anterior interhemispheric approach, the subtentorial part of the tumor and the quadrigeminal cistern through the splenium of the corpus callosum can be well exposed without cutting the tentorium.

In the occipital interhemispheric approach, although gravity retraction can be maximized with proper head position, a significant degree of fixed retraction is still needed to provide adequate working space in the interhemispheric fissure. This is because the occipital lobe is confined by the tentorium and falx cerebri. Prolonged retraction of the occipital lobe is highly associated with a visual field defect. In the parietooccipital interhemispheric approach, the presence of several bridging veins may not allow enough interhemispheric space to work without retraction, even after dissection of these veins. The retraction of the medial parietal lobe may cause asterognosis.

Pineal tumors generally displace the vessels of the deep venous system posteriorly and superiorly toward the retrosplenial area. If so, when approaching from parietooccipital or occipital interhemispheric routes, tumor removal between those venous structures becomes a challenge.
FIG. 3. A: In a stepwise manner, the body of the corpus callosum has been removed to expose the lateral ventricle, while the left cingulum was preserved. B: The cingulum was removed and the hippocampal commissure was opened. The floor of the lateral ventricle is formed by the thalamus and the body of the fornix, while the lateral wall of the lateral ventricle is formed by the caudate nucleus. Both crura of the fornix meet to form the body of the fornix in the midline. C: The splitting of the body of the fornix and the opening of the hippocampal commissure expose the third ventricle and pineal region. The quadrigeminal cistern is located underneath the splenium of the corpus callosum. D: Superior view. Splitting the body of the fornix and the hippocampal commissure exposes the third ventricle and pineal region. In the subpial area, the pineal gland, posterior commissure, and habenular commissure that form the posterior wall of the third ventricle are exposed. The anterior commissure and massa intermedia within the third ventricle can also be seen. Ant. = anterior; For. = foramen; Inter. = intermedia; Nucl. = nucleus; Quad. = quadrigeminal. Dissections were prepared by Kaan Yağmurlu, MD, and the images are reproduced with permission from the Rhoton Collection (http://rhoton.ineurodb.org), CC BY-NC-SA 4.0 (http://creativecommons.org/licenses/by-nc-sa/4.0).
FIG. 4. Surgical procedure in a stepwise manner. A: The patient is placed supine, with the sagittal plane of the head turned parallel to the floor. B: The head is elevated 45° to decrease venous pressure and allow the frontal lobe to retract gravitationally. C: The linear incision is made precrorally, one-third contralateral to the craniotomy side and two-thirds to the ipsilateral side. D: Two bur holes are placed over the superior sagittal sinus, and 2 bur holes are placed 3 cm off midline. The craniotomy is performed in the order shown by the numbers. The medial edge of the craniotomy flap (indicated by 4) is placed at the contralateral side using the 2 bur holes over the sinus. E: After removal of the craniotomy flap, any bleeding from the sinus is controlled using Surgicel. F: The dura is opened in a U shape, reflected, and retracted with retention sutures over the sinus. G: The interhemispheric fissure is accessed and easily opened without using a retractor. H: There is 1 or no bridging vein at the level of the pericoronal suture; the vein can be coagulated, if necessary. I: At the deeper portion of the interhemispheric fissure, the corpus callosum has a white appearance. Thereafter, it is accessed posteriorly to reach the splenium of the corpus callosum. J: After exposure of the splenium, the pericallosal arteries are retracted laterally. Fiss. = fissure; Inf. = inferior; Interhem. = interhemispheric; Pericall. = pericallosal. Panels A and B are used with permission from Barrow Neurological Institute, Phoenix, Arizona. Dissections in Panels C–J were prepared by Kaan Yağmurlu, MD, and the images are reproduced with permission from the Rhoton Collection. (http://rhoton.ineurodb.org), CC BY-NC-SA 4.0 (http://creativecommons.org/licenses/by-nc-sa/4.0).
with increased potential for iatrogenic injury to these lesions. Conversely, meningiomas arising from the velum interpositum or falx tentorial junction, and epidermoid or other tumors originating from the corpus callosum, displace the deep venous system in anterior and inferior directions. The internal cerebral veins are located above the pineal region, and these veins are usually pushed superiorly or laterally by the tumor. In this situation, with the anterior interhemispheric subtemporal route, the internal cerebral veins may be encountered first. The removal of the tumor is carefully initiated at the corridor between these veins, or the veins are dissected and retracted away from the working trajectory.

There are a variety of different scenarios regarding the relationship of the internal cerebral veins with a pineal region tumor. 1) Both internal cerebral veins can be displaced superiorly or laterally on the surface of the tumor. 2) One internal cerebral vein can be embedded in the tumor, while the other vein is displaced superiorly or laterally. 3) Both internal cerebral veins can be embedded in the tumor. 4) Both internal cerebral veins can be pushed inferiorly. The medial posterior choroidal arteries usually supply the pineal region tumor. Approaching from the anterior interhemispheric route allows the posterior medial choroidal arteries to be controlled at an early stage, but the arterial supply of the tumor is usually encountered on the posterior surface of the tumor at the end of the procedure.

In the anterior interhemispheric transsplenial approach, if the tumor extends farther to the posterior portion of the third ventricle, we usually do not prefer the interfor nicel velum interpositum route to split the body of the fornix and pass through the velum interpositum. We believe that there is tremendous risk for severe memory deficit caused by bilateral fornical injury if midline structures are not well defined. An early report noted up to 25%–33% loss of verbal learning and recognition difficulty in patients treated via the transcallosal interfor nicel approach. The hippocampal commissure is located on the inferior surface of the splenium just behind the body of the fornix. A 1977 case report of a patient with amnesia and a glioma originating from the hippocampal commissure documented permanent amnesia after subtotal resection. However, in that case, structural verification of the lesion site was not clear. Notably, in patients with a pineal region tumor extending into the third ventricle, we usually prefer using the supracerebellar infratentorial approach rather than supratentorial approaches so that we do not section or split the fornix or hippocampal commissure (Fig. 7C–E). Our description is not aimed at surgery of the third ventricle, but instead is aimed at pathologies in the pineal region that have major supracerebellar extensions.

The splenial incision is tailored according to the supratentorial extension of the tumor (Fig. 6). When a splenial section is required to expose the tumor in the anterior or posterior approach, the anterior approach is preferred because it involves less manipulation of bridging veins and the deep venous system. Although the importance of the deep venous system and collateral veins is debated, sacrificing bridging or deep veins is undesirable to avoid venous infarction and potentially devastating results.

A splenial incision may cause hemialexia. Functional outcomes are variable for the splenial incision, which is used for different purposes (e.g., in hemispherectomy, removal of splenial glial tumors). Duffau et al. reported splenial low-grade glioma tumor resection with remarkable functional recovery in 31 of 32 patients, despite split-brain symptoms associated with disturbances of multimodal sensory processing and visuospatial coordination or cognitive impairment generated by a callosotomy at the splenial level. Another study noted that a splenial section of about 2 cm, even with a posterior extension, has not resulted in any postoperative deficit.

We performed a splenial section centered over the bulge of the tumor mass. A splenial section may be contraindicated for a patient with a preoperative dominant-hemisphere homonymous hemianopsia because of the
FIG. 6. Preoperative and postoperative MR images and intraoperative photographs. The preoperative MR images (A, axial; B, sagittal; C, coronal) show a homogeneously enhancing mass that arises from the falcotentorial junction and rises above the internal cerebral veins. It is associated with anterior and inferior displacement of the splenium of the corpus callosum. The intraoperative photographs show microsurgical dissection over the splenium of the corpus callosum (D, with illustration in inset showing patient position); exposure of the tumor in the interhemispheric space (E); the operative field after debulking and dissection of the capsule of the tumor from surrounding structures (F); and the operative field after removal of the tumor (G). The postoperative MR images (H, axial; I, sagittal; J, coronal) show removal of the tumor. Panels D–G are used with permission from Barrow Neurological Institute, Phoenix, Arizona.
risk of global alexia. At the same time, when the splenial section is planned through the occipital interhemispheric route, left occipital damage accompanied by the existing hemialexia caused by tumor infiltration or surgical incision may result in the patient being unable to read at all. Hence, retraction of the left occipital pole should be avoided when approaching through the splenium. For these reasons, we believe that the anterior interhemispheric route may be the better option when planning sectioning of the splenium.

Conclusions

The anterior interhemispheric transsplenial approach provides a safe and effective surgical corridor for patients with supratentorial extension of pineal region tumors that 1) extend superiorly, involve the splenium of the corpus callosum, and push the deep venous system in a posteroinferior or anteroinferior direction; 2) are tentorially based and displace the deep venous system inferiorly; or 3) originate from the splenium of the corpus callosum. In select cases, the anterior interhemispheric approach provides more protection to the deep venous complex than the posterior interhemispheric and supracerebellar infratentorial approaches.

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Conception and design: Spetzler, Yağmurlu. Acquisition of data: Yağmurlu, Zaidi. Analysis and interpretation of data: Yağmurlu. Drafting the article: Yağmurlu, Preul. Critically revising the article: Yağmurlu, Zaidi, Kalani, Preul. Reviewed submitted version of manuscript: Spetzler, Rhoton, Preul. Approved the final version of the manuscript on behalf of all authors: Spetzler. Statistical analysis: Yağmurlu, Zaidi. Administrative/technical/material support: Preul. Study supervision: Spetzler.

Supplemental Information
Videos
Video 1. https://vimeo.com/185803252.

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