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Surgical approaches to pituitary tumors

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Procedures for surgically accessing and removing lesions of the sella turcica have interested pituitary surgeons since the late 1800s. Pierre Marie's landmark paper in 1886 [1], in which he described two patients with acromegaly who had enlarged pituitary tumors, spurred the birth of neuroendocrinology and resulted in the development of surgical approaches to the pituitary gland. Initial approaches to the sella turcica were attempted transcranially [2–7], but high mortality rates led surgeons to pursue extracranial routes. Schloffer [8] successfully removed a pituitary tumor using the transsphenoidal route in 1907. In subsequent years, the transnasal transsphenoidal approach underwent many modifications and was embraced by Cushing, who successfully operated on 231 pituitary tumors with a mortality rate of 5.6% [9,10]. Although Cushing abandoned the approach in pursuit of perfecting transcranial techniques, the transsphenoidal approach was preserved by Dott and later repopularized by Guiot [11]. Morbidity and mortality rates continued to decrease with the advent of improved illumination and the use of glucocorticoids in patients with associated hypopituitarism [12,13]. Hardy further refined the approach by introducing microsurgical techniques [14].

Today, the transnasal transsphenoidal approach is the preferred route for removal of more than 90% of lesions of the sella turcica, including pituitary tumors, craniopharyngiomas, cysts, clival chordomas, and meningiomas [15–21]. In the hands of experienced surgeons, transsphenoidal resection of extensive lesions is achieved with mortality rates of less than 1% [22–27]. The approach has further evolved with newer applications of frameless stereotaxy [28], endoscopy [29–31], and extended transsphenoidal approaches [20,32–42] in an effort to achieve complete tumor resection and low morbidity rates.

Surgical indications

The goals of surgery for pituitary tumors are to (1) eliminate tumor mass, (2) normalize hormonal hypersecretion, (3) preserve normal pituitary function, and (4) eliminate potential for recurrence [43]. A common indication for surgery of pituitary adenomas is a macroadenoma that produces progressive visual loss from mass effect [44]. In some cases, hemorrhage or necrosis into an existing pituitary tumor can cause precipitous visual loss associated with headache, cranial neuropathies, and, sometimes, acute adrenal insufficiency, a condition termed *pituitary apoplexy*. Immediate steroid replacement and emergent decompression of the optic nerves and chiasm via a transsphenoidal approach are then warranted to preserve visual function [17,45,46].

Transsphenoidal removal of growth hormone–secreting adenomas remains the primary treatment of choice in acromegaly [19,47–49]. Successful removal results in a prompt decrease in growth hormone levels. Large tumors in which a "chemical cure" may not be achieved may require additional medical or radiation therapy. Transsphenoidal extirpation of a microadenoma in

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Cushing's disease is also superior to medical management in obtaining prompt and long-term remission [50]. Often, failure of prior medical or radiation therapy may warrant surgical intervention to treat recurrent tumor [51]. Although prolactinomas can shrink dramatically with medical management, in rare cases, some tumors may be refractory to medical treatment and maintain persistently high levels of prolactin. Alternatively, some patients may not tolerate the effective medical therapy. These tumors require surgical removal. The transsphenoidal approach is also useful in the removal of sellar craniopharyngiomas and Rathke's cleft cysts, clival chordomas, and occasional meningiomas or metastatic lesions.

Preoperative radiographic considerations

The best method of delineating sellar pathologic findings and planning the optimal surgical approach is T1-weighted MRI, with and without gadolinium, performed in the sagittal and coronal planes. MRI is superior to CT because of its inherently greater soft tissue contrast, which allows clear visualization of the optic chiasm, optic nerves, carotid arteries, and cavernous sinuses [52]. The proximity of the tumor to the intracavernous carotid arteries is an important consideration when using a transsphenoidal approach to the tumor. In rare cases, severely ectatic carotid arteries may deviate into the midline trajectory and preclude a transsphenoidal approach.

Preoperative endocrinologic considerations

The endocrine status of the patient must be evaluated before surgery is performed on lesions near the hypothalamic-hypophysial axis. If a patient has an inadequate pituitary reserve, there is a risk of intraoperative or postoperative hypopituitarism, which can be dangerous in the perioperative period. The two most important hormone axes are those related to cortisol and thyroid production. A thyroid function profile and a baseline cortisol level should be obtained before surgery in anticipation of intraoperative manipulation of the hypothalamic-hypophysial axis. The risk of hypocortisolemia is controlled by the concomitant use of exogenous glucocorticoids. Preoperative recognition of hypothyroidism is also important, because hypothyroidism can manifest acutely during the early postoperative period. Ideally, patients should be given oral replacements approximately 1 week before surgery so as to establish a euthyroid state. In urgent or emergent cases, intravenous replacement may be undertaken.

As discussed elsewhere in this issue, any patient with a presumptive pituitary tumor should have a comprehensive endocrine evaluation of all major pituitary hormones in addition to those mentioned previously. This evaluation is performed to (1) establish the secretory or nonsecretory status of the tumor, (2) identify those patients in whom efficacious medical therapy should be initiated (eg, prolactinoma), and (3) provide a preoperative evaluation of baseline pituitary function. Preoperative endocrine evaluation should include measurement of growth hormone, serum prolactin, cortisol, thyroxine, triiodothyronine, follicle-stimulating hormone (FSH), and luteinizing hormone (LH) [53]. Mild hyperprolactinemia ($<$200 ng/mL) is usually a result of hypothalamo-hypophysial disconnection, or the "stalk effect."

Surgical technique

Transsphenoidal approaches

Sublabial transsphenoidal approach

After induction of general anesthesia and oral intubation, the patient is positioned supine with the face parallel to the ceiling and the head elevated approximately 15° above the heart to encourage venous drainage (Fig. 1). The patient's head is placed on a horseshoe-shaped headrest. The Mayfield three-point headrest is only used by the authors in cases of large or extensive tumors or those in which extended approaches are planned and image guidance is desired. Most intrasellar and suprasellar tumors can be readily approached with the head parallel to the ceiling. Further flexion allows visualization of lesions that extend inferiorly along the clivus. Extension of the head allows visualization of lesions with suprasellar extension. The endotracheal tube is placed slightly to the left of the midline, and the oropharynx is packed with moist gauze to prevent swallowing of blood and secretions. The thigh is prepared for a possible fat or fascia lata graft should that be necessary. A Foley catheter is not used in most cases.

Although the procedure is performed in a semisterile field, preoperative antibiotics are not required. The field is irrigated vigorously with bacitracin-impregnated lactated Ringer's solution (50,000 U per 500 mL) during the operation to reduce the potential for contamination from the paranasal sinuses. The authors' postoperative

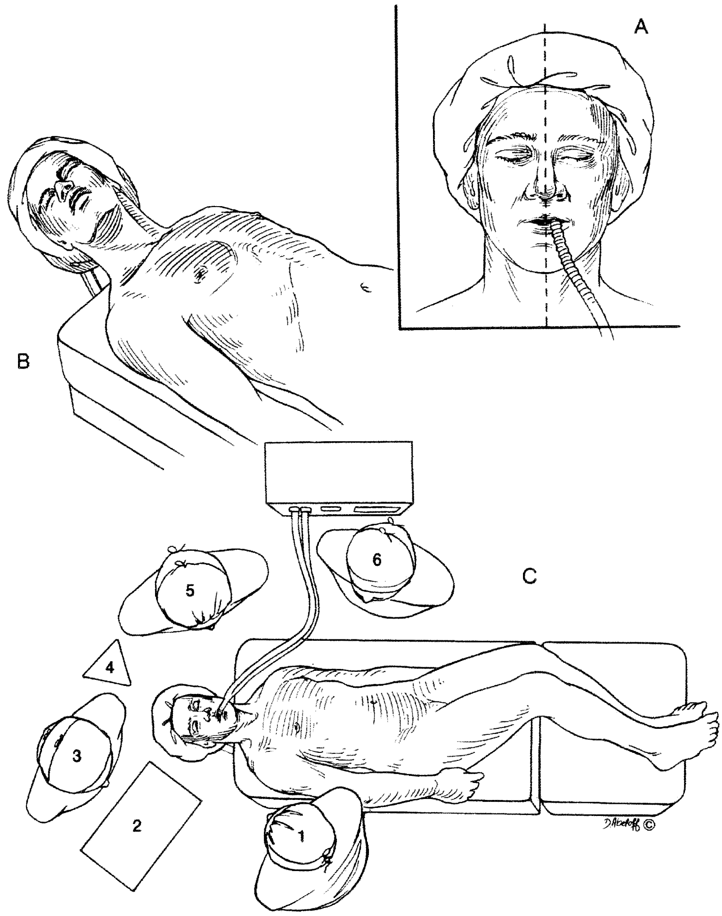

Fig. 1. Standard sublabial transsphenoidal approach: preparation. (*A*) The endotracheal tube is placed to the left of midline. (*B*) The patient is placed supine, with the face parallel to the ceiling and the head elevated approximately 15° above the heart. (*C*) Operating room setup: (1) surgeon, (2) Mayo stand, (3) nurse, (4) microscope base, (5) assistant, and (6) anesthesiologist. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

infection rate has remained less than 1% using this technique.

After final positioning, a povidone-iodine preparation is applied to the nasopharynx and sublabial gingival area of the maxilla. The nasal mucosa and gingival mucosa are infiltrated with 0.5% lidocaine containing epinephrine at a ratio of 1:200,000, and the nasal cavity is packed with cottonoid sponges soaked with the same solution to enhance hemostasis and shrink the turbinates. The upper lip is everted with skin hooks, and a sublabial incision is made from one canine fossa to the other down to the subperiosteal plane of the maxilla, leaving a 3-mm cuff of mucosa for later closure (Fig. 2). Subperiosteal dissection is carried out superiorly to expose the piriform aperture and the rostrum of the maxilla. If there is a prominent nasal spine or markedly heightened maxillary rostrum, it can be resected to allow adequate visualization of the posterior nasal pharynx. The nasal cottonoids are then removed before proceeding with the intranasal dissection. Smooth suction tips should be used at this juncture to prevent tearing of the mucosa.

Once the floor of the nasal cavity is identified, the mucosa is dissected from the floor along the mesial aspect and is carried posteriorly and superiorly to free the mucosa from one side of the nasal septum, preferably the right. Significant adhesion bands must be freed from the nasal septum

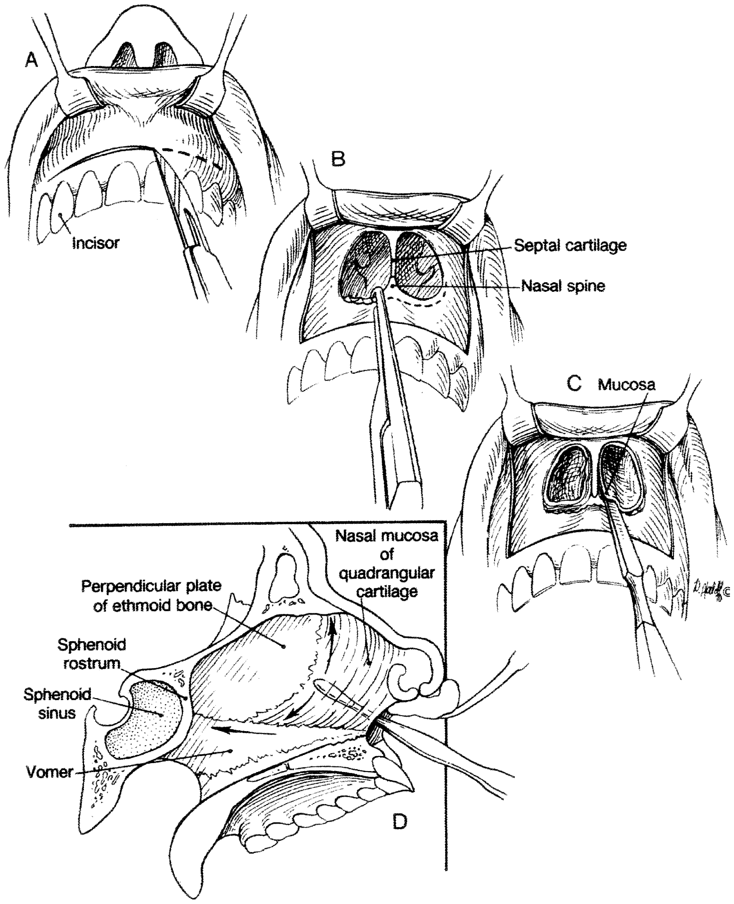

Fig. 2. Standard sublabial transsphenoidal approach: incision and submucosal dissection. Gingival incision is made, leaving a 3-mm cuff of mucosa for closure. Subperiosteal dissection is carried superiorly to expose the upper aspect of the rostrum of the maxilla. Submucosal dissection is carried out along the floor of the nose and medially up along the nasal septum. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

carefully to avoid a mucosal tear. The surgeon should be able to visualize the attachment of the quadrangular cartilage to both the vomer inferiorly and the perpendicular plate of the ethmoid posteriorly. Once the quadrangular cartilage is adequately visualized, it is disarticulated from the attachments of the vomer and perpendicular plate and mobilized away from the midline, usually to the patient's left. The perpendicular plate of the ethmoid now serves as a landmark to guide the dissection posteriorly toward the rostrum of the sphenoid sinus (Fig. 3). A handheld retractor is placed into the cavity, and the mucosa is retracted laterally from each side of the perpendicular plate of the ethmoid, exposing its junction to the rostrum of the sphenoid.

The ostia of the sphenoid sinus, which mark the most superior extent of bone removal of the sphenoid, are then identified. A self-retaining bivalve Hardy speculum is inserted to free both hands of the surgeon. The operative microscope is employed at this time for better magnification. The rostrum is resected with rongeurs, using the sphenoid ostia to gain entrance into the sinus (Fig. 4). The sphenoid sinus mucosa is then exenterated to prevent postoperative mucocele formation and to control any bleeding from the mucosa (Fig. 5). The position of the sphenoid sinus septum, if present, is anticipated by coronal MRI or CT imaging. In contrast to the predictable midline position of the perpendicular plate of the ethmoid, the sphenoid septum may be eccentric or

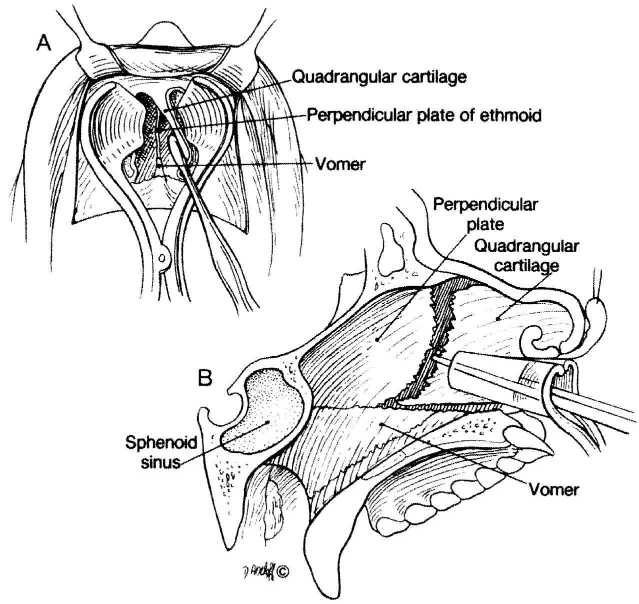

Fig. 3. Submucosal dissection. (*A*) The quadrangular cartilage can be mobilized from its attachment to the perpendicular plate of the ethmoid and the vomer. (*B*) Further posterosuperior dissection is performed toward the rostrum of the sphenoid sinus. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

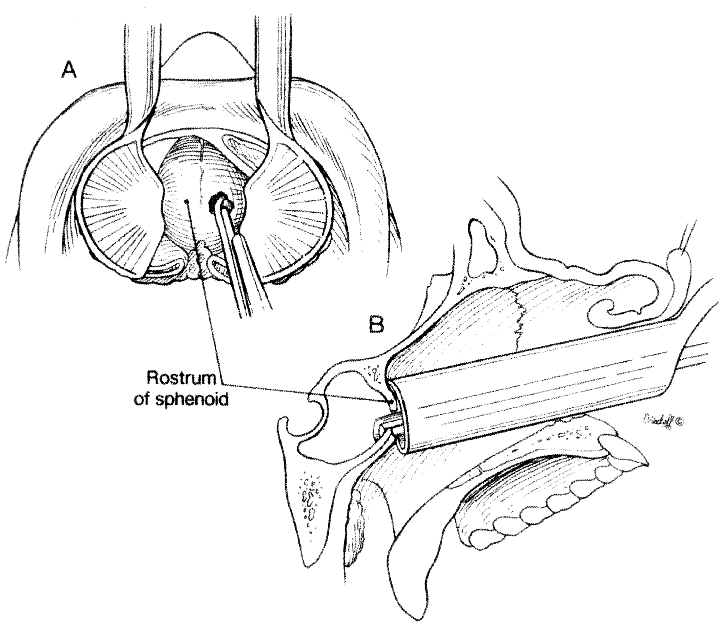

Fig. 4. Resection of the sphenoid sinus by using the sphenoid ostia to gain access. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

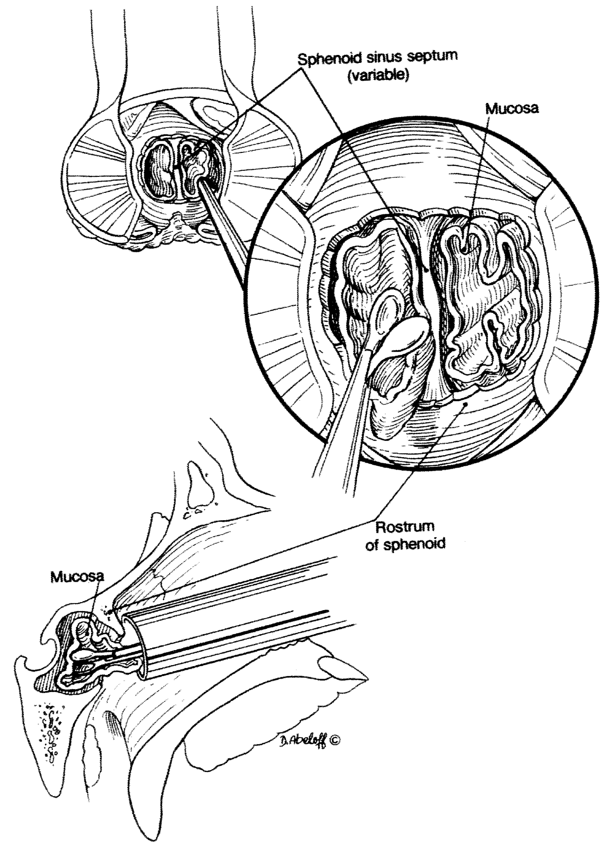

Fig. 5. Transsphenoidal approach. The sphenoid sinus mucosa is exenterated to prevent postoperative sphenoid sinus mucocele. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

multiple. The septum is removed with microrongeurs to allow optimal exposure of the floor of the sella turcica. If the sphenoid sinus is not pneumatized or is only partially pneumatized, a high-speed drill is used under fluoroscopic or image-guided control to access the sella turcica.

The sellar floor is identified posterosuperiorly and removed carefully with microrongeurs or a high-speed drill. Caution should be exercised when the sellar floor is removed, because the bone may be exceptionally thin and the underlying dura may be violated. The boundaries of the bony removal are demarcated by the cavernous sinus laterally and the circular sinus superiorly. The dura is then incised in a cruciate fashion with a number 11 blade, using caution laterally, and the dural flaps are elevated to give a square shape for maximal access to the tumor (Fig. 6).

The normal pituitary gland typically appears solid and yellow, whereas the adenoma appears gray-white and soft and amorphous in most cases. During removal of pituitary macroadenomas, cerebrospinal fluid (CSF) pulsations with an intact arachnoid membrane from above may facilitate delivery of the tumor through the dural opening. A Valsalva maneuver or bilateral jugular venous compression further delivers the tumor in the field in those lesions with large suprasellar extension. Curettes and scoops are used to aid in tumor removal (Fig. 7). The critical relation between the tumor, normal gland, and suprasellar arachnoid must be recognized, because the integrity of the arachnoid is preserved if possible to minimize the potential for a postoperative CSF fistula. On completion of tumor removal in larger tumors, the thickened arachnoid herniates into the field.

Often, the tumor appears to invade the cavernous sinus on preoperative images but may be bowing the sinus without true invasion. Extreme caution must be taken not to injure the carotid

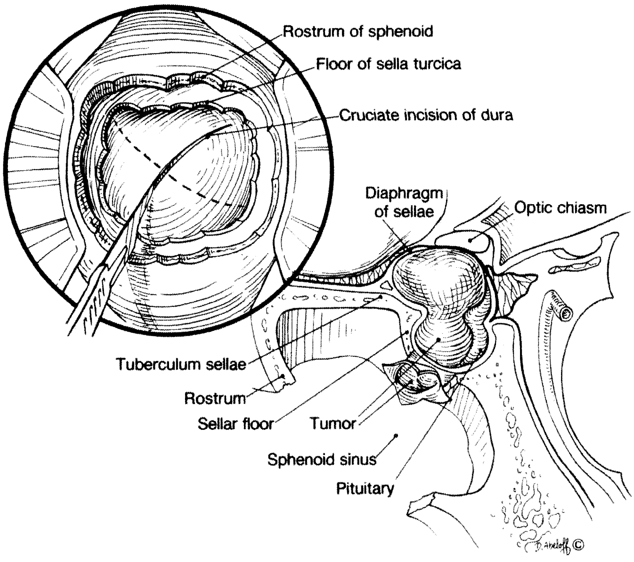

Fig. 6. Dural opening. Once the floor of the sella has been removed, the dura is opened in a cruciate fashion to give maximal surface area of exposure. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

arteries while removing a laterally placed tumor with ring curettes.

If no CSF leakage is observed, the authors occasionally place a cottonoid soaked in absolute alcohol for 30 seconds as an adjunct for tumor bed sterilization in small functional tumors. If a tear in the arachnoid is encountered, fascia lata and fat are harvested for a dural graft. A small piece of fascia lata is placed adjacent to the dural opening. The sphenoid sinus is then packed with fat to buttress the graft into position. A piece of Marlex mesh is fashioned to hold the fat within in the sphenoid. A Valsalva maneuver is performed after the graft is inserted to assess the integrity of the graft. The self-retaining retractor is then removed, the nasal septum is reduced by inserting small digits in the nares, the nasal mucosa is approximated, and bilateral nasal tampons are placed. If, however, a CSF leak is not encountered, the sphenoid sinus cavity is lined with Surgicel (Ethicon, Inc., Johnson and Johnson Co., Somersville, NJ). Finally, the sublabial gingival incision is sutured with plain catgut sutures, and a 2-cm × 2-cm gauze mustache dressing is applied under the nose (Fig. 8). Inadequate insertion of nasal tampons can result in insufficient tamponade of the mucosa and postoperative bleeding. The blood can migrate retrograde and cause a suprasellar clot.

Endonasal transsphenoidal approach

Increasingly, the authors have used an endonasal approach through one nostril to access the sphenoid sinus. This approach requires a narrow-caliber endonasal speculum. In rare cases, the size of the adult nares may limit the accessibility of this approach. The patient is prepared and positioned as described previously. A handheld speculum is inserted, usually in the right nares. While retracting the columella to the left, an incision is made along the inferior and posterior border of the cartilaginous septum. The submucosal plane is elevated posterior to the perpendicular plate of the ethmoid and inferior to the nasal floor. The mucosa is freed on the contralateral side of the perpendicular plate, and the quadrangular cartilage is disarticulated in its most posterior aspect only. If the bivalve speculum cannot be advanced through the nasal opening, a lateral alar incision is made to facilitate retractor placement. The remainder of the sphenoid sinus exenteration and tumor resection then proceeds as previously described.

This approach has the advantages of avoiding the potential need for resection of the anterior nasal spine and reducing the incidence of numbness of the upper teeth associated with the sublabial approach. The potential for scarring of the vestibule is also avoided. The main disadvantages are the limitations of access and the possibility of

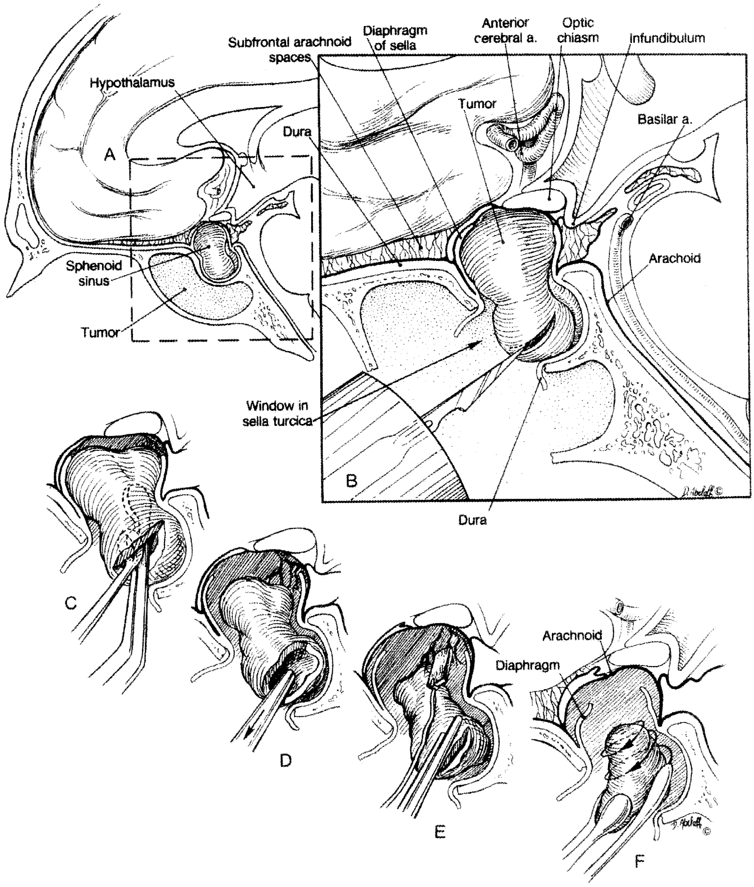

Fig. 7. Tumor removal. Tumor is readily removed with various curettes and scoops. It is imperative that the integrity of the arachnoid is preserved so as to minimize the potential for a postoperative cerebrospinal fluid fistula. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

needing to perform a relaxing alar incision in patients with small nares, which is necessary in only a few cases. Elias and Laws [54] use a sublabial conversion in cases where the endonasal approach is limited and a wider exposure is desired.

Extended transsphenoidal approaches

In the last decade, the classic transsphenoidal approach as described by Hardy [14] has undergone further modifications. Regions of the skull base that were once thought to be accessible only transcranially, such as the cavernous sinus and suprasellar cistern, can now be accessed with extended transsphenoidal approaches [20,32,34–42]. In some cases, additional skull base exposure may be necessary to access pituitary tumors with extensive parasellar and clival extension. This approach is best used for small tumors without significant lateral intradural extension. Various modifications of extended transsphenoidal approaches used by the authors are described below.

Exposure of the anterior skull base

Pituitary tumors with midline suprasellar extension anteriorly over the tuberculum sellae that resist extraction from the sellar floor can be removed with an extended transsphenoidal approach [32]. Access to the anterior skull base is facilitated by slight extension of the patient's head and manipulation of the speculum to point more superiorly. The bony resection of the sellar floor is extended superiorly to remove bone of the tuberculum sellae so as to expose the anterior skull

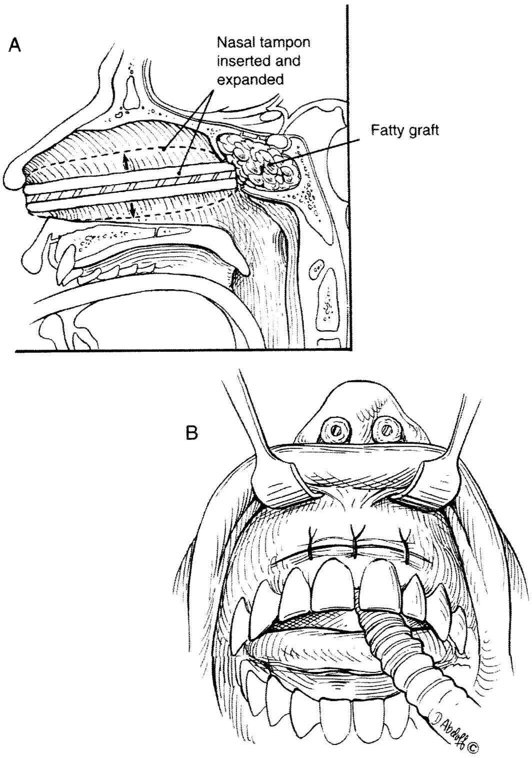

Fig. 8. Closure. (*A*) The nasal mucosa is approximated and tamponaded by placing a pair of nasal tampons. (*B*) The gingival mucosa, which heals rapidly and readily, is approximated with absorbable sutures. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

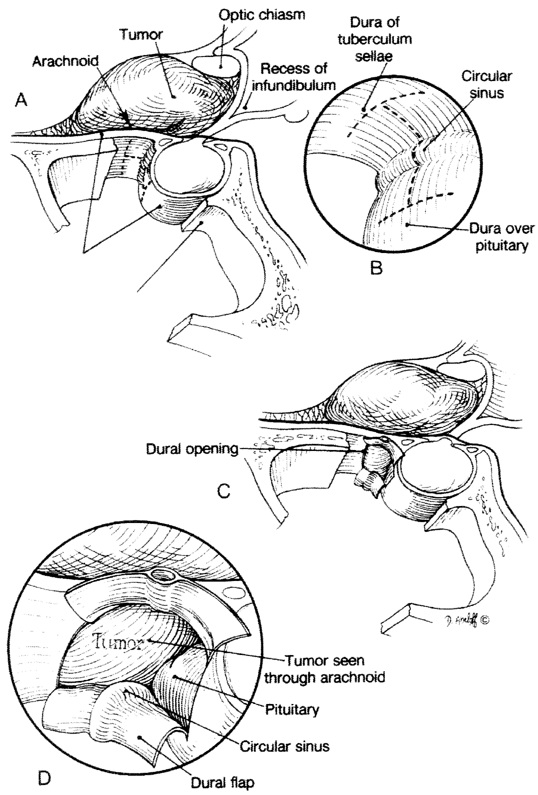

Fig. 9. Extended transsphenoidal approach: exposure of the anterior skull base. A pure suprasellar tumor can be approached by extending the bony resection anteriorly over the tuberculum sellae, thus exposing the dura mater lying anterior to the circular sinus. An incision is made in the dura anteriorly and inferiorly to the circular sinus. The sinus is then coagulated and transected to gain a direct view of the suprasellar cistern without disturbing the pituitary gland. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

base (Fig. 9). Bone over the anterior sellar wall is removed so as to expose the anterior circular sinus. The bony removal is extended anteriorly with microrongeurs. The circular sinus, which demarcates the anterior extension of the sella, should not be compromised during the bone removal. Once the bone of the tuberculum sellae has been removed, the dura anterior and inferior to the circular sinus is opened in the midline. The sinus is then coagulated and transected to gain a direct view of the suprasellar cistern while preserving the pituitary in its position. In this situation, the arachnoid is frequently opened to drain CSF so as to visualize the suprasellar compartment. The suprasellar tumor can be resected piecemeal. This approach enables an unencumbered view of the suprasellar cistern above the pituitary gland.

After the tumor is removed, the dural defect must be repaired with a fascia lata graft that is buttressed in place and supported by packing the sphenoid sinus and subfrontal region with fat. The closure is as described previously. Other pituitary surgeons have used this approach with success to remove adenomas of the pituitary stalk, craniopharyngiomas, tuberculum meningiomas, hemangioblastomas, and other lesions involving the suprasellar cistern and anterior skull base [37,38,40,41]. Alternatively, a transsellar/transdiaphragmatic approach to the suprasellar cistern has been reported for the excision of pituitary adenomas and craniopharyngiomas [33].

Inferior exposure of the clivus

Occasionally, a large pituitary adenoma may erode the dorsum sellae and upper clivus. In these cases, more inferior exposure can be facilitated by slightly flexing the patient's head and repositioning the nasal retractor to point inferiorly toward the upper portion of the clivus (Fig. 10). Additional exposure of the mid- and lower clivus requires a more inferior trajectory. The posterior wall and floor of the sphenoid sinus are removed with rongeurs and a high-speed drill. During tumor resection, caution is taken to stay in the extradural plane so as to avoid damage to the basilar artery or disruption of the arachnoid, resulting in CSF leakage. In the event that the arachnoid is violated, careful grafting and packing as described previously with postoperative lumbar drainage usually suffice.

Inferolateral exposure of the cavernous sinus

Pituitary tumors with lateral or inferolateral extension below or into the cavernous sinus pose a formidable surgical challenge. In such cases, a decision is made before surgery whether an aggressive surgical endeavor is warranted or whether subtotal resection and adjuvant radiosurgical treatment are indicated. Increasingly, the authors have chosen to perform selective tumor removal with radiosurgical treatment of residual adenoma within the cavernous sinus to avoid complications of cranial neuropathies. Careful review of preoperative coronal MRI studies is essential to surgical planning. The anatomic relation between the tumor and cavernous carotid arteries must be delineated. Vascular injury can be encountered if the surgeon does not recognize deviations in the course of the carotid arteries, such as an ectatic carotid artery that underlies the sellar dura. The dura underlying the sellar floor is exposed in the same manner as described previously. The bony removal is extended laterally to expose the cavernous sinus, including the dura overlying the carotid grooves [32]. The lateral extent of the bony removal is delineated by the cavernous cranial nerves. After the bony removal, the dura medial to the C3 portion of the internal carotid artery is first incised with a size 11 blade (Fig. 11). The incision is extended with curved alligator microscissors. The sub- or intracavernous tumor is removed with microring curettes. Any venous bleeding can be controlled by gentle packing with Surgicel.

Others have used modified approaches to access tumor extension into the cavernous sinus [34,36]. Fraioli and co-workers [34] have used a transmaxillosphenoidal approach to resect sellar tumors invading the medial wall of the cavernous sinus. In addition to the standard transsphenoidal exposure, this approach involves a unilateral or bilateral maxillary osteotomy and removal of the medial wall of the maxillary sinus. This exposure allows direct visualization of the intracavernous carotid artery during tumor resection. The extension of tumor lateral to the carotid artery poses limitations for this approach, however.

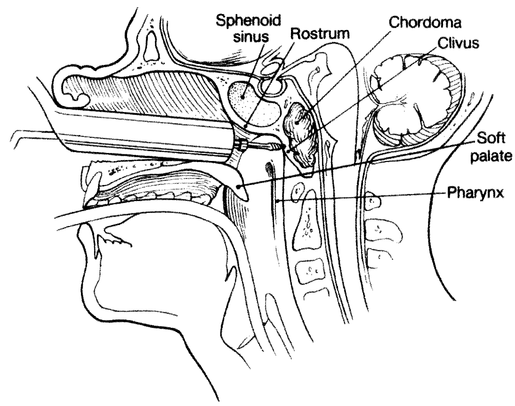

Fig. 10. Extended transsphenoidal approach: inferior exposure of the clivus. Exposure of the clivus is facilitated by slight flexion of the patient's head and repositioning of the nasal self-retaining retractor to point inferiorly. The upper clivus lies directly posterior to the sphenoid sinus, but additional exposure to the mid- and lower clivus requires more inferior exposure. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

Combined transmaxillary transsphenoidal approach

In an effort to avoid the need for a craniotomy, excessive brain retraction, or a wide transfacial dissection, transmaxillary approaches have been described to access lesions of the anterior cavernous sinus [55]. Access to midline structures is limited, however. Sabit et al [42] have described an extradural, extranasal, combined transmaxillary transsphenoidal approach that facilitates access to the anterior cavernous sinus and subhypophysial region without violating the nasal cavity.

Initially, a sublabial incision is made, followed by soft tissue elevation of the mucosa to expose the maxilla at the level of the infraorbital nerve. After a maxillotomy is performed and the mucosa of the maxillary sinus is removed, the course of the

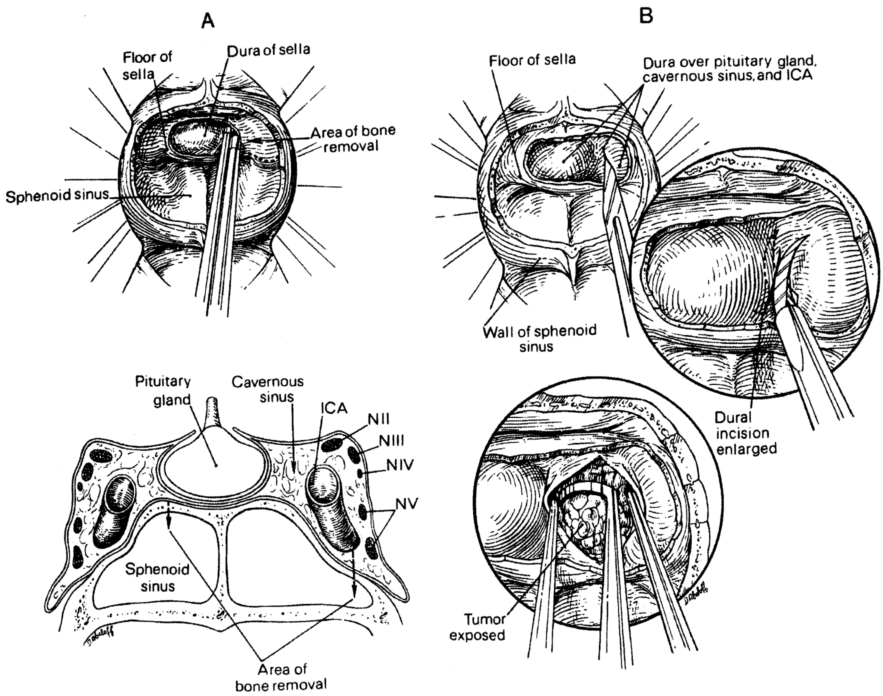

Fig. 11. Extended transsphenoidal approach: inferolateral exposure of the cavernous sinus. (*A*) After exposure of the dura overlying the sella, the bone overlying the cavernous sinus, including that overlying the carotid grooves, is carefully removed. This removal defines the lateral extent of the exposure limited by the cavernous cranial nerves. (*B*) The dura medial to the internal carotid artery is first incised with a number 11 blade and opened with curved alligator microscissors. The intracavernous portion of the tumor is then removed with a microcurette. (*From* Couldwell WT, Weiss MH. The transnasal transsphenoidal approach. In: Apuzzo MLJ, editor. Surgery of the third ventricle. 2nd edition. Baltimore: Williams & Wilkins; 1998. p. 553–74, with permission.)

infraorbital nerve on the roof of the maxillary sinus is exposed and traced back to the pterygopalatine fossa and foramen rotundum. The superomedial aspect of the foramen rotundum is removed with a high-speed drill to reveal the contents of the superior orbital fissure. Medial enlargement into the cavernous sinus is made by drilling the lateral and posterior wall and septum of the sphenoid sinus. Next, by removing the infrasellar bone, the dura overlying the pituitary gland is opened and the entire ipsilateral cavernous sinus and infrasellar region is visualized. The lateral wall of the contralateral sphenoid wall is removed to access the contralateral cavernous sinus.

This approach offers clear visualization of the ipsilateral loop of the carotid artery, the pituitary fossa, and the cranial nerves of the ipsilateral cavernous sinus. The operative reach provided by this approach allows adequate access to the ipsilateral cavernous sinus, the medial aspect of the contralateral cavernous sinus, the infrasellar and subdiaphragmatic region, and the ventral surface of the upper third of the clivus [42]. This approach has the advantage of a better cosmetic outcome by avoiding extensive osteotomies of the facial bones or external facial incisions. It is also provides a safe alternative route for gaining access to lesions with significant lateral extension and involvement of the intracavernous carotid artery that would otherwise require both transsphenoidal and pterional approaches [42,56].

Transcranial approaches

Cushing's abandonment of the transsphenoidal approach in pursuit of transcranial approaches to the pituitary [57] influenced the rest of the neurosurgery community to focus on transcranial approaches through the 1950s [58]. As transsphenoidal microsurgery was restored to prominence, however, the indications for transcranial approaches to pituitary tumors became few. In cases where a transnasal approach is contraindicated, such as sphenoid sinusitis or ectatic midline (''kissing'') carotid arteries, a transcranial approach may be warranted. Some patients who harbor pituitary macroadenomas with significant lateral suprasellar extension that cannot be adequately removed transsphenoidally may benefit from a transcranial approach. The two most widely used transcranial approaches to pituitary tumors are the pterional (frontotemporal) approach and the anterior subfrontal approach.

Pterional approach

The pterional approach described by Yasargil [59] has become the most widely used approach to access the circle of Willis for treating anterior circulation aneurysms. With removal of the sphenoid wing, a straight trajectory to the parasellar structures provides excellent visualization for removing pituitary tumors with minimized brain retraction. It represents the shortest transcranial trajectory to the suprasellar cistern. This should be the method of choice when a transcranial approach is used in a patient with a prefixed chiasm, because the tumor can be resected beneath the chiasm.

After induction of anesthesia, a lumbar drain usually can be placed to facilitate brain retraction. The patient is placed in the supine position with the head in three-point pin fixation. The head is rotated laterally 35° and slightly extended. The approach is preferably made on the right; however, the approach is individualized if tumor extension is preferentially to the left. The details of the frontotemporal bone flap and approach are well described in other standard operative texts [60,61]. After the dura is opened, the microscope is brought into the field. The Sylvian fissure is sharply divided with arachnoid scissors. The lumbar drain is opened to facilitate placement of frontal and temporal retractors. As the fissure is progressively opened, the optic nerve and anterior clinoid process come into view. The tumor is identified, and the overlying arachnoid is opened with microscissors. The tumor is removed from multiple corridors as indicated, between the optic nerve and carotid artery (opticocarotid cistern), between the optic nerves, and lateral to the carotid. Attention is paid to microperforating vessels, which are left intact at all costs. Before closure, meticulous hemostasis is achieved.

Anterior subfrontal approach

The anterior subfrontal approach, although less commonly used than the pterional approach, has the advantage of a straight frontal trajectory with direct visualization of the tumor as it is being removed between the optic nerves. The disadvantages include the potential violation of the frontal sinus and damage to olfactory nerves. This procedure is usually not performed in patients with a prefixed chiasm.

The patient is positioned supine with the head extended, and a bicoronal incision is made behind the hairline. Details of bone flap elevation are provided in previous publications [60,61]. The parasellar structures are exposed by gentle elevation of one or both frontal lobes with brain retractors. An olfactory tract may need to be sacrificed to improve exposure; care is taken to avoid bilateral injury. The tumor is removed in the same manner as with the pterional approach.

Endoscope-assisted transsphenoidal approach

Technologic advances in the areas of endoscope-assisted microneurosurgery [29,30] have been applied to the classic transsphenoidal operation in an attempt to further decrease morbidity and mortality risks [30,31,62]. Although Bushe and Halves [63] reported the first use of the endoscope in pituitary surgery in 1978, its popularity did not flourish until the mid-1990s, when endoscopic sinus surgery had become universally adopted by otolaryngologists in treating inflammatory sinonasal disorders. The excellent visualization and surgical results offered by the endoscope in sinus surgery have prompted neurosurgeons to explore its potential application to transsphenoidal surgery [29,64,65].

Jho and associates [31] have reported a series of 50 patients who underwent endoscopic endonasal transsphenoidal surgery with encouraging results. This approach involves only one nostril. The endoscope is held in the surgeon's nondominant hand, and surgical instruments are held in the dominant hand. Once the anterior sphenoidotomy is made, the endoscope is mounted, thereby freeing up both of the surgeon's hands to maneuver instruments. Some use the endoscope for the initial sphenoidotomy, which is then converted to a microsurgical approach for the tumor resection [62]. Others use the endoscope to inspect for residual tumor that may be out of the surgeon's view [54]. One of the main advantages of this approach is excellent panoramic visualization of the sellar and suprasellar anatomy with increased illumination and magnification [65]. Anatomic studies have demonstrated that the endoscope provides a volume of exposure superior to that of the operating microscope [66]. Major drawbacks include the lack of stereoscopic vision and the lack of adequate instrumentation. Working through the limited space of one nostril can also pose potential conflicts, especially between the surgeon's hands and the endoscope [29]. Moreover, there is a learning curve for using this technique. Nevertheless, the endoscopic technique offers many advantages of a minimally invasive procedure with satisfying preliminary results. Whether these techniques will lead to more effective management of sellar lesions awaits longer follow-up studies and additional experience.

Summary

The transnasal transsphenoidal technique is the preferred approach for pituitary tumors confined primarily to the sella and parasellar regions. In the hands of experienced pituitary surgeons, the rates of morbidity and mortality are extremely low. Extended transsphenoidal approaches have been applied to gain access to the cavernous sinus and suprasellar regions. In some cases, resection via a transcranial approach may be warranted. Endoscopic techniques are being increasingly used and offer a minimally invasive approach and further reduce morbidity associated with the approach to pituitary tumors.

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