Endoscopic skull base surgery represents a unique collaboration between the otolaryngologist and neurosurgeon. Although multidisciplinary approaches to the skull base have existed for decades, endoscopic surgery demands a far greater collaboration among the surgical team members. Surgeons are required to appreciate complex neurovascular and osseous anatomical relationships from a transnasal perspective as well as understand the nuances of each other’s field. For example, the neurosurgeon must understand the benefits of meticulous mucosal preservation in avoiding sinonasal complications, and the otolaryngologist must appreciate the catastrophic consequences of sacrificing a seemingly minor intracranial vessel. The goal of this work is to familiarize surgeons with the transnasal extracranial and intracranial skull base anatomy.

**Ethmoid bone/fovea ethmoidalis**

The medial portion of the ethmoid bone is a cruciate membranous bone composed of the crista galli, cribiform plate, and perpendicular ethmoidal plate. The crista is a thick piece of bone, shaped like a “cock’s comb,” that projects intracranially and attaches to the falx cerebri. This dural attachment is often transected to remove the crista galli during an endoscopic anterior craniofacial resection. The cribiform plate transmits olfactory fibers through numerous perforations to the superior turbinate, nasal septum, and middle turbinate (Figure 1). The perpendicular ethmoidal plate connects with the quadrangular cartilage antero-inferiorly and the vomer postero-inferiorly to form the nasal septum. Preservation of the superior septum is advisable to preserve the olfactory fibers during a posterior septectomy.
or harvesting a nasoseptal flap. If preserved in continuity, the vomer may be used for rigid skull base reconstruction.

The vertical lamella of the middle turbinate divides the anterior skull base into the cribriform plate medially and fovea ethmoidalis laterally. The ethmoid air cells lie lateral to the middle turbinate and medial to the lamina papyracea, the paper-thin wall of the medial orbit. The fovea ethmoidalis slopes inferiorly when traveling in an anterior to posterior or lateral to medial direction along the skull base (Figure 1). Understanding this orientation is important to prevent a trajectory causing an inadvertent violation of the skull base during endoscopic procedures.

The ethmoid roof is composed of a thicker horizontal part called the orbital plate, and a thinner vertical portion called the lateral cribriform plate lamella (LCPL). The thickness of the LCPL varies between 0.05 and 0.2 mm, and its height defines the depth of the olfactory cleft, where the dura is tightly adherent to bone (Figure 1). Greater depths of the olfactory cleft increase the risk of a cerebrospinal fluid leak, pneumocephalus, or intracranial injury during surgery. A shallow, type I (1-3 mm) olfactory cleft is less likely to be violated than a deep, type III (8-16 mm) cleft.

**Lateral nasal wall**

Multiple constant and variable parallel landmarks exist along the lateral nasal wall. Constant landmarks include the uncinate process, anterior face of the ethmoid bulla, basal lamella of the middle turbinate, and sphenoid face. Variable landmarks include the posterior wall of the ethmoid bulla, the superior turbinate basal lamella, and supreme turbinate basal lamella. Progression from anterior to posterior through the sinonasal cavity, in order of appearance, reveals the uncinate process, anterior and posterior ethmoidal bulla, basal lamella of the middle, superior turbinate, supreme turbinate, and sphenoid sinus (Figure 2).

Three to four projections originate from the lateral nasal wall called turbinates (conchae). These include the inferior, middle, superior, and supreme turbinates. Each turbinate has a meatus (space) named for the turbinate above it. The turbinates function to warm, humidify, and purify the air before entering the lungs. The inferior turbinate is derived from the maxilloturbinal whereas the middle, superior and supreme turbinates are derived from the ethmoturbinal (Figure 2).

The middle turbinate is an important anatomic landmark for endoscopic skull base surgery. It is comprised of a body, anterior buttress, posterior buttress, and horizontal and vertical lamellae. The anterior buttress attaches the turbinate to the lateral nasal wall in the agger nasi region, whereas the posterior buttress fixes it to the lateral nasal wall in the posterior ethmoidal region. The vertical lamella attaches the turbinate to the LCPL, which separates the cribriform plate from ethmoid roof. The horizontal lamella (basal lamella) marks the division between the anterior and posterior ethmoid air cells. Preservation of the buttresses and vertical lamella prevent lateralization of the turbinate and subsequent sinonasal obstruction. The turbinate is usually preserved except in malignancies or expanded approaches to the skull base (Figure 2).

The uncinate process is a saber-shaped ethmoid bone attached to the lateral nasal wall through multiple bony and fibrous attachments. It lies lateral to the middle turbinate and extends from the maxillary ostium to the frontal recess. It forms the medial wall of the ethmoid infundibulum, a 3-dimensional space that drains the maxillary, frontal, and anterior ethmoidal sinuses. The superior attachment of the uncinate process influences the frontal sinus drainage pathway. When attached to the lamina, the frontal sinus drains into the middle meatus. If attached to the skull base or middle turbinate, the sinus empties into the ethmoid infundibulum (Figure 2).

The ethmoid bulla is the largest anterior ethmoidal cell and lies posterior to the uncinate process, superior to the infundibulum, and anterior to the basal lamella. The bulla...
extends up to the skull base or is bordered superiorly by a suprabullar cell or a cleft called the suprabullar recess. The space between the bulla and basal lamella is the retobullar recess, which often communicates with the suprabullar recess. The bulla may sometimes be tethered to the skull base by a vertical lamella called the bulla lamella (Figure 2). The anterior ethmoidal artery is often found within millimeters of the bulla lamella coursing superiorly from lateral to medial supplying the lamina, ethmoid sinuses, and septum. If the bulla lamella is absent, the anterior ethmoidal artery usually lies at the base of the frontal recess (Figure 1).

The ostiomeatal complex represents a 3-dimensional space bordered by the lamina papyracea laterally, the middle turbinate medially, the frontal recess superiorly, and the maxillary sinus ostium inferiorly. This space includes the uncinate process, ethmoid infundibulum, ethmoid bulla, and middle turbinates. Inflammation and edema of the ostiomeatal complex after endoscopic skull base surgery must be minimized to prevent anatomic and functional obstruction, leading to chronic rhinosinusitis.

**Frontal sinus/recess**

Although the exact configuration and pathway of the frontal recess is variable, it is usually bound anteriorly by the posterior wall of the agger nasi cell, superiorly by the frontal sinus, medially by the LCPL, laterally by the lamina papyracea, and posteriorly by the anterior wall of the ethmoid bulla, or suprabullar recess. The anatomy of the frontal recess is made complex by the variety of anterior ethmoidal cells that populate the space. Some common prominent cells include the agger nasi cell, supraorbital ethmoid cell, and four types of frontal cells (type I to IV). Frontal recess dissection is necessary to address frontal sinus disease (tumors, mucoceles, cerebrospinal fluid leaks) or provide access for anterior cranial fossa pathology.

**Sphenoid bone/sphenoid sinus**

The sphenoid bone is a butterfly-shaped bone divided into the body centrally, a single greater and lesser wing laterally, and pterygoid processes inferiorly. The lesser wing and planum sphenoidale (sphenoid sinus roof) form the medial wall centrally, a single greater and lesser wing laterally, and pterygoid processes inferiorly. The planum sphenoidale is elliptic in shape and found at the junction of the inferior and middle thirds of the superior turbinate. It is visualized with gentle lateralization of the superior turbinate in the sphenoethmoid recess enclosed by the septum medially, superior turbinate laterally, cribiform plate superiorly, and the nasal floor inferiorly (Figure 4). The sphenoid sinus may also be entered past the posterior ethmoid cells through the medial-inferior triangle of the sphenoid face. This avoids any risk to the optic nerve and carotid artery located in the superior-lateral triangle. It may also be accessed through a transpterygoid approach.

The Onodi (sphenoethmoid) cell is a posterior ethmoidal cell that pneumatizes posterior, lateral and superior to the sphenoid face. It is present in 7%-25% of white patients.
include the lateral optico-carotid recess, the depression between the cavernous sinus apex and V2, and the depression between V2 and V3 (Figure 6). The lateral optico-carotid recess is bound by the optic nerve supero-laterally, and parasellar ICA infero-medially. It corresponds to the optic strut and anterior clinoid process intracranially. The oculomotor nerve (CN III) may also be found inferiorly in this recess (Figure 3). The next recess is triangular in shape with the base at the parasellar region of the carotid and apex which corresponds to the superior orbital fissure. Finally, the region between V2 and V3 represents an embryologic fusion plane of the base-sphenoid called the Sternberg’s canal. Lateral sphenoid sinus encephaloceles from the middle cranial fossa (MCF) may be found in this region secondary to a dehiscence (Figure 6). Another recess, located at the medial intersection of the optic canal, and carotid protuberance, corresponds to the medial clinoid intracranially and is called the medial optico-carotid recess. This recess has been coined the “anatomic keyhole” in endoscopic skull base surgery (Figure 3).7

Sellar/suprasellar anatomy

The pituitary gland, located in the sella turcica is surrounded by several neurovascular structures, including the optic nerves, optic chiasm, and anterior circulation superiorly; the cavernous sinuses, internal carotid arteries and multiple CNs laterally; and the brainstem along with the posterior circulation posteriorly. Anteriorly, the pituitary gland is enclosed by the sphenoid sinus and frontal lobes. Given the high density of critical neurovascular structures around the pituitary gland superiorly, laterally, and posteriorly, anterior approaches are the preferred surgical route to the sellar region (Figure 7).

The cavernous sinuses are located on the lateral aspects of the sphenoid sinus, sella, and pituitary gland. They extend from the superior orbital fissure anteriorly to the petrous apex posteriorly. The medial cavernous sinus walls abut the lateral walls of the pituitary gland, usually separated by a single layer of dura. The internal carotid artery is the most medial structure in the cavernous sinus. It enters the cavernous sinus after exiting the foramen lacerum, lateral to the posterior clinoid processes. The artery travels anteriorly and then superiorly, medial to the anterior clinoid processes where it penetrates the roof of the cavernous sinus. The intracavernous carotid artery is fixed at multiple points which include the bony rings of the anterior and middle clinoid processes and carotid sulcus.

A number of venous channels called intercavernous sinuses connect the bilateral cavernous sinuses. These sinuses are located anterior, posterior, and inferior to the pituitary gland. If the anterior and posterior intercavernous sinuses connect, the entire venous channel is called the circular sinus. The largest, constant intercavernous sinus is the posterior basilar sinus located behind the dorsum sellae and upper clivus. The anterior intercavernous sinus is usually larger than its posterior counterpart and can sometimes
occupy the entire anterior sellar wall. This configuration may cause troublesome but easily controlled bleeding during a transsphenoidal approach. Multiple other combinations of intercavernous sinuses may occur.

Nerves in the medial cavernous sinus wall from superior to inferior include oculomotor (CN III), trochlear (CN IV), ophthalmic (CN V1), and abducens (VI) nerves. CNs III, IV, and V1 lie between 2 dural leaves of the lateral sinus wall, whereas CN VI abuts the medial wall of the internal carotid artery, lateral to the ophthalmic nerve. The oculomotor nerve enters the cavernous sinus lateral and anterior to the dorsum sellae, whereas the ophthalmic nerve enters inferiorly and travels upward to exit the superior orbital fissure. The abducens nerve penetrates the cavernous sinus at the inferior and posterior border, bends around the intracavernous carotid and runs parallel to the ophthalmic nerve (Figure 8).

The suprasellar anatomy has been described as an equilateral pyramid by Perneczky. The anterior wall is made of the optic nerves, anterior optic chiasm, lamina terminalis, anterior cerebral arteries, and their communicating branches. The lateral walls are composed of the internal carotid arteries, optic tracts, anterior choroidal vessels, and posterior cerebral arteries. The posterior wall consists of the mesencephalon, basilar artery, posterior cerebral and superior cerebellar vessels, and oculomotor nerve. The infundibulum and stalk of the pituitary forms the vertical axis of the pyramid. Knowledge of this pyramid aids in conceptualizing the anatomical relationship of neurovascular structures during endoscopic skull base surgery (Figure 9).8

The optic nerves pass through the suprasellar region and anterior incisural space. The anterior incisural space is located between the free edges of the tentorium and anterior part of the midbrain, roughly corresponding to the suprasellar region. The optic nerves exit the optic canals medial to the anterior clinoid processes and are directed posterior, medially and superiorly to the optic chiasm. The optic tracts leave the optic chiasm and travel posteriorly and laterally around the cerebral peduncles to enter the middle incisural space. The optic chiasm is located at the junction of the anterior wall and floor of the third ventricle. Structures situated superior to the optic chiasm are the anterior cerebral and anterior communicating arteries, lamina terminalis and third ventricle. Inferior to the optic chiasm lie diaphragma sellae and pituitary gland, laterally lie the internal carotid arteries and posteriorly lies the infundibulum. The infundibular recess lies at the base of pituitary stalk behind the chiasm (Figure 10).9
Clival/basilar region

The clivus is formed by the posterior portion of the sphenoid body (basi-sphenoid) and occipital bone (basiocciput). It is divided into the intrasphenoidal (upper one-third) and extrasphenoidal (lower two-thirds) clivus. The upper third is formed by the basisphenoid and dorsum sellae, the middle third by the portion of the basiocciput above the petroclival fissures, and the lower third is formed by the lower part of the basiocciput. The tectorial membrane overlies the clival dura in the lower two-thirds of the clivus. The basilar plexus, the largest intercavernous sinus, lies between 2 layers of dura and extends from the dorsum sellae and posterior wall of the sphenoid sinus to the lower clivus. Dissection through the inner dural layer and arachnoid reveals the vertebral arteries, basilar artery and its branches (superior cerebellar arteries, anterior inferior cerebellar ar-

Figure 6  Lateral sphenoid sinus wall. ON, optic nerve; * depressions; Max n, Maxillary nerve; Mand n, Mandibular nerve.

Figure 7  Sellar anatomy. PG, pituitary gland; PS, Pituitary Stalk; OC, Optic Chiasm; ON, Optic Nerve; 1 and 2, anterior cerebral circulation.

Figure 8  Cavernous sinus neural anatomy. Cavallo’s triangles.
tery), posterior cerebral arteries, brainstem, and CNs III, IV, V, and VI (Figure 11).

The oculomotor nerve originates from the midbrain on the medial portion of the cerebral peduncle and passes through the posterior cerebral and superior cerebellar arteries. The oculomotor nerve travels through the interpeduncular cistern, pierces the roof of the cavernous sinus, and travels posteriorly in the superior and lateral corner of the cavernous sinus. The trochlear nerve also arises in the midbrain below the inferior colliculus, travels around the midbrain and pons, and enters the cavernous sinus behind the anterior tentorial attachment. The abducens nerve originates at the lower edge of the pons and then passes either above or below the antero-inferior cerebellar artery. It travels through the preopticine cistern to the upper border of the petrous apex and finally enters the posterior part of the cavernous sinus. The branches of the trigeminal nerve, namely ophthalmic, maxillary and mandibular arise from the pons and divide at the anterior edge of the trigeminal ganglion. The ophthalmic nerve travels in the lower anterior portion of the cavernous sinus and the maxillary nerve runs under the cavernous sinus in the lateral wall of the sphenoid sinus.10

Vascular anatomy sellar/suprasellar region

The vast majority of blood supply to the sellar region is derived from the intracavernous portion of the internal carotid artery. The meningohipophyseal artery is the largest intercavernous carotid artery branch which exits the carotid at the level of the dorsum sellae. The inferior hypophyseal artery originates from the meningohipophyseal trunk, travels medially, and supplies the posterior pituitary. This artery also anastomoses with its counterpart from the opposite side to supply the dura of the sellar floor (Figure 12).

The internal carotid artery and its perforating branches also supply the optic nerve, chiasm, optic tract, infundibulum, and floor of the third ventricle. The superior hypophyseal artery exits the carotid artery in the suprachiasmatic region, and runs medially below the floor of the third ventricle, connects with its counterpart on the contralateral side to form a vascular ring around the infundibulum (Figure 12). The ophthalmic artery, the first branch of the internal carotid artery, arises and enters the optic canal below the optic nerve. It typically arises from the suprachiasmatic portion of the carotid artery but sometimes comes from the intracavernous

Figure 9  Perneczky’s pyramid.

Figure 10  Suprasellar anatomy.

Figure 11  Clival anatomy. PG, pituitary gland; PS, pituitary stalk; OC, optic chiasm; ON, optic nerve; PCA, posterior cerebral artery; SCA, superior cerebellar artery; BA, basilar artery; BS, brainstem.
carotid and rarely as a branch of the middle meningeal artery (Figure 13).

The anterior circle of Willis, anterior cerebral, and anterior communicating arteries are adjacent to the anterior wall of the third ventricle. The posterior circle of Willis and apex of the basilar artery are situated just inferior to the floor of the third ventricle. The anterior cerebral artery comes from the internal carotid artery, and runs anteromedially above the optic nerve and chiasm, connecting contralaterally via the anterior communicating artery near the interhemispheric fissure. The confluence of the anterior communicating artery with bilateral A1 segments typically lies right above the chiasm. Shorter A1 segments are usually found above the chiasm, whereas large A1 segment are located above the optic nerves. Compression of these arteries by the chiasma may result in visual compromise long before tumor impinges on the optic pathway itself. The anterior cerebral and anterior communicating arteries give off branches which supply the third ventricle, hypothalamus, and fornix (Figure 12). 11

The posterior communicating artery originates from the posterior wall of the internal carotid artery, travels postero-medially below the optic tracts and floor of the third ventricle to join the posterior cerebral artery. Its branches supply the optic chiasma in addition to the thalamus, hypothalamus, and internal capsule. The anterior choroidal artery arises from the posterior aspect of the internal carotid artery above the origin of the posterior communicating artery. It travels postero-laterally below the optic tract between the uncus and cerebral peduncle and supplies the optic tract, and posterior part of the third ventricle.

Venous channels in the suprasellar region are small and do not typically cause significant bleeding. The suprasellar region is usually drained by tributaries of the basal vein, which is formed by a confluence of veins draining the suprasellar area. These veins travel between the midbrain and temporal lobes and dump into the internal cerebral vein. The internal cerebral veins typically travel in the roof of the third ventricle and are rarely involved with pituitary adenomas.

**Pterygopalatine fossa**

The pterygopalatine fossa (PPF) is a small (2 × 1.5 × 1 cm) inverted pyramidal space that serves as the gateway for several antero-laterally endoscopic skull base approaches. It is grossly located behind the postero-medial wall of the maxillary sinus. It is enclosed posteriorly by the pterygoid plates, medially by the perpendicular plate of the palatine bone, and laterally by the pterygomaxillary fissure. Superiorly and inferiorly, it is bound by the greater wing of the sphenoid bone, and the pyramidal process of the palatine bone, respectively. The PPF may be divided into an anterior compartment containing fat and blood vessels, and a posterior one encompassing the neural structures. Major neurovascular structures in the PPF include the branches of the internal maxillary artery (IMA), pterygopalatine ganglion, V2 and the VN (Figure 14).

Pterygopalatine branches (third portion) of the IMA located in the PPF include the posterior superior alveolar artery, the infraorbital artery, the descending palatine artery, the pharyngeal artery, artery of the pterygoid canal, and the sphenopalatine artery. Sphenopalatine artery branches provide blood supply for several pedicled flaps used for endoscopic skull base reconstruction. These branches include the posterior lateral nasal artery which supplies the nasal turbinates, and the posterior septal artery which anastomoses with the ethmoidal arteries to supply the posterior nasal septum. Venous drainage from the PPF is provided by the pterygoid venous plexus which lies between the masticator, temporal, and the internal and external pterygoid muscles (Figure 14).
The sphenopalatine (pterygopalatine) ganglion, one of four head and neck parasympathetic ganglions is located in the neural compartment of the PPF. Nerves associated with the ganglion include ascending (to the orbit), posterior (to the pharynx), internal (to the nose), and inferior (to the palate). These nerves include the VN, pharyngeal nerve, descending palatine nerves, nasopalatine nerves, and posterior superior nasal nerve. The VN is formed by preganglionic parasympathetic fibers carried by the greater petrosal nerve, and postganglionic sympathetic fibers from the deep petrosal nerve. It travels through the vidian canal and its parasympathetic fibers synapse on the pterygopalatine ganglion and distribute to the nose, palate and lacrimal gland through multiple foramina leaving the PPF. The VN is a critical surgical landmark for the safe identification of the horizontal petrous carotid during supra- and infrapetrous transpterygoid approaches (Figure 15). The maxillary nerve exits the foramen rotundum, enters the PPF, gives off branches, and continues as the infraorbital nerve through the infraorbital canal, which separates the PPF (medial) from the infratemporal fossa (ITF; lateral). Laterally, it is bound by the zygomatic arch and mandible and medially, it is bordered by the lateral pterygoid plate, the pyramidal process of palatine bone, and squamous portion of the temporal bone. The ITF communicates superiorly with the temporalis fossa transmitting the temporalis muscle, nerve, and vessels. It also accepts the mandibular division of the trigeminal nerve (V3) exiting the foramen ovale and the middle meningeal vessels coming from the foramen spinosum. Anteriorly, it communicates with the orbital cavity through the infraorbital fissure, which is located between the greater wing of the sphenoid and maxilla; and medially with the PPF via the pterygomaxillary fissure sending through the terminal branches of the IMA. The fossa contains several structures that are bound by fibrofatty tissues.

Infratemporal fossa

The ITF is a large irregular space located above the parapharyngeal space that is bound superiorly by greater wing of the sphenoid, inferiorly by the alveolar processes, anteriorly by the posterior surface of the maxilla, and posteriorly by the auricular tubercle of the temporalis bone. Laterally, it is bound by the zygomatic arch and mandible and medially, it is bordered by the lateral pterygoid plate, the pyramidal process of palatine bone, and squamous portion of the temporal bone. The ITF communicates superiorly with the temporalis fossa transmitting the temporalis muscle, nerve, and vessels. It also accepts the mandibular division of the trigeminal nerve (V3) exiting the foramen ovale and the middle meningeal vessels coming from the foramen spinosum. Anteriorly, it communicates with the orbital cavity through the infraorbital fissure, which is located between the greater wing of the sphenoid and maxilla; and medially with the PPF via the pterygomaxillary fissure sending through the terminal branches of the IMA. The fossa contains several structures that are bound by fibrofatty tissues.
connective tissue, which include muscles (medial and lateral pterygoid), ligaments (sphenomandibular ligament), nerves (mandibular division of the trigeminal nerve, chorda tympani), and vessels (IMA and branches of its mandibular and pterygoid divisions, the middle meningeal artery, and the pterygoid venous plexus).

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