Comprehensive Management of Skull Base Tumors

Edited by Ehab Y. Hanna & Franco DeMonte

Otalaryngology/Neurosurgery

about the book...
The management of tumors in and adjacent to the skull base is challenging given the complex and critically important anatomy of the region and the wide diversity of tumor pathologies that may be encountered. To help navigate the complexities of contemporary multidisciplinary management of these patients, Drs. Hanna and DeMonte bring you Comprehensive Management of Skull Base Tumors, a comprehensive guide filled with updated information from authorities around the world.

Comprehensive Management of Skull Base Tumors is divided into three sections consisting of:
• general principles
• site specific surgery
• tumor specific management

Filled with scientific tables and lavishly illustrated, this text is written with an emphasis on surgery, radiation and chemotherapy, and will appeal to all neurosurgeons, otolaryngologists, plastic surgeons, maxillofacial surgeons, ophthalmologists, medical and radiation oncologists, and radiologists.

about the editors...
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This book is dedicated to

My wife, Sylvie,
for her grace, gentle spirit, and beauty.
Our daughters, Gabrielle Grace “Gigi” Hanna and Camille Lauren Hanna,
for the joy and blessing they bring to our lives;
My parents,
who encouraged me to follow my dreams;
My Fellows, residents, and students,
who continue to teach me;
And my patients,
Whose endurance, resilience, and faith continue to amaze me.

Ehab Y. Hanna, MD

My parents, Dolinda and Giacomo, for their love, their sacrifices, and their dedication to my education.
To my children, Evan and Madeline who fill me with pride.
And, with limitless love, to Paula, my wife and best friend.

Franco DeMonte, MD
The management of patients with tumors of the skull base has evolved significantly in the last two decades. Major advances have been achieved in the surgical management of these patients, particularly in the areas of tumor resection and surgical reconstruction. These advances can be mainly attributed to the collaborative efforts of dedicated teams representing various surgical disciplines including neurosurgery, head and neck surgery, neuro-otology, oromaxillofacial surgery, ophthalmology, and plastic and reconstructive surgery. Meanwhile significant advances in radiation delivery using various methods of conformal therapy, including three-dimensional computerized tomography (3D-CT), intensity-modulated radiation therapy (IMRT), proton beam therapy, and stereotactic radiation, as well as advances in chemotherapy and targeted biologic therapy have added significantly to the menu of treatment options for patients with tumors of the skull base. Although there are many excellent references describing the surgical management of patients with tumors of the cranial base, this textbook is intended to be a comprehensive guide to help navigate the complexity of contemporary multidisciplinary management of these patients. In addition, we hope that this reference will also provide the reader with a deeper understanding of the unique biologic behavior and the underlying molecular and genetic aberrations of the various tumor types originating from or involving the cranial base, and the potential for these molecular derangements to be putative targets for future development of more effective biologic therapy. To address these goals, we have organized the book in three sections: general principles, site-specific chapters, and tumor-specific chapters.

Section one covers general topics pertinent to all patients with neoplasms of the skull base, regardless of specific location or tumor type. These topics include anatomy, pathology, genetics, clinical evaluation, diagnostic imaging, anesthesia, minimally invasive surgery, surgical reconstruction, prosthetic rehabilitation, radiation and radiobiology, chemotherapy, evaluation and rehabilitation of speech and swallowing, functional outcomes and quality of life issues, neurocognitive assessment, and cerebrovascular management.

Section two covers site-specific information regarding the various anatomic regions of the cranial base, including surgical anatomy, regional pathology, differential diagnosis, clinical assessment, diagnostic imaging, and surgical approaches. This regional classification includes the anterior cranial fossa, sinonasal region, nasopharynx, clivus, infratemporal fossa, parapharyngeal space, temporal bone, sella turcica, middle cranial fossa, petrous apex, cerebellopontine angle, jugular foramen, and craniovertebral junction.

Section three covers comprehensive multidisciplinary discussion of tumor-specific topics such as tumor incidence and epidemiology, pathology, staging, treatment, outcome, and prognosis. This section covers the following tumors of the cranial base: squamous and non-squamous cell carcinoma, olfactory neuroblastoma, melanoma, sarcomas, angiofibromas and other vascular tumors, chordomas and chondrosarcomas, meningiomas, schwannomas, paragangliomas, pituitary adenomas, craniopharyngiomas, epidermoid and dermoid cysts, fibro-osseous lesions, and metastatic tumors.

This organizational schema is intended to provide a simple yet comprehensive way for readers to find the information they need. For example, the reader who wants to know about the latest advances in radiation therapy of skull base tumors is referred to the first section, a reader who has a patient with a tumor of the petrous apex is referred to the second section, and another who wants to know all the available treatment options and prognostic factors for esthesioneuroblastoma is referred to the third section. With such an organizational structure, some redundancy is unavoidable, but not, as you will see, detrimental. As with any textbook, some omissions are inevitable and we hope our readership will forgive any shortcomings of this work. We believe that the greatest value of this book is the incredible expertise of the contributing authors. They truly represent the world’s experts on their specific topics. We are honored by their contribution and humbled by their graciousness to join us in this work.

Ehab Y. Hanna
Franco DeMonte
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Section 1

General Principles
Anatomy of the Cranial Base

Carolina Martins and Albert L. Rhoton, Jr.

OVERVIEW

No part of the cranial base is immune to surgical pathology or to its use as a pathway to access lesions in the intra- or extracranial spaces. Tumors and multiple other lesions can involve any of the intracranial fossae, and can appear in the paranasal sinuses, nasal cavity, infra-temporal and pterygopatine fossae, and the infratemporal and infrapetrosal spaces (Fig. 2). Both surfaces are connected by canals, foramina, and fissures through which numerous neurovascular structures pass. Both the endocranial and exocranial cranial base surfaces are divided into anterior, middle, and posterior parts, each of which has a central and paired lateral portions. On the intracranial side, the three parts correspond to the anterior, middle, and posterior cranial fossae (Figs. 2 and 4) (1,2). On the endocranial side, the border between the anterior and middle cranial bases is the sphenoid ridge joined medially by the chiasmatic sulcus, and the border between the middle and posterior cranial bases is formed by the petrous ridges joined by the dorsum sellae and posterior clinoid processes. On the exocranial side, the anterior and middle cranial bases are divided at the level of the transverse line extending through the pterygopatine fossae and the greater sphenoid wing at the upper level and the posterior edge of the alveolar process of the maxilla at a lower level. Medially, this corresponds to the anterior part of the attachment of the vomer to the sphenoid bone. The middle and posterior cranial bases are separated by a transverse line crossing at or near the posterior border of the vomer–sphenoid junction, the foramen lacerum, carotid canal, jugular foramen, styloid process, and the mastoid tip. The osseous structures, their foramina and fissures, canals and their muscular, and neural and vascular relationships are described in this chapter.

ANTERIOR CRANIAL BASE

Endocranial Surface

The anterior endocranial surface, formed by the ethmoid, sphenoid, and frontal bones, is divided into medial and lateral portions (Figs. 3–5). The medial part, covering the upper nasal cavity and the sphenoid sinus, is formed by the crista galli and the cribriform plate of the ethmoid bone anteriorly and the planum of the sphenoid body posteriorly. The lateral part, which covers the orbit and the optic canal, is formed by the frontal bone and the lesser wing of the sphenoid bone, which blends medially into the anterior clinoid process (Figs. 3 and 4). The foramen caecum in the midline serves as the site of passage of an emissary vein and the cribiform plate is pierced by the filaments of the olfactory nerve. The optic canal transmits the optic nerve and the ophthalmic artery. The anterior cranial base faces the frontal lobes with the gyri recti medially and the orbital gyri laterally along with the branches of the anterior cerebral arteries medially and middle cerebral arteries laterally.
annular tendon of Zinn, a fibrous ring that surrounds the central part of the superior orbital fissure and the optic canal, gives attachment to the superior, medial, inferior, and lateral rectus muscles (Fig. 4). The superior oblique branches above the annular tendon and the inferior oblique arises from the intermuscular septum just behind the rim. The oculomotor foramen, located inside the annular tendon and through which the oculomotor nerve passes, is located between the upper and lower attachment of the lateral rectus muscle. Just before passing through the superior orbital fissure and the oculomotor foramen in the annular tendon, the oculomotor nerve divides into an upper division supplying the superior rectus and lateral muscles and a lower division to the medial and inferior rectus and inferior oblique muscles. The oculomotor nerve gives rise to the parasympathetic motor root to the ciliary ganglion which has the same origin as the oculomotor nerve. The abducens nerve passes through the oculomotor foramen and enters the medial surface of the lateral rectus muscle. The oculomotor nerve divides just behind the annular tendon into lateral and frontal nerves which pass outside the annular tendon, and into the nasociliary nerve which passes through the annular tendon. The oculomotor nerve gives rise to the lateral ciliary nerve, the sensory root to the ciliary ganglion, the former conveys the sympathetic pupillomotor fibers and the latter conveys corneal sensation. The trochlear nerve passes above and outside the superomedial edge of the annular tendon. The optic nerve passes superior and medial from the globe to reach the optic canal and divides the retro-orbital space in medial and lateral parts. The main arterial supply to the orbit is by the ophthalmic artery and its branches. This artery courses below the optic nerve in the optic canal, crosses to the lateral side of the nerve at the orbital apex, and then courses from lateral to medial above the optic nerve. The main branches are the central retinal artery and the lacrimal, ciliary, ethmoidal, supraorbital, and dorsal nasal arteries, plus numerous muscular branches. The main venous drainage of the orbit is through the superior and inferior ophthalmic veins that exit the orbit by passing outside the annular tendon and through the superior orbital fissure. The lacrimal gland, located in the superolateral part of the orbit, receives its sensory innervation from the lacrimal nerve, and its parasymptomatic and sympathetic innervation from the greater and deep petrosal nerves. The petrosal nerves join to form the vidian nerve that enters the pterygopalatine ganglion, which sends branches to the zygomatic nerve that anastomoses with the lacrimal nerve to reach the gland.

MIDDLE CRANIAL BASE

Endocranial Surface

The endocranial surface of the middle portion of the middle cranial base, formed by the sphenoid and temporal bones, has medial and lateral parts (Figs. 2, 3, 5, and 9). The medial part is formed by the body of the sphenoid bone, the site of the tuberculum sellae, pineal body and the ventral part of the posterior clinoid processes, the carotid siphon, and the dorsum sellae (Fig. 8). The lateral part is formed by the lesser and greater sphenoid wings, with the superior orbital fissure between them (Figs. 3 and 5). The lesser wing is connected to the body of the sphenoid bone by an anterior root, which forms the roof of the optic canal, and by a posterior root, also called the optic strut, which forms the floor of the optic canal and separates the optic canal from the superior orbital fissure (Fig. 3). The greater wing forms the largest part of the endocranial surface of the middle fossa, with the squamosal and the petrosal parts of the temporal bone completing this surface. The superior orbital fissure transmits the oculomotor, trochlear, ophthalmic, and abducens nerves, a recurrent meningeal artery, and the superior and inferior ophthalmic veins (6). The maxillary and mandibular nerves pass through the foramen rotundum and ovale, both located in the greater wing of the sphenoid. The neuromeningeal emissary foramen, located antrumeral to the fora men spinosum, gives passage to a vein connecting the cavernous sinus and the pterygoid venous plexus. The upper surface of the petrous bone is grooved along the course of the greater and lesser petrosal nerves (Figs. 5) (7). The carotid canal extends upward and medially and provides passage to the internal carotid artery and carotid sympathetic nerves in their course to the cavernous sinus. The posterior trigeminal root reaches the middle fossa and the impression on the upper surface of the petrosal bone where Meckel’s cave and the semilunar ganglion sit. The roof of the carotid canal opens below the trigeminal ganglion near the distal end of the carotid canal (Figs. 5, 6, and 9). The arcuate eminence approximates

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Figure 1. Anterior and middle cranial base. (A) On the left side, the floor of the anterior fossa and the upper portion of the maxilla have been removed to expose the structures deep to the anterior and middle cranial fossa. The frontal, ethmoidal, and sphenoid sinuses and the nasal cavity lie below the medial part of the anterior cranial base. The orbit and maxilla are located below the lateral part of the anterior cranial base. The sphenoid sinus and sella are located in the medial part of the middle cranial base, and the infra-temporal and pterygopalatine fossae are located below the lateral part of the middle cranial base. The carotid arteries pass upward on the medial part of the middle cranial base and are intimately related to the sphenoid and cavernous sinuses. The infra-temporal fossa, which contains branches of the mandibular nerve, pterygoid muscles, pterygoid venous plexus, and maxillary artery, is located below the middle cranial base and greater sphenoid wing. The alveolar process of the maxilla, which encloses the roots of the upper teeth, has been preserved on the left side. The maxillary nerve enters the pterygopalatine fossa, which is located medial to the infratemporal fossa between the posterior wall of the maxilla and the pterygoid process of the sphenoid bone. (B) Superior view of the anterior and middle cranial base. The infratemporal fossa is located posterosmedial to the maxilla. The right ethmoidal arteries pass upward on the medial side of the right orbit. The nasal cavity extends upward between the ethmoidal sinuses. (C) Oblique anterior view. The facial structures on the right side have been removed to expose the orbital apex located above the maxillary sinus. The wall of the right maxillary sinus forms the floor of the orbit, much of the lateral wall of the nasal cavity, and the anterior wall of the pterygopalatine and infratemporal fossae. On the left side, the maxillary nerve enters the pterygopalatine fossa. The maxillary nerve enters the pterygopalatine fossa, which is located in the lateral wall of the nasal cavity and contains the maxillary nerve, pterygopalatine ganglion, and terminal branches of the maxillary artery. (D) Anterior view. The orbital apex is located above the pterygopalatine fossa. The frontal branch of the ophthalmic nerve passes along the roof of the orbit, and the infraorbital branch of the maxillary nerve courses in the floor of the orbit. The carotid and maxillary arteries are located posterior to the orbital apex. The former forms the posterior part of the nasal septum and attaches to the maxillary region. The latter forms the pterygopalatine fossa, which is located medial to the orbital apex, and its branches and palatine bones below and to the body of the sphenoid bone above. The sphenoid sinus is located in the middle cranial base below the sella turcica. The upper brain stem is seen in the posterior part of the exposure. (L) Abbreviations: A., artery; Al., alveolar; Br., branch; Car., carotid; Cant., cartilage; CN, cranial nerve; Eth., ethmoid; Ex., maxilla; For., frontal; Gang., ganglion; Int., infraorbital; Infra., infratemporal; Ltg., lachrymal; Max., maxilla; M., muscle; Nas., nasal; Naso., nasoalveolar; Orh., orbital; Pit., pituitary; Pl., pterygoid; Pteryg., pterygopalatine; Sph., Sphenoid.
Figure 2  Lateral view of the anterior, middle, and posterior cranial base. (A) The bone and structures lateral to the orbit, infratemporal, and pterygopalatine fossa, and the parapharyngeal space and petrous part of the temporal bone have been removed to expose the structures below the anterior, middle, and posterior cranial base. The orbit and maxillary sinus are located below the anterior cranial base. The infratemporal and pterygopalatine fossae and the parapharyngeal space are located below the middle cranial base, and the suboccipital area is located below the temporal and occipital bones. The first trigeminal division is related to the upper part of the orbit. The second trigeminal branch is related to the lower part of the orbit and maxilla. The mandibular nerve exits the cranium through the foramen ovale and enters the infratemporal fossa. The pterygoid and levator and tensor veli palatini muscles have been removed to expose the eustachian tube and its opening into the nasopharynx. The lateral part of the temporal bone has been removed to expose the cochlea, vestibule, and semicircular canals. The petrous carotid passes upward and turns medially below the cochlea. The sigmoid sinus turns downward under the semicircular canals and vestibule where the jugular bulb is located. The segment of the vertebral artery passing behind the atlanto-occipital joint is located below the posterior cranial base. (B) The dura has been opened to show the relationships of the frontal and temporal lobes and the cerebellum to the cranial base. The orbit is exposed below the frontal lobe. The pterygopalatine and infratemporal fossae and the temporal bone are located below the temporal lobe. The jugular bulb and internal jugular vein have been removed to show cranial nerves IX through XII exiting the jugular foramen. (1) Abbreviations: A., artery; Car., carotid; CN, cranial nerve; Eust., eustachian; Front., frontal; Gr., greater; Inf., inferior; Infraorb., infraorbital; Infraorb., infratemporal; Int., internal; Jug., jugular; Lat., lateral; M., muscle; Max., maxillary; N., nerve; Ped., peduncle; Pet., petrosal; Pterygopal., pterygopalatine; Rec., rectus; Semicirc., semicircular; Sphen., sphenoid; Temp., temporal; V., vein; Vert., vertebral.
For. lacerum is interposed above the anterior nasal aperture between the maxillae. The nasal cavity is located between the ethmoid bones, the nasal bone, and the vomer. The inferior concha is a separate bone, and above and the maxillae and palatine bones, and sphenoid pterygoid process below. It is roofed by the frontal and ethmoid bones and the floor is formed by the maxilla to create the pterygomaxillary fissure, which opens medially into the pterygopalatine fossa. 

The posterior part of the cranial base is formed by the temporal and occipital bones. The orbit opens through the superior orbital fissure into the middle fossa and through the inferior orbital fissure into the pterygopalatine and infratemporal fossae.

On the endocranial surface, the anterior and middle cranial bases correspond to the anterior and middle fossae. The anterior part of the cranial base is separated from the middle fossa by the sphenoid ridge and the chiasmatic cistern. The middle cranial base is separated from the posterior cranial base by the dorsum sellae and the petrous ridges. The upper surface of the anterior cranial base is formed by the frontal bone, which roofs the orbit; the ethmoid bone, which is interposed between the frontal bones and the site of the cribriform plate; and the lesser wing and anterior part of the body of the sphenoid, which forms the anterior part of the floor of the anterior fossa. The upper surface of the middle cranial base floor is formed by the greater sphenoid wing and posterior two-thirds of the sphenoid body anteriorly and the upper surface of the temporal bone posteriorly. The posterior part of the cranial base is formed by the temporal and occipital bones. The cribriform plate, sella, and clivus are located in the medial part of the cranial base. The lateral part of the cranial base is located above the orbits, pterygopalatine and infratemporal fossae, and the subtemporal and lateral part of the suboccipital areas.

On the endocranial surface, the anterior and middle cranial bases correspond to the anterior and middle fossae. The anterior part of the cranial base is separated from the middle fossa by the sphenoid ridge and the chiasmatic cistern. The middle cranial base is separated from the posterior cranial base by the dorsum sellae and the petrous ridges. The upper surface of the anterior cranial base is formed by the frontal bone, which roofs the orbit; the ethmoid bone, which is interposed between the frontal bones and the site of the cribriform plate; and the lesser wing and anterior part of the body of the sphenoid, which forms the anterior part of the floor of the anterior fossa.
Figure 3 (Continued) (F) Inferior view of a cross section extending through the maxillae. The maxilla, which contains a large air-filled sinus, forms the anteromedial wall of the infratemporal fossa, the anterior wall of the pterygopalatine fossa, the lateral wall of the nasal cavity, the anterior portion of the hard palate, and much of the floor of the orbit. The pterygopalatine fossa is located between the pterygoid process and the posterior maxillary wall. The nasal septum is formed anteriorly and above by the perpendicular ethmoid plate and posteriorly and below by the vomer. (G) The right half of the maxilla and zygomatic arch has been removed. The inferior orbital fissure is located between the greater sphenoid wing and the maxilla. The right orbital roof and ethmoid air cells have been preserved. The right pterygoid process has been removed at its junction with the sphenoid body. The roof of the vidian canal, which extends through the base of the pterygoid process, has been preserved. (H) Anterior view of the cranial base. The midline of the cranial base is formed, from anterior to posterior, by the frontal, ethmoid, sphenoid, and occipital bones. The roof of the orbit is formed by the frontal bone and lesser sphenoid wing. The ethmoidal sinuses are located anterior to the sphenoid sinus between the orbits. (I) Lateral view of the pterygoid air cells. The pterygoid air cell is located between the posterior maxillary wall and the pterygoid process. The pterygoid air cell opens from the infratemporal fossa into the pterygopalatine fossa. The mandibular fossa is formed above by the squamous part of the temporal bone and posteriorly by the tympanic part of the temporal bone, which also forms the anterior and lower wall of the external auditory meatus. (J) Anterior view through the maxillary sinus. The anterior and posterior walls of the maxillary sinus have been removed to expose the pterygoid process, which forms the posterior wall of the pterygopalatine fossa. The lower part of the superior orbital fissure is seen through the upper part of the maxillary sinus. The foramen rotundum opens into the pterygopalatine fossa and is separated from the superior orbital fissure by the maxillary strut. The vidian canal opens through the pterygoid process below and medial to the foramen rotundum. (K) Anterior view of a cranium sectioned through the posterior part of the ethmoid and maxillary sinuses. The ethmoidal sinuses are located anterior to the sphenoid body and sphenoid sinus. The part of the posterior wall of the maxilla forming the anterior wall of the pterygopalatine fossa has been preserved. The perpendicular plate of the palatine bone forms the medial wall of the pterygopalatine fossa. The ethmoidal sinus overlaps the lateral margin of the sphenoid ostia. The superior orbital fissure is located between the lesser and greater sphenoid wings and the sphenoid body. The infratemporal fossa is located below the greater wing of the sphenoid. The temporal fossa, which contains the temporal muscle, is located between the greater wing and the zygomatic arch. (L) The posterior wall of the maxilla and ethmoidal sinuses have been removed to expose the sphenoid sinus and pterygopalatine fossa. The lateral wing of the sphenoid sinus extends posteriorly into the pterygoid process below the foramen rotundum. Septae divide the sphenoid sinus. The vidian canal opens through the base of the pterygoid process into the pterygopalatine fossa. (Continued).
Figure 3 (Continued) (N) Posterior view of the specimen in K showing the anterior part of the middle fossa from behind. The superior orbital fissure is positioned below the lesser sphenoid wing. The optic strut extends from the base of the anterior clinoid to the sphenoid body and separates the optic canal from the superior orbital fissure. The greater wing extends laterally to form part of the floor and anterior and lateral walls of the middle fossa. The medial and lateral pterygoid plates project backward from the pterygoid process. The horizontal plate of the palatine bone forms the posterior part of the hard palate. The posterior opening into the vidian canal is located above the medial pterygoid plate and extends forward through the pterygoid process at its junction with the sphenoid body (1).

Abbreviations: Ant., anterior; Car., carotid; Clin., clinoid; Cond., condyle; Crib., cribiform; Eth., ethmoid; Fiss., fissure; For., foramen; Front., frontal; Gr., greater; Horiz., horizontal; Inf., inferior; Infraorb., infraorbital; Infratemp., infratemporal; Jug., jugular; Lat., lateral; Less., lesser; Mandib., mandibular; Max., maxillary; Med., medial; Orh., orbital; Occip., occipital; Palat., palatine; Perp., perpendicular; Pet., petrosal; Petros.; Post., posterior; Proc., process; Pteryg., pterygoid; Pterygomax., pterygomaxillary; Pterygopal., pterygopalatine; Sphin., sphenoid; Squam., squamosal; Sup., superior; Supraorb., supraorbital; Temp., temporal.
Figure 4  Anterior fossa, orbit, and perinasal sinuses. (A) Superior view. The anterior cranial fossa is formed by the frontal, ethmoid, and sphenoid bones. The frontal bone splits anteriorly into two laminae, which enclose the frontal sinus. The ethmoid bones, which contain the ethmoid air cells and are the site of the crista galli and cribiform plate, are interposed between the frontal bones. Posteriorly, the frontal and ethmoid bones join the sphenoid bone, which encloses the sphenoid sinus and has the pituitary fossa on its upper surface. The olfactory bulbs and tracts have been preserved. (B) The roof of the right orbit has been removed to expose the periorbita. The right anterior clinoid process and roof of the optic canal have been removed to expose the optic nerve enclosed within the optic sheath as it passes through the optic canal to reach the orbital apex. (C) The frontal, trochlear, and lacrimal nerves can be seen through the periorbita. The trochlear nerve crosses above the orbital apex to reach the superior oblique muscle. (D) The orbital fat has been removed and the sphenoid sinus opened. The frontal branch of the ophthalmic nerve courses above the levator muscle. The ophthalmic artery, nasociliary nerve, and superior ophthalmic vein are located medially in the anterior part of the orbit and cross between the optic nerve and the superior rectus muscle and are thus situated on the lateral side of the optic nerve at the orbital apex. (E) Enlarged view. The superior oblique muscle has been retracted medially to expose the anterior and posterior ethmoidal branches of the ophthalmic artery and nasociliary nerve entering the anterior and posterior ethmoidal canals. The trochlea of the superior oblique muscle is attached to the superomedial margin of the orbit just behind the orbital rim. The frontal nerve divides into supraorbital and supratrochlear branches. (F) The levator and superior rectus muscles have been retracted posteriorly to expose the nasociliary nerve, ophthalmic artery, and superior ophthalmic vein passing above the optic nerve. (G) Superior view of the anterior fossa in another specimen. The nasal cavity, sphenoid sinus, and orbit have been unroofed. The dura has been removed from the roof and lateral wall of the cavernous sinus. The medial strip below the anterior cranial base is formed, from anterior to posterior, by the frontal, ethmoidal, and sphenoid sinuses. The orbital fat has been removed to expose the intraorbital structures. The frontal nerve courses above the levator muscle. The trochlear nerve passes above the annular tendon to reach the superior oblique muscle. The trochlea of the superior oblique muscle is attached in the superomedial part of the anterior orbit. The lacrimal nerve courses above the lateral rectus muscle. The ophthalmic artery and superior ophthalmic vein are seen in the interval between the levator and superior oblique muscles. The anterior and posterior ethmoidal branches of the ophthalmic artery course through the anterior and posterior ethmoidal canals. (Continued).
Figure 4 (Continued) (H) Enlarged view of cavernous sinus, superior orbital fissure, and orbital apex. The superior oblique, levator, and superior rectus muscles have been removed. The ophthalmic artery and nasociliary nerve enter the orbital apex on the lateral side of the optic nerve and cross between the optic nerve and superior rectus muscle to reach the medial part of the orbit. The optic nerve has been elevated to expose the ophthalmic artery, which courses through the optic canal on the lower side of the optic nerve and enters the orbital apex on the lateral side of the optic nerve. The ophthalmic artery then crosses medially between the optic nerve and the superior rectus muscle, as does the nasociliary nerve. The maxillary nerve exits the foramen rotundum to enter the pterygopalatine fossa, and the mandibular nerve exits the foramen ovale to enter the infratemporal fossa. (1) Abbreviations: A., artery; ACA, anterior cerebral artery; Ant., anterior; Car., carotid; Cav., cavernous; Clin., clinoid; CN, cranial nerve; Cribr., cribriform; Eth., ethmoid; Eth., ethmoidal; Front., frontal; Lac., lacrimal; Less., lesser; Lev., levator; M., muscle; Med., medial; MCA, middle cerebral artery; N., nerve; Nasocil., nasociliary; Olf., olfactory; Ophth., ophthalmic; Post., posterior; Rec., rectus; Seg., segment; Sphen., sphenoid; Sup., superior; Supraeth., supraethtial; Supratroch., supratrochlear; Tr., tract; V., vein.
Figure 5  Superior view of middle cranial base. (A) The floor of the middle fossa has been preserved. The anterior part of the floor of the middle fossa is formed by the greater sphenoid wing, which roofs the infratemporal fossa, and the posterior part of the floor is formed by the upper surface of the temporal bone. The internal acoustic meatus, mastoid antrum, and tympanic canals have been unroofed. The dural roof and lateral wall of the cavernous sinuses have been removed. The petrosal segment of the internal carotid artery is exposed lateral to the trigeminal nerve. The temporalis muscle is exposed in the temporal fossa lateral to the greater sphenoid wing. (B) The floor of the middle fossa has been removed to show the relationship below the floor. The temporalis muscle descends medial to the zygomatic arch in the temporal fossa to insert on the coronoid process of the mandible. The infratemporal fossa is located medial to the temporal bone, below the greater sphenoid wing, and contains the pterygoid muscles and venous plexus and branches of the mandibular nerve and maxillary artery. The mandibular condyle is located below the posterior part of the middle fossa floor, which is formed by the temporal bone. (C) Enlarged view of the posterior part of the area below the middle fossa floor. The roof of the temporal bone, which forms the posterior part of the floor of the middle fossa, has been opened to expose the mastoid antrum, eustachian tube, semicircular canals, cochlea, the nerves in the internal acoustic meatus, and the mandibular condyle. (D) The trigeminal nerve has been reflected forward. The abducens nerve passes below the petrosphenoid ligament and through Dorello’s canal. The petrosal segment of the carotid passes below the petroclival ligament to enter the cavernous sinuses. The greater petrosal nerve is joined by the deep petrosal branch of the carotid sympathetic plexus to form the vidian nerve, which passes forward in the vidian canal, which has been unroofed. The lesser petrosal nerve arises from the tympanic branch of the glossopharyngeal nerve, which passes across the promontory to the tympanic nerve plexus and regroups to cross the floor of the middle fossa, exiting the cranium to provide parasympathetic innervation through the otic ganglion to the parotid gland. The tensor tympani muscle and eustachian are layered, with the former above the latter, along and separated from the anterior surface of the petrous carotid by a thin layer of bone (1). Abbreviations: A., artery; Ac., acoustic; Cav., cavernous; CN, cranial nerve; Cond., condyle; Cnt., cavernous; Ext., external; Gr., greater; Lat., lateral; Less., lesser; Lig., ligament; M., muscle; Mandib., mandibular; Mast., mastoid; Max., maxillary; N., nerve; Ophth., ophthalmic; Petroling., petrolingual; Petrol., petrosal; Petrosphen., petrosphenoid; Plex., plexus; Pltny., pterygoid; Seg., segment; Semicirc., semicircular; Temp., temporalis; Tymp., tympanic.
Figure 6  (A) Inferior view of cranial base. The right pterygoid process has been sectioned and removed at its junction with the greater wing and body of the sphenoid bone to expose the pterygopalatine fossa and the vidian canal. The vidian nerve, formed by the union of the superficial and deep petrosal nerves, courses in the vidian canal, which passes through the root of the pterygoid process. It opens posteriorly at the anterolateral margin of the foramen lacerum and anteriorly into the medial portion of the pterygopalatine fossa. The sulcus tubae, which is the attachment site of the cartilaginous part of the eustachian tube to the cranial base, is located on the extracranial surface of the sphenopetrosal fissure, anterolateral to the foramen lacerum and the carotid canal, and posteromedial to the foramen ovale and spinosum. The lateral part of the inferior orbital fissure opens into the infratemporal fossa, located below the greater sphenoid wing, and the medial part opens into the pterygopatine fossa, located below the orbital apex between the maxilla and pterygoid process. The right zygomatic arch has been removed. (B) Inferior view of axial section of a cranium at the level of the maxillary sinus. The pterygopalatine fossa is located between the posterior wall of the maxillary sinus and the pterygoid process. The roof of the maxillary sinus forms the floor of the orbit. The infratemporal fossa is located below the greater wing of the sphenoid and opens medially into the pterygopalatine fossa. The medial wall of the pterygopalatine fossa is formed by the perpendicular plate of the palatine bone, which has an opening, the sphenopatine foramen, through which branches of the maxillary artery and nerve reach the nasal cavity. The ethmoid air cells are located medial to the orbit. (Continued).
the position of the superior semicircular canal. A thin lamina of bone, the tegmen tympani, roofs the area above the middle ear and auditory ossicles on the anterolateral side of the arcuate eminence. The internal auditory canal can be identified below the floor of the middle fossa by drilling along a line approximately 60 degrees medial to the arcuate eminence, near the middle portion of the angle between the greater petrosal nerve and arcuate eminence (Fig. 5). The petrous apex, medial to the internal acoustic meatus, is free of important structures.
Chapter 1: Anatomy of the Cranial Base

The middle cranial base can be divided into a lateral portion, containing the middle cranial fossa and the upper surface of the temporal bone, and a medial portion, the sellar and the parasellar region, where the pituitary gland and cavernous sinus are located (Figs. 3 and 8) (8). The basal temporal lobe, formed by the parahippocampal, occipitotemporal, infratemporal gyr, and uncus and supplied by branches of the anterior choroidal, posterior cerebral, and middle cerebral arteries, rests on the middle fossa floor. The cavernous sinus, situated between two layers of dura, is formed by an outer layer facing the brain, and inner or peristeum layer, covering the bone of the middle fossa (9). The inner layer splits into two parts when it reaches the cavernous sinus, one invests the nerves and forms the inner layer of the lateral wall, and the medial layer faces the sphenoid body and forms the medial wall of the sinus. The same inner layer invests the oculomotor, trochlear, and ophthalmic nerves and the distal part of the abducens nerve in their course through the lateral wall of the cavernous sinus. The internal carotid artery with its vertical posterior bend, horizontal anterior bend, and clinoidal segments runs inside the cavernous sinus. The clinoidal segment of the internal carotid artery is between the distal and proximal dural rings and is covered by a layer of dura, which forms a collar, the carotid collar, around the artery (10). In a previous study, we found that the venous plexus, forming the cavernous sinus, extends through the lower
Figure 8 Structures below the medial part of the anterior and middle cranial fossae. (A) Midsagittal section of the anterior and middle cranial base to the right of the nasal septum. The area below the medial part of the anterior cranial fossa is formed by the frontal and ethmoidal sinuses and the nasal cavity. The nasal cavity is divided into the inferior, middle, and superior meati and the sphenethmoidal recess by the inferior, middle, and superior conchae. The inferior meatus is located below the inferior turbinate, and the sphenethmoidal recess, into which the sphenoid sinus opens, is located above the superior turbinate. The central part of the middle cranial base is formed by the body of the sphenoid bone, which contains the sphenoid sinus and sella with the pituitary gland. The olfactory plate is located in the roof of the nasal cavity. The nasopharynx and the opening of the eustachian tube are located below the sphenoid sinus. (B) Some of the mucosa has been removed from the concha. The inferior concha is a separate bone attached to the maxilla. The middle and superior conchae are appendages of the ethmoid bone. The carotid artery courses along the lateral margin of the sphenoid sinus. The prominence within the sphenoid sinus, formed by the superior orbital fissure, is located anterior to the intracavernous carotid, and the prominence overlying the maxillary nerve is located below the intracavernous carotid. (C) The middle and superior turbinates have been removed to expose the ostia of the maxillary and frontal sinuses. Both open into the middle meatus below the middle turbinate. The nasolacrimal duct opens below the inferior concha, Rosenmuller’s fossa is located behind the eustachian tube. (D) The medial wall of the maxillary sinus and the ethmoid air cells have been removed to expose the orbit. The optic nerve enters the orbit above the superior orbital fissure. The maxillary nerve exits the foramen rotundum to enter the pterygopalatine fossa. (E) Enlarged view of the pterygopalatine fossa. The maxillary nerve exits the foramen rotundum to enter the pterygopalatine fossa, where it gives rise to the infraorbital, zygomatic, and palatine nerves and communicating rami to the pterygopalatine ganglion. The vidian nerve exits the vidian canal to enter the pterygopalatine ganglion. The pterygopalatine fossa contains branches of the maxillary nerve, the vidian nerve with the pterygopalatine ganglion, and terminal branches of the maxillary artery (1).

Abbreviations: A., artery; Car., carotid; Cav., cavernous; Crib., cribriform; CN, cranial nerve; Eust., eustachian; Fiss., fissure; Front., frontal; Gang., ganglion; Inf., inferior; Infraorb., infraorbital; Int., internal; M., muscle; Max., maxillary; Med., medial; Mid., middle; N., nerve; Obl., oblique; Orb., orbital; Palat., palatine; Pterygopal., pterygopalatine; Rec., recess; Rectus; Sphen., sphenoid; Sphenoeth., sphenethmoidal; Sphenopal., sphenopalatine; Sup., superior; Zyg., zygomatic.
Figure 9  (A) The branches of the facial nerve, which form a fine plexus in the fat pad overlying the temporalis fascia and are directed to the orbicularis oculi and frontalis muscle, have been dissected free and a small piece of black material placed deep to their fine branches to highlight this neural network in the fat pad. (B) Enlarged view of the facial nerve plexus innervating the orbicularis oculi and frontalis muscle. (C) Lateral view of the structures superficial to the anterior and middle cranial base. The frontotemporal and zygomatic branches of the facial nerve are exposed anterior to the parotid gland. The orbicularis oculi surrounds the orbit, and the frontalis muscle extends upward from the superior orbital rim. The levators of the lid and zygomaticus muscles are located in front of the maxilla. The orbicularis oris surrounds the mouth and the buccinator muscle surrounds the oral cavity deep to the masseter muscle. The parotid duct crosses the masseter muscle. The superficial temporal artery divides into anterior and posterior branches. The parotid gland has been removed to show the branches of the facial nerve. (D) The parotid gland has been removed to expose the facial nerve exiting the stylomastoid foramen. The facial nerve branch to the frontalis muscle has been preserved in the dissection and has been laid back against the temporalis muscle to show it crossing the zygomatic arch in its course to the forehead. The superficial temporal artery passes deep to the facial nerve in front of the ear. (E) The masseter muscle has been removed to expose the temporalis muscle inserting on the coronoid process. The buccinator muscle, which surrounds the oral cavity, is situated on the deep side of the masseter muscle. (F) The coronoid process and lower part of the temporalis muscle have been removed to expose the deep temporal branches of both the maxillary artery and the mandibular nerve passing upward along the greater sphenoid wing and temporal squama to enter the deep side of the temporalis muscle. The lateral pterygoid muscles extend backward from the pterygoid process and greater wing of the sphenoid to insert along the mandibular condyle and temporomandibular joint. (G) A craniotomy has been done to expose the floor of the middle fossa, and the lateral wall of the orbit has been removed to expose the extracranial muscles. The mandibular condyle has been removed and the pterygoid muscles reflected to expose the mandibular nerve at the foramen ovale. The ptgnoptialine fossa is located behind the maxilla. The floor of the orbit and the upper part of the maxilla has been removed to expose the nasal cavity. (Continued).
Figure 9 (Continued) (H) Enlarged view following resection of the floor of the middle fossa and the external auditory canal to expose the tympanic membrane and the mandibular nerve below the foramen ovale. The mastoid segment of the facial nerve has been preserved. The greater petrosal nerve crosses above the petrosus caroticus. The tensor tympani muscle and eustachian tube are layered along the petrous caroticus and petrosus caroticus. The nasopharyngeal mucca has been opened to expose the longus capitus and rectus capitus anterior muscles. (J) The carotid artery has been reflected forward out of the carotid canal. This exposes the petrous apex in front of the jugular foramen on the medial side of the internal carotid artery. (K) The petrous apex has been drilled and the dura opened below the trigeminal nerve to expose the upper anterior part of the posterior cranial fossa. A segment of the internal jugular vein and jugular bulb has been resected to expose the IX through XII cranial nerves below the jugular foramen and hypoglossal canal (1). Abbreviations: A., artery; Ant., anterior; Brs., branches; Bucc., buccinator; Cap., capitis; Car., carotid; CN, cranial nerve; Cond., condylar; Eust., eustachian; Front., frontal; Frontal; Frontotemp., frontotemporal; Gr., greater; Inf., inferior; Int., internal; Jug., jugular; Lat., lateral; Long., longus; M., muscle; Mandib., mandibular; Mass., masseter; Max., maxillary; Med., medial; Memb., membrane; N., nerve; Obl., oblique; Obh., oblique; Pet., petrosal, petrous; Plex., plexus; Post., posterior; Proc., process; Pteryg., pterygoid; Pterygopal., pterygopalatine; Rec., rectus; Seg., segment; Sig., sigmoid; Sup., superficial; Temp., temporal; Temporalis; Temp., tympanic; TM, temporomandibular; Vert., vertebral; Zyg., zygomatic.
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Figure 1.0 (A) Anterior view of a coronal section, anterior to the sphenoid sinus, through the nasal cavity, orbits, and maxillary sinuses. The upper part of the nasal cavity is separated from the orbits by the ethmoidal sinuses. The lower part of the nasal cavity is bounded laterally by the maxillary sinuses. The middle conchae projects medially from the lateral nasal wall at the junction of the roof of the maxillary and ethmoidal sinuses. The posterior ethmoid air cells are located in front of the lateral part of the sphenoid sinus. (B) The middle and inferior nasal conchae on the left side and the nasal septum and the posterior ethmoidal sinuses on both sides have been removed to expose the posterior nasopharyngeal wall, the anterior aspect of the sphenoid body, and the sphenoid ostia. The posterior ethmoid air cells overlap the lateral margin of the sphenoid ostia. (C) Enlarged view showing the relationships of the nasal cavity, pterygopalatine and infratemporal fossae, orbit, and sphenoid sinus. The nasopharynx is located below the sphenoid sinus. The pterygopalatine fossa is located in the lateral wall of the nasal cavity behind the upper part of the maxillary sinus and below the orbital apex. The posterior maxillary wall is so thin that the maxillary artery coursing in the pterygopalatine fossa can be seen through the bone. The sphenopalatine branch of the maxillary artery passes through the sphenopalatine foramen to reach the walls of the nasal cavity and the sphenoid face. (D) The posterior wall of the maxillary sinus has been removed to expose the pterygopalatine and infratemporal fossae and the internal carotid artery and nerves coursing through the cavernous sinus. The maxillary nerve exits the foramen rotundum to enter the pterygopalatine fossa where it gives rise to branches that follow the branches of the maxillary nerve. Some of these arteries course along the sphenoid face where careful hemostasis during transsphenoidal surgery reduces the need for nasal packing after transsphenoidal operations. The maxillary nerve exits the foramen rotundum to enter the pterygopalatine fossa where it gives rise to the infraorbital and greater palatine nerves and communicating rami to the pterygopalatine ganglion. The eustachian tube opens into the nasopharynx along the posterior edge of the medial pterygoid plate (1).

Abbreviations: A., artery; Cav., cavernous; CN, cranial nerve; Eth., ethmoid; Eust., eustachian; For., foramen; Gang., ganglion; Gr., greater; Inf., inferior; Infraorb., infraorbital; Infratemp., infratemporal; Lat., lateral; M., muscle; Max., maxillary; Med., medial; Mid., middle; N., nerve; Ophth., ophthalmic; Palat., palatine; Pet., petrosal; Proc., process; Pteryg., pterygoid; Pterygopal., pterygopalatine; Rec., rectus; Seg., segment; Sphen., sphenoid.
Figure 11. Anterior view. Stepwise dissection of a cross section showing the relationships below the middle cranial base. (A) The soft palate, which has been preserved, is located at the level of the foramen magnum. The infratemporal fossa, located below the greater sphenoid wing and middle cranial fossa, contains the pterygoid muscles, maxillary artery, mandibular nerve branches, and the pterygoid venous plexus and opens posteriorly into the area around the carotid sheath as shown on the left side. (B) Enlarged view. The soft palate has been divided in the midline, and the leaves reflected laterally. The atlanto-occipital joints and the foramen magnum are located at approximately the level of the hard palate. The anterior arch of C1 and the dens are located behind the sphenoidal and the clival is located behind the nasopharynx and sphenoid sinus. The prominence over the longus capitus and the anterior arch of C1 are seen through the pharyngeal mucosa. (C) The maxilla lying the posterior pharyngeal wall has been reflected to the right, exposing the longus capitus, which attaches to the clival, and the part of the longus colli that attaches to the anterior arch of C1. The left exostosin tube has been divided. (D) The clival and anterior arch of C1 have been removed. The dura has been opened to expose the vertebral and basilar arteries. The dens has been preserved. The structures in the right infratemporal fossa and a segment of the right carotid artery and mandible have been removed to expose the right vertebral artery ascending between the C2 and C3 transverse processes. (E) Cross section through the ethmoidal and maxillary sinuses and the nasal cavity in front of the posterior maxillary wall. The posterior wall of the maxillary sinus has been removed to expose the pterygopalatine fossa and ganglion on both sides. The maxillary nerves enter the pterygopalatine fossa by passing through the sphenoid sinus and the sphenopalatine ganglion. Another branch enters the greater palatine canal with the greater palatine nerves. (F) Enlarged view of the pterygopalatine fossa. The vidian nerve exits the sphenoidal canal to enter the pterygopalatine ganglion, which receives communicating rami from the maxillary nerve. The sphenopalatine branch passes through the sphenopalatine foramen to enter the lateral nasal cavity. Abbreviations: A., artery; Bas., basilar; Cap., capitus; Car., carotid; Cav., cavernous; Comm., communicating; Cond., condylid; Eth., ethmoid; Eust., eustachian; For., foramen; Gang., ganglion; Gr., greater; Inf., inferior; Infraorb., infraorbital; Infraorb., infratemporal fossa; Int., internal; Jug., jugular; Lat., lateral; Lig., ligament; Long., longus; M., muscle; Mandib., mandibular; Mass., masseter; Max., maxillary; Med., medial; Mid., middle; N., nerve; Palat., palatine; Pteryg., pterygoid; Pterygopal., pterygopalatine; Sphen., sphenoid; Sphenopal., sphenopalatine; Sup., superficial; Trans., transverse; V., vein; Vort., Vertebral.
Figure 12  (A) Superior view of the posterior cranial fossa. The osseous walls of the posterior fossa are formed by the occipital, temporal, and sphenoid bones. The fossa is bounded in front by the dorsum sellae and posterior part of the sphenoid bone and the clival part of the occipital bone; behind by the lower portion of the squamous part of the occipital bone; and on each side by the petrous and mastoid parts of the temporal bone, and the lateral part of the occipital bone. One small part above the temporal bone is formed by the inferior angle of the parietal bone. (B) Nerves and arteries of the posterior fossa. Only two of the twelve pairs of cranial nerves course entirely outside the posterior fossa. The tentorium, which is attached along the petrous ridges, roofs the posterior fossa. The superior cerebellar artery courses below the oculomotor and trochlear nerves and above the trigeminal nerve; the anteroinferior cerebellar artery courses near the abducent, facial, and vestibulococchlear nerves; and the postero-inferior cerebellar artery courses near the glossopharyngeal, vagus, accessory, and hypoglossal nerves (12). Abbreviations: A., artery; Ac., acoustic; AICA, anteroinferior cerebellar artery; Bas., basilar; CN, cranial nerve; For., foramen; Int., internal; Jug., jugular; Occip., occipital; PCA, posterior cerebral artery; PICA, posteroinferior cerebellar artery; SCA, superior cerebellar artery; Temp., temporal; Tent., tentorial; Vert., vertebral.
The temporal bone has a squamosal part, which forms some of the floor and lateral wall of the middle cranial fossa. It is also the site of the mandibular fossa in which the mandibular condyle sits. The tympanic part forms the anterior, lower, and part of the posterior wall of the external canal, part of the wall of the tympanic cavity, the osseous portion of the eustachian tube, and the posterior wall of the middle ear. The mastoid portion contains the mastoid air cells and mastoid antrum. The petrous part is the site of the auditory and vestibular labyrinth, the carotid canal, the internal acoustic meatus, and the facial canal. The petrous part also forms the anterior wall and the dome of the jugular fossa. The styloid part projects downward and serves as the site of attachment of three muscles. Anterior and lateral to the arcuate eminence is the tegmen, a thin plate of bone overlying the mastoid antrum and epitympanic area. The temporal bone articulates anteriorly with the sphenoid bone, above with the parietal bone, and posteriorly with the occipital bone. The zygomatic process of the squamosal part has an anterior and a posterior root between which, on the lower surface, is located the mandibular condyle. The sigmoid sulcus descends along the posterior surface of the mastoid portion. The internal acoustic meatus enters the central portion of the petrous part of the bone. The trigeminal impression and arcuate eminence are located on the upper surface of the petrous part. The vestibular aqueduct connects the vestibule in the petrous part with the endolymphatic sac, which sits on the posterior petrous surface inferolateral to the internal acoustic meatus. The transverse crest divides the meatal fundus into superior and inferior parts. The anterior part above the transverse crest is the superior vestibular area. Below the transverse crest the cochlear area is anterior and the inferior vestibular area is posterior. The vertical crest, also called "Bill's Bar," separates the facial and superior vestibular areas (7).
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Figure 14  Occipital bone, foramen magnum, and jugular foramen. (A–D) Occipital bone and foramen magnum. (A) Inferior view. (B) Superior view. (C, D) Anteroinferior views. (A–C) The occipital bone surrounds the oval shaped foramen magnum, which is wider posteriorly than anteriorly. The narrower anterior part sits about the odontoid process and is encroached on from laterally by the occipital condyles. The wider posterior part transmits the medulla. The occipital bone is divided into a squamosal part located above and behind the foramen magnum; a basal (clival) part situated in front of the foramen magnum; and paired condylar parts located lateral to the foramen magnum. The basilar part of the occipital bone, which is also referred to as the clivus, is a thick quadrangular plate of bone, concave from side to side, that extends forward and upward to join the sphenoid bone just below the dorsum sellae. The clivus is separated on each side from the petrous part of the temporal bone by the petroclival fissure, which ends posteriorly at the jugular foramen. The condylar parts of the occipital bone, on which the occipital condyles are located, are situated lateral to the foramen magnum on the external surface. The hypoglossal canal is situated above the condyle. The jugular process of the occipital bone extends laterally from the posterior half of the condyle and articulates with the jugular surface of the temporal bone. The sulcus of the sigmoid sinus crosses the superior surface of the jugular process. The jugular foramen is bordered posteriorly by the jugular process of the occipital bone and anteriorly by the jugular fossa of the petrous temporal bone. (Continued).
ring, inside the collar of dura, and around the clinoid segment to the level of the upper ring. The meningo- hyposphenal trunk, with its terminal, inferior hypophysial, and dorsal meningeal branches, is the hypophysial trunk, also called the artery of the inferior cavernous sinus, arise from the intracavernous carotid artery. The proximal abduces nerve passes through Dorello's canal, located below the petrosphenoid ligament, and receives sympathetic branches from the internal carotid nerve, which pass to the ophthalmic nerve to enter the orbit.

The main venous afferents to the cavernous sinus are the superior and inferior ophthalmic veins and the ophthalmic sinus, or, by way of the foraminina in the middle fossa floor, into the petrosphenoid venous plexus (4). The sella houses the pituitary gland and is partially closed above by the diaphragma sellae. Anterior to this is the diaphragm, the carotid cave, a dilation at the level of the distal dural ring, extends downward medially to the initial intradural segment of the internal carotid artery.

The tensor tympani muscle and eustachian tube cross medially to the foramen spinosum, below the floor of the middle fossa, and anterior to the horizontal segment of the petrosal artery (Fig. 5). The greater petrosal nerve crosses the area above and parallel to the petrosal carotid artery, laterally joins the gniculate ganglion, and medially joins the deep petrosal branch of the carotid sympathetic nerves to form the vidian nerve, which enters the pterygopalatine ganglion. (Figs. 2, 5, and 6). The lesser petrosal nerve runs anterior to the greater petrosal nerve and exits the cranium, passing through the foramen spinosum to join the otic ganglion. The cochlea is situated below the floor of the middle cranial fossa, at the apex of the angle between the greater petrosal and labyrinthine segment of the facial nerve.

**Exocranial Surface**

The exocranial surface of the middle cranial base is also divided into central and lateral parts (Figs. 2, 3, 6, and 9) (1). The central part encompasses the sphenoid body and the upper part of the basal (clival) part of the occipital bone and corresponds to the sphenoid sinus and the nasopharynx. The lateral part is formed by the greater sphenoid wing, the petrous, tympanic, and squamous parts of the temporal bone; the styloid process; and the zygomatic, palatine, and maxillary bones. The medial and lateral parts are separated by a parasagittal plane passing through the medial petrygoid plate. The foramen lacerum is located at the union of the sphenoid, occipital, and petrous parts of the bone and is continued on its lower side by fibrocartilaginous tissue to form the inferior wall of the carotid canal. Structures transversing the lateral part include the carotid arteries and the internal carotid canal, the glossopteryngeal, vagus, and accessory nerves in the jugular foramen, the third trigeminal division in the foramen ovale, the middle meningeal artery in the foramen spinosum, and the facial nerve in the facial canal. The pterygomaxillary fissure is the lateral opening of the pterygopalatine fossa into the infratemporal fossa. The glenoid fossa harbors the mandibular condyle. The roof of the fossa is divided into anterior and posterior parts by the squamosotympanic fissure, along which the chorda tympani passes.

The area below the middle cranial base includes the infratemporal fossa, parapopharyngeal space, infratemporal space, and pterygopalatine fossa (Figs. 6, 9, 10, and 11). The boundaries of the infratemporal fossa are the middle pterygoid muscle and the pterygoid process medially, the mandible laterally, the posterior wall of the maxillary sinus anteriorly, and the great wing of the sphenoid superiorly, and the medial pterygoid muscle joining the mandible and the pterygoid fascia posteriorly. The fossa opens into the neck below. The infratemporal fossa contains the branches of mandibular, the maxillary, and the pterygoid muscles and venous plexus. The mandibular nerve, after exiting the
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Figure 15 Retrosigmoid exposure of the nerves in the right cerebellopontine angle. (A) The vestibulocochlear nerve enters the internal acoustic meatus with a labyrinthine branch of the AICA. The PICA courses around the glossopharyngeal, vagus, and accessory nerves. The abducens nerve ascends in front of the pons. The subarcuate branch of the AICA enters the subarcuate fossa superolateral to the pons of the meatus. Choroid plexus protrudes into the cerebellopontine angle behind the glossopharyngeal and vagus nerves. (B) The posterior wall of the internal acoustic meatus has been removed. The cleavage plane between the upper bundle, formed by the superior vestibular nerve, and the lower bundle, formed by the inferior vestibular and cochlear nerves, was begun laterally where the nerves normally separate near the meatal fundus and extended medially. The nervus intermedius arises on the anterior surface of the vestibulocochlear nerve, has a free segment in the cistern and/or meatus, and joins the facial nerve distally. The facial nerve is located anterior to the superior vestibular nerve and the cochlear nerve is anterior to the inferior vestibular nerves. (C) The cleavage plane between the cochlear and inferior vestibular nerves, which is well developed in the lateral end of the internal acoustic meatus, has been extended medially. Within the cerebellopontine angle, the superior vestibular nerve is posterior and superior, the facial nerve anterior and superior, the inferior vestibular nerve posterior and inferior, and the cochlear nerve anterior and inferior. (D) The superior and inferior vestibular nerves have been divided to expose the facial and cochlear nerves. A labyrinthine branch of the AICA enters the internal meatus (15). Abbreviations: A. artery; AICA, anteroinferior cerebellar artery; Chor. Plex., choroid plexus; CN, cranial nerve; Coch., cochlear; Flocc., flocculus; Inf., inferior; Intermed., intermedius; Labyr., labyrinthine; N., nerve; Nerv., nervus; Pet., petrosal; PICA, posteroinferior cerebellar artery; Subarc., subarcuate; Sup., superior; V., vein; Vest., vestibular.
The SCA arises at the midbrain level and encircles the brain stem near the pontomesencephalic junction. The SCA courses below the oculomotor and trochlear nerves and above the trigeminal nerve. The SCA loops down closer to the trigeminal nerve in C than in B. The AICA arises at the pontine level and courses by the abducens, facial, and vestibulocochlear nerves. In C, the left abducens nerve passes in front of the AICA and the right abducens nerve passes behind the AICA. The PICAs arise from the vertebral artery at the medullary level and course in relation to the glossopharyngeal, vagus, accessory, and hypoglossal nerves. The origin of the SCAs is quite symmetrical from side to side. There is slight asymmetry in the level of origin of the AICAs and marked asymmetry in the level of the origin of the PICAs, especially in B. (B) The veins on the anterior surface of the pons and medulla and the petrosal cerebellar surface drain predominantly into the superior petrosal veins which empty into the superior petrosal sinuses. The median anterior pontomesencephalic and median anterior medullary veins ascend on the front of the brain stem. The transverse pontine and transverse medullary veins run transversely across the pons and medulla surfaces. The anterior hemispheric veins drain the petrosal cerebellar surface and commonly empty into the vein of the cerebellum/petrous fissure, which ascends to join the superior petrosal veins. The vein of the petrosal cerebellar sulcus passes across the pontomesencephalic junction. The peduncular veins cross the central peduncle. Abbreviations: A., artery; AICA, anterior inferior cerebellar artery; Ant., anterior; Cer. Pon., cerebellopontine; Chor., choroid; CN, cranial nerve; Fiss., fissure; Hem., hemispheric; Med., medial, medullary; Ped., petrous; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; Sp., spinal; Pon., pontine; Pon. Med., pontomedullary; Pon. Mes., pontomesencephalic; SCA, superior cerebellar artery; Sulc., sulcus; Sp., spinal; Sup., superior; Trans., transverse; V., vein; Vert., vertebral.

Figure 16. Brain stem, anterior cerebellar surface, and posterior skull base. (A) The petrosal (anterior) surface of the cerebellum, called the petrosal surface, and front of the brain stem face the endocranial surface of the posterior fossa. The fourth ventricle is positioned between the pons and medulla. The midbrain and pons are separated by the pontomesencephalic sulcus and the pons and medulla by the pontomedullary sulcus. The trigeminal nerves arise from the midpons. The abducens nerve arises in the medial part of the pontomedullary sulcus, rostral to the medullary pyramids. The facial and vestibulocochlear nerves arise at the lateral end of the pontomedullary sulcus immediately rostral to the foramen of Luschka. The hypoglossal nerves arise anterior to the olives and the glossopharyngeal, vagus, and accessory nerves arise posterior to the olives. Choroid plexus protrudes from the foramen of Luschka behind the glossopharyngeal and vagus nerves. (B) Anterior view of the brain stem with the arteries preserved. (C) Posterior view of the skull base with the cranial nerves and arteries preserved.
accessory middle meningeal (enters through the foramen ovale), and the inferior alveolar artery. The second, or pterygoid segment, courses through the middle of the infratemporal fossa and gives rise to the posterior superior alveolar, infraorbital, masseteric, pterygoid, temporal, and buccal branches. The third, or pterygopalatine segment, courses in the fossa of the same name. The pterygoid venous plexus connects through the middle fossa foramen and inferior orbital fissure with the cavernous sinus and empties into the retromandibular and facial veins.

The pterygopalatine fossa is located between the maxillary sinus in the front, the pterygoid process behind, the

Figure 17 (A-D) Far-lateral and transcondylar approach. (A) A suboccipital scalp flap is commonly selected for the far-lateral exposure. The medial limb extends downward in the midline so that a wide upper cervical laminectomy can be completed if needed. The lateral limb extends below the level of the C1 transverse process (×), which can be palpated between the mastoid tip and the angle of the jaw, to access the vertebral artery as it courses through the C1 transverse process. The muscles superficial to the suboccipital triangle can be reflected from the suboccipital area in a single layer with the scalp flap, leaving a cuff of suboccipital muscle and fascia attached along the superior nuchal line to aid in closure. (B) The scalp and muscles are reflected in a single layer to expose the suboccipital triangle in the depths of which the vertebral artery courses behind the atlanto-occipital joint and across the posterior arch of C1. The triangle is located between the superior and inferior oblique and the rectus capitis posterior major. (C) A suboccipital craniectomy has been completed, the posterior arch of C1 has been removed, the posterior root of the transverse foramen of the C1 has been removed, the area above the occipital condyle has been drilled to expose the hypoglossal canal, and the dura has been opened. The dural incision completely encircles the vertebral artery, leaving a narrow dural cuff on the artery, so that the artery can be mobilized. The drilling in the supracondylar area can be extended extradurally to the level of the jugular tubercle to increase access to the front of the brain stem. (D) Comparison of the exposure with the far-lateral and transcondylar approaches. On the right side, the far-lateral exposure has been extended to the posterior margins of the atlantal and occipital condyles and the atlanto-occipital joint. The prominence of the condyles limits the exposure along the anterolateral margin of the foramen magnum. On the left side, a transcondylar exposure has been completed by removing the posterior part of the condyles. The dura can be reflected further laterally with the transcondylar approach than with the far-lateral approach. The condylar drilling provides an increased angle of view of the clivus and front of the brain stem. The dentate ligament and accessory nerve ascend from the region of the foramen magnum (18). Abbreviations: A., artery; Atl., atlanto; Cap., capitis; CN, cranial nerve; Cond., condyle; Dent., dentate; Digast., digastric; Hypogl., hypoglossal; Inf., inferior; Lev., levator; Lig., ligament; M., muscle; Maj., major; Obl., oblique; Occip., occipital; PICA, posteroinferior cerebellar artery; Post., posterior; Proc., process; Rec., rectus; Scap., scapula; Suboccip., suboccipital; Sup., superior; Trans., transverse; Vent., ventricle; Vert., vertebral.
Figure 18  Atlas and Axis. (A-D) The atlas. (A) Superior view. (B) Inferior view. (C) Anterior view. (D) Posterior view. The atlas consists of two thick lateral masses situated at the anteromedial part of the ring, and which are connected in front by a short anterior arch and posteriorly by a longer curved posterior arch. The anterior and posterior tubercles are at the anterior and posterior midline. The superior articular facet is an oval, concave facet that faces upward and medially to articulate with the occipital condyle. The inferior articular facet is a circular, flat, or slightly concave facet that faces downward, medially, and slightly backward and articulates with the superior articular facet of the axis. The medial aspect of each lateral mass has a small tubercle for the attachment of the transverse ligament of the atlas. The transverse process projects from the lateral masses. The transverse foramina transmit the vertebral arteries. The upper surface of the posterior arch adjacent to the lateral masses has paired grooves in which the vertebral arteries course. (E-H) The axis. (E) Anterior view. (F) Lateral view. (G) Superior view. (H) Inferior view. The axis is distinguished by the odontoid process (dens). On the front of the dens is an articular facet that forms a joint with the facet on the back of the anterior arch of the atlas. The dens is grooved at the base of its posterior surface where the transverse ligament of the atlas passes. The oval superior articular facets articulate with the inferior facets of the atlas. The superior facets are anterior to the inferior facets. The pedicles and laminae are thicker than on the other cervical vertebra and the lamina fuses behind to form a large spinous process. The transverse foramina are directed superolaterally, thus permitting the lateral deviation of the vertebral arteries as they pass up to the more widely separated transverse foramina in the atlas. The inferior articular facets face downward and forward. 

Abbreviations: A., artery; Ant., anterior; Art., articular; For., foramen; Inf., inferior; Lat., lateral; Mass., masses; Post., posterior; Proc., process; Sup., superior; Trans., transverse; Vert., vertebral.
Figure 19 (A–F). Relationships in the transbasal and extended frontal approaches. (A) The inset shows the bicoronal scalp incision. A large bifrontal craniotomy and a fronto-orbitozygomatic osteotomy have been completed. The osteotomized segment may extend through the nasal bone and from one to the other lateral orbital rims, as shown. However, for most lesions, a more limited bone flap and osteotomy will suffice and can be tailored as needed to deal with the involvement of the cranial base, nasal cavity, paranasal sinuses, or orbit. For an orbital lesion, an orbitofrontal craniotomy, elevating only the superior orbital rim (yellow arrows) and orbital roof, is all that is needed. For a cavernous sinus or unilateral lesions of the anterior or middle fossa, an orbitozygomatic osteotomy will usually suffice (blue arrow). For a clival lesion, a more limited bifrontal approach (red arrow) will suffice. (B) The periorbita has been separated from the walls of the orbit in preparation for the osteotomies. Division of the medial canthal ligament is not necessary for most lesions, but may be required for lesions extending into the lower nasal cavity or orbit. The ligaments should be re-approximated at the end of the operation. (C) The right medial canthal ligament has been divided and the orbital contents retracted laterally to expose the nasolacrimal duct and the anterior ethmoidal branch of the ophthalmic artery at the anterior ethmoidal foramen. (D) The osteotomies have been completed and the frontal dura elevated. The dura remains attached at the cribriform plate. The upper part of both orbits are exposed. (E) An osteotomy around the cribriform plate leaves it attached to the dura and olfactory bulbs, a maneuver that has been attempted in order to preserve olfaction but has been uncommonly successful. The anterior face of the sphenoid sinus and both sphenoid ostia are exposed between the orbits. (F) The sphenoid sinus has been opened to expose the septa within the sinus. The sphenopalatine arteries cross the anterior face of the sphenoid. (Continued).
Figure 19 (Continued) (G) The septa within the sphenoid sinus, the sellar floor, and the lateral sinus wall have been removed to expose the intracavernous carotid, pituitary gland, and optic canals. (H) The clivus has been opened to expose the dura facing the brain stem. The basilar sinus, which interconnects the posterior parts of the cavernous sinuses, is situated between the layers of dura on the upper clivus. (I) The exposure has been extended laterally by opening the medial and posterior wall of the maxillary sinus to expose the branches of the maxillary nerve and artery in the pterygopalatine fossa, located behind the posterior maxillary wall. The posterior wall of the pterygopalatine fossa is formed by the pterygoid process. The maxillary nerve enters the pterygopalatine fossa where it gives rise to the infraorbital nerve, which courses along the floor of the orbit and to the palatine nerves, which descend to the palatine area. The eustachian tube opens into the nasopharynx by passing along the posterior edge of the medial pterygoid plate. The lateral wing of the sphenoid sinus extends laterally below the maxillary nerve. (J) The frontal dura has been opened and the frontal lobes elevated to expose the olfactory and optic nerves and the internal carotid and anterior and middle cerebral arteries (1). 

Abbreviations: A., artery; ACA, anterior cerebral artery; Ant., anterior; Bas., basilar; Car., carotid; Cav., cavernous; CN cranial nerve; Crib., cribriform; Eth., ethmoid, ethmoidal; Eust., eustachian; Front., frontal; Gang., ganglion; Infraorb., infraorbital; Lac., lacrimal; Lig., ligament; Max., maxillary; Med., medial; MCA, middle cerebral artery; N., nerve; Nasolac., nasolacrimal; Off., olfactory; Peryg., pterygoid; Pterygopal., pterygopalatine; Seg., segment; Sphen., sphenoid; Sphenopal., sphenopalatine; Sup., superior; Tr., Tract.

The fossa opens laterally through the pterygomaxillary fissure into the infratemporal fossa and medially through the spheno-palatine foramen to the nasal cavity. Both the foramen rotundum for the maxillary nerve and the pterygoid canal for the vidian nerve open through the posterior wall of the fossa formed by the sphenoid pterygoid process. The palatovaginal canal carrying the pharyngeal nerve and artery and the greater and lesser palatine canals conveying the greater and lesser palatine arteries open into the pterygopalatine fossa. The inferior orbital fissure, across which the orbital muscle stretches, lies in front of the pterygopalatine fossa. This fossa contains branches of the maxillary nerve, vidian nerve, the pterygopalatine ganglion, and the pterygopalatine segment of the maxillary artery. The maxillary nerve passes through the foramen rotundum to enter the fossa and, after giving communicating rami to the pterygopalatine ganglion, divides into the posterosuperior alveolar, infraorbital, and zygomatic nerves. The zygomatic nerve, in addition to its sensory fibers, carries the parasympathetic fibers from the pterygopalatine ganglion to the lacrimal gland. The vidian (nerve of the pterygoid canal) ends in the pterygopalatine ganglion, which sends rami to the maxillary nerve and gives rise to the greater and lesser palatine, pharyngeal nerves, and nasal branches. The third part of the maxillary artery enters the fossa and divides into its terminal lesser and greater palatine, sphenopalatine, vidian, and pharyngeal branches.

The parapharyngeal space lies between the structures in the pharynx wall medially, the medial pterygoid muscle
Chapter 1: Anatomy of the Cranial Base

Uvula
Ant. Arch C1
Soft palate reflected
For. magnum
Soft palate
Clivus
C
Dens
Clivus
Hard Palate
Long. Cap. M.
Long. Colli M.
Ant. Arch C1
AB
Max.
sinus
Max.
sinus
Maxilla
Max.
sinus
Nasal septum
Gr. Palat. A. & N.
Nasal septum
Vert. A.
Max.
sinus
Nasal floor
Figure 20

(A) Anterior view through the open mouth. The soft palate, which extends backward from the hard palate, will block the view of the upper clivus. An incision has been outlined in the midline of the soft palate. (B) The soft palate has been divided to expose the mucosa lining the lower clivus. (C) The pharyngeal mucosa has been opened in the midline and the left longus capitus and longus colli have been reflected laterally. (D) The transverse maxillary (Le Fort I) osteotomy extends through the maxillary sinus above the apex of the tooth and below the infraorbital canals. (E) The lower maxilla has been displaced downward. A clival window and vertebral arteries are seen through the exposure (1).

Abbreviations: A., artery; Ant., anterior; Cap., capitis; For., foramen; Gr., greater; Long., longus; Max., maxillary; M., muscle; N., nerve; Palat., palatine; Vert., vertebral.

and the parotid fascia laterally, and the stylohyoid fascia investing the styloglossus, stylopharyngeal, and the stylohyoid muscles posteriorly (Fig. 6). In its upper medial wall, the eu-

stachian tube, covered below by the tensor and levator veli palatine muscles, runs from the tympanic cavity to the pha-

ryngeal wall. This is predominantly a fat-filled space, but also contains pharyngeal branches of the ascending pharyngeal and facial arteries and branches from the glossopharyngeal

nerve. The last of the four spaces below the middle fossa is the infrapetrosal space, also referred to as the poststyloid part of the parapharyngeal space: It is located behind the styloid fascia, below the petrous bone, and medial to the mastoid process (Figs. 2, 6, and 9). Among the foramina in the area connecting the intra- and extracranial spaces is the jugular foramen containing the jugular bulb and lower end of the inferior petrosal sinus. It also contains branches of the ascending pharyngeal artery, the glossopharyngeal, vagus, and accessory nerves, and the opening of the carotid canal through which the carotid artery and the carotid sympathetic
and petrous segments. The branches of the petrous segment are the carotidotympanic and vidian arteries. The ascending pharyngeal artery ascends medial to the carotid artery, giving meningeal branches which pass through the hypoglossal canal and jugular foramen as well as pharyngeal branches. The occipital artery passes posteriorly on the medial side of the posterior belly of the digastric muscle. The veins in the area are the internal jugular vein, which receives drainage from the inferior petrosal sinus, and the venous plexus of the hypoglossal canal outside the jugular foramen. The main structures in the area are the styloglossus, stylopharyngeal, and stylohyoid, the digastric nerve, and the stylomandibular ligament.

The medial part of the temporal bone is constituted mainly by the internal auditory canal, the carotid canal, and the petrous apex (7,11). Laterally, within the petrous part of the temporal bone on the medial side of the mastoid antrum, lies the semicircular canals and vestibule enclosed within the otic capsule (Fig. 5).

The tympanic segment of the facial nerve passes below the lateral semicircular canal, and the mastoid segment descends to the stylomastoid foramen. The vestibule (vestibular cavity), which communicates with both ends of the semicircular canals, is situated medial to the lateral semicircular canal and below the superior semicircular canal. The aditus of the mastoid antrum opens into the tympanic cavity, which contains the malleus, incus, and stapes; the chorda tympani and tympanic nerve; the tensor tympani; and stapedius muscles. The tympanic cavity is limited laterally by the tympanic membrane, medially by the bone over the cochlea, and opens anteriorly into the eustachian tube. The arteries feeding the area arise from the stylohyoid, anterior tympanic, petrosal, and carotidotympanic arteries. Posteroslateral to the otic capsule, anterior to the sigmoid sinus, and inferior to the
Figure 22 (A–C) Transmaxillary exposure of the cranial base. (A) In this dissection, a midfacial soft tissue flap has been reflected laterally to expose the anterior surface of the right maxilla. The operative approach to the maxillary sinus is more commonly performed using a sublabial incision in the gingivobuccal margin rather than through an incision on the face. The approach can be completed without dividing the infraorbital nerve, but in this dissection, it was divided below the infraorbital foramen. The nerve, if divided, can be reinserted at the time of closing. The infratemporal fossa, which is situated below the greater sphenoid wing, has been exposed by removing the coronoid process of the mandible and a narrow wedge of zygoma. (B) The anterior wall of the maxillary sinus has been removed. The roof of the maxillary sinus forms the majority of the floor of the orbit. The infratemporal fossa contains the pterygoid muscles, mandibular nerve, maxillary artery, and the pterygoid venous plexus. (C) The medial and lateral walls of the maxillary sinus have been opened, but the posterior part of the sinus wall, which forms the anterior wall of the pterygopalatine fossa, has been preserved. Removing the medial wall of the sinus exposes the nasal cavity, turbinates, and nasal septum. The maxillary artery crosses the lateral pterygoid muscle to reach the pterygopalatine fossa, which is located behind the upper part of the posterior wall of the maxillary sinus and below the orbital apex. (D) The posterior wall of the maxillary sinus has been removed to expose the pterygopalatine fossa and orbital floor. The pterygopalatine fossa is located below the orbital apex and the posterosuperior part of the inferior orbital fissures. The maxillary nerve enters the pterygopalatine fossa by passing through the foramen rotundum. The maxillary nerve gives rise to the infraorbital nerve, which passes forward in the infraorbital canal and anterior wall of the maxillary sinus and orbital floor. (E) Enlarged view of infratemporal and pterygopalatine fossae. Distally, the maxillary artery enters the pterygopalatine fossa, which is located in the lateral wall of the nasal cavity below the orbital apex. (F) The exposure has been directed medially through the nasal cavity to the clivus, which has been opened to expose the vertebral and basilar arteries and the front of the brain stem. The exposure has been extended upward by opening the sphenoid sinus and exposing the left intracavernous carotid. The margin of the foramen magnum has been preserved (1). Abbreviations: A., artery; Bas., basilar; Brs., branches; Cav., cavernous; CN, cranial nerve; For., foramen; Inf., inferior; Infrorb., infraorbital; Infratemp., infratemporal; Lat., lateral; M., muscle; Max., maxillary; Mid., middle; N., nerve; Nasal., nasal; Nasolacr., nasolacrimal; Pct., petrous; Plex., plexus; Post., posterior; Pteryg., pterygoid; Pterygopal., pterygopalatine; Seg., segment; Sphen., sphenoid; V., vein; Venous, Vert., vertebral.
Figure 23  Upper subtotal maxillotomy. Exposure obtained with mobilization of the upper part of the maxilla. (A) This approach uses paranasal, lower conjunctival, transverse temporal, and preauricular incisions. In the usual approach, the cheek flap is elevated as a single layer using subperiosteal dissection. In this dissection, the layers of the cheek flap were dissected separately to illustrate the structures in the flap. The facial muscles and branches of the facial nerve are exposed. The parotid gland has been removed. The frontal branch of the facial nerve crosses the mid portion of the zygomatic arch. If facial nerve branches are transected in the approach, they are tagged in preparation for re-approximation at closure. (B) A hemicoronal scalp incision and reflection of the temporalis muscle expose the lateral orbital rim. The cheek flap containing the facial muscles, branches of the facial nerve, parotid gland, and masseter muscle has been reflected inferiorly to the level of the maxillary attachment of the buccinator muscle. The orbital, maxillary, and zygomatic osteotomies have been completed and the lower half of the orbital rim; the anterior, medial, and lateral walls of the maxillary sinus; and the zygomatic arch have been reflected. The lower horizontal cut, located at Le Fort I level, extends above the apical dental roots and hard palate and along the inferior nasal meatus medially. The maxillotomy, at this stage, does not include the posterior maxillary wall or cross the greater and lesser palatine canals. The lateral nasal wall was included with the maxillotomy to expose the nasal cavity. The infraorbital nerve, which crosses the orbital floor, may be preserved for reconstruction. (C) The posterior wall of the maxillary sinus has been removed to expose the pterygopatineal fossa and the palatine nerves and arteries. The base of the sphenoid process was divided, and the temporalis reflected downward to expose the lateral pterygoid muscle and maxillary artery in the infratemporal fossa. (D) A frontotemporal bone flap has been elevated, and the dura covering the frontal and temporal lobes and lateral wall of the cavernous sinus has been opened, and the temporal lobe has been elevated. The pterygoid muscles, the pterygoid process and plate, and the part of the middle fossa floor formed by the greater sphenoid wing have been removed to expose the nerves passing through the foramina rotundum and ovale. The oculomotor tube is exposed behind the mandibular nerve and the middle meningeal artery. (E) Magnified view of the cavernous sinus, superior orbital fissure, and orbit. The oculomotor, trochlear, and ophthalmic nerves course through the lateral wall of the cavernous sinus. The ophthalmic nerve sends its branches along the upper part of the orbit. The maxillary nerve sends the foramen rotundum and passes through the pterygopalatine fossa, where it gives rise to the infraorbital nerve that courses along the floor of the orbit. The mandibular nerve passes through the foramen ovale and sends its branches through the infratemporal fossa. The vidian nerve passes forward in the vidian canals below the maxillary nerve to join the pterygopalatine ganglion in the pterygopalatine fossa. (F) Enlarged view of the orbital exposure. The lacrimal gland sits on the superolateral margin of the globe. The lacrimal nerve courses above the lateral rectus muscle. The inferior oblique muscle passes below the attachment of the inferior rectus muscle and upward between the globe and lateral rectus muscle to insert on the globe near the tendon of insertion of the superior oblique muscle (1). Abbreviations: A., artery; Br., branch; Cav., cavum; CN, cranial nerve; Eust., eustachian; Front., frontal; Gr., greater; Inf., inferior; Infraorb., infraorbital; Lai., lacrimal; Lat., lateral; Lig., ligament; M., muscle; Mass., masseter; Max., maxillary; Mes., meningeal; Mid., middle; N., nerve; Obi., oblique; Palat., palatine; Proc., process; Pfng., pterygoid; Pfngosp., pterygospalatine; Rec., rectus; Sup., superior; Temp., temporal; Temporalis.
Figure 24 Middle fossa approach to the internal acoustic meatus. (A) The vertical line shows the site of the scalp incision and the stippled area outlines the bone flap bordering the middle fossa floor. (B) The dura has been elevated to expose the middle meningeal artery, the greater petrosal nerve, and the arcuate eminence. (C) The roof of the meatus has been opened to expose the superior and inferior vestibular, facial, and cochlear nerves. The vestibule and semicircular canals are located posterolateral and the cochlea is located anteromedial to the meatal fundus. In the middle fossa approach, for an acoustic neuroma, the cochlea and semicircular canal are not opened, as seen in this dissection illustrating the important structures which are to be avoided in opening the meatus. The vertical crest (Bill’s Bar) separates the facial and superior vestibular nerves at the meatal fundus. The superior and inferior vestibular nerves are located posteriorly and the facial and cochlear nerves anteriorly in the meatus with the cochlear nerve passing below the facial nerve to enter the modiolus. The labyrinthine segment of the facial nerve courses suprolateral to the cochlea. (D) The bone of the petrous apex between the trigeminal nerve and the internal acoustic meatus has been removed to complete an anterior petrosectomy and to expose the inferior petrosal sinus and the lateral edge of the clivus. (E) The dura, exposed in the anterior petrosectomy and facing the posterior fossa and the tentorium, has been opened to expose the upper brain stem, oculomotor, trochlear, and trigeminal nerves and the basilar artery (7). Abbreviations: A., artery; Ac., acoustic; Ant., anterior; Arc., arcuate; Bas., basilar; Car., carotid; Chor., choroidal; CN, cranial nerve; Coch., cochlear; Comm., communicating; Emph., emissary; Gang., ganglion; Gen., geniculate; Gr., greater; Inf., inferior; Int., internal; Laby., labyrinthine; M., muscle; Meat., meatal; Mid., middle; Men., meningeal; N., nerve; PCA, posterior cerebral artery; Pet., petrous; Post., posterior; SCA, superior cerebellar artery; Seg., segment; Sup., superior; Tens., tensor; Tymp., tympanic; Vert., vertebral; Vest., vestibular.
Figure 25 | Mastoidectomy, retrolabyrinthine, partial labyrinthine, translabyrinthine, and transcochlear approaches. (A) Right mastoid. The retroauricular flap and the sternocleidomastoid muscle have been reflected forward and the trapezius and underlying splenius capitus have been reflected backward to expose the mastoid and attachment of the longissimus capitus muscle. The posterior belly of the digastric muscle originates medial to the mastoid tip along the digastric groove. The spine of Henle is positioned at the posterosuperior margin of the external meatus, superficial to the deep site of the lateral semicircular canal and junction of the tympanic and mastoid segments of the facial nerve. The supramastoid crest, a continuation of the superior temporal line, is positioned at approximately the level of the upper margin of the transverse and sigmoid sinuses. The area below the anterior part of the supramastoid crest and behind the spine of Henle, called the suprameatal triangle, is positioned superficial to the mastoid antrum. The semicircular canals are positioned deep to the mastoid antrum and suprameatal triangle. The superior canal projects upward below the arcuate eminence. The posterior canal faces the posterior fossa dura and the superior canal projects downward to form the mastoid segment. The dura between the sigmoid sinus and the semicircular canals, named Trautman’s triangle, faces the anterior surface of the cerebellum and cerebellopontine angle. A meningeal branch of the ascending pharyngeal artery passes through the jugular foramen and ascends in the dura of Trautman’s triangle. The jugular bulb is positioned medial to the cortical bone overlying the digastric groove. The sinodural angle is positioned at the junction of the sigmoid, transverse, and superior petrosal sinuses, and where the sigmoid sinus intersects the middle fossa dura. The short process of the incus points toward the tympanic segment of the facial nerve passing between the lateral semicircular canal and the stapes sitting in the oval window. The endolymphatic sac sits beneath the dura on the posterior surface of the temporal bone above and medial to the lower part of the sigmoid sinus. (Continued).
superior petrosal sinus lies the presigmoid dura, referred to as Trautman’s triangle, under which the endolymphatic sac sits.

**POSTERIOR CRANIAL BASE**

**Endocranial Surface**

The posterior cranial base corresponds to the floor of the posterior fossa, an area around the foramen magnum. It is formed by the occipital bone, petrous, and mastoid bones (Figs. 12, 13, and 14) (7,12–14). Medially, it is formed by the dorsum sellae, basilar (clival) portion of the occipital bone, and the foramen magnum. Laterally, the endocranial surface is formed by the posterior surface of the temporal and the occipital bones, with the petro-occipital fissure and the jugular foramen lying between the occipital and temporal bones. The endolymphatic sac, which sits beneath the dura, inter nal to the occipital bone is connected through the endolymphatic duct with the vestibule. The facial-vestibulocochlear nerve complex courses through the internal auditory canal (Figs. 15 (15)). The arrangement of the nerves inside the meatus is as follows: the facial nerve, anterior and superior; the superior vestibular nerve, superior and posterior; the cochlear nerve, anterior and inferior; and the cochlear nerve, anterior and inferior (Figs. 5 and 15) (7,11). The intermediate nerve courses with the eighth nerve adjacent to the brain stem and jumps to the seventh nerve at some point along the cisternal or the meatal segments of the facial nerve. The trigeminal nerve exits the posterior fossa by passing through the porus trigeminus, a bone that is located between the superior petrosal sinus and the petrous apex along the posterior margin of the trigeminal impression. The subarcuate fossa, a depression lateral to the internal auditory canal, is pierced by the subarcuate artery, which ends in bone in the region of the superior semicircular canal (Fig. 15). The jugular foramen lies below the internal auditory canal between the petrous part of the temporal bone and the condylar part of the occipital bone (Figs. 12 and 14) (16). It is divided into a medially situated petrosal part, through which the inferior petrosal sinus passes, a laterally situated sigmoid part through which the sigmoid sinus passes, and an intermediate and anteriorly positioned intraglenoid part through which the nerves pass. The hypoglossal canal is located below and medial to the jugular tubercle and above the middle third of the occipital condyles, which project downward along the anterior half of the foramen magnum. The posterior condylar canal, located behind the condyle, conveys the posterior condylar vein, which connects the vertebral venous plexus with the sigmoid sinus. The inferior petrosal sinus courses along the petroclival fissure, connecting the posterior cavernous sinus and jugular bulb. The abducens nerve ascends and pierces the dura to course extradural through Dorello’s canal located between the petrosphenoid ligament and the upper edge of the fissure between the dorsum sella and the petrous apex, to enter the cavernous sinus. Below the foramen magnum, at the level of the atlanto-occipital joint, and anterior to the torcular membrane, the cruciform, apical, and alar ligaments maintain the stability of the odontoid and atlantoaxial junctions.

The petrosal cerebellar surface, which faces the posterior surface of the temporal bone, the anterior surface of the brain stem, and the cerebellar peduncles, faces the endocranial surface of the posterior skull base (Fig. 16). The medulla, pons, and mesencephalon face the clivus. The surface of the medulla is divided longitudinally by the preolivary and postolivary sulci, with the pyramid in front and the inferior cerebellar peduncle behind the olive. The hypoglossal nerve arises along the preolivary sulcus and the glossopharyngeal, vagus, and accessory nerves arise near the retro-olivary sulcus. The vestibulocochlear and facial nerves arise a few millimeters above the retro-olivary sulcus in the lateral part of the pontomedullary sulcus. The abducens nerve arises in the medial part of the pontomedullary sulcus and ascends behind the clivus. The trigeminal nerve arises from the an terolateral surface of the midpons which joins the motor root arising around the superior third of the sensory root. The trochlear nerve arises below the inferior colliculus and passes forward along the pontomesencephalic sulcus in the quadrigeminal plate to enter the interpeduncular fossa just behind the cavernous sinus. The oculomotor nerve crosses the interpeduncular cistern and pierces the roof of the cavernous sinus. Both vertebral arteries enter the cranium at the posterior edge of the occipital condyles and ascend to join in the midline, thus forming the basilar artery (Figs. 12 and 16).

The main branches of the intradural vertebral artery are the posterior lateral spinal artery, which supplies the posterior third of the medulla and upper spinal cord; the anterior spinal artery, which joins its mate from the opposite side on the anterior surface of the cord to supply the anterior two-thirds of the medulla and upper spinal cord; and the
Presigmoid approach. (A) The insert shows the temporo-occipital craniotomy and the mastoid exposure. The mastoidectomy has been completed and the dense cortical bone around the labyrinth has been exposed. The tympanic segment of the facial nerve and the lateral canal are situated deep to the spine of Henle. Trautman’s triangle, the patch of dura in front of the sigmoid sinus, faces the cerebellopontine angle. (B) Retrolabyrinthine exposure. The presigmoid dura has been opened and the superior petrosal sinus and tentorium divided, taking care to preserve the vein of Labbé, which joins the transverse sinus, and the trochlear nerve, which enters the anterior edge of the tentorium. The abducent and facial nerves are exposed medial to the vestibulocochlear nerve. The PICA courses in the lower margin of the exposure with the glossopharyngeal and vagus nerves. The SCA passes below the oculomotor and trochlear nerves and above the trigeminal nerve. (C) The semicircular canals have been opened. The superior canal is located under the middle fossa’s arcuate eminence and the posterior canal is located immediately lateral to the posterior wall of the internal acoustic meatus. (D) The labyrinthectomy has been completed to expose the internal acoustic meatus. Abbreviations: A., artery; Ac., acoustic; AICA, anteroinferior cerebellar artery; Bas., basilar; Br., branch; Chor., chorda; CN, cranial nerve; Int., internal; Lat., lateral; Marg., margin; N., nerve; Pet., petrosal; PICA, posteroinferior cerebellar artery; Post., posterior; SCA, superior cerebellar artery; Sp., spine; Sup., superior; Tymp., tympanic; V., vein; Vert., vertebral.
Figure 27 (A–D) Postauricular exposure of the jugular foramen. (A) The C-shaped retroauricular incision (insert) provides access for the mastoidectomy, neck dissection, and parotid gland displacement. The scalp flap has been reflected forward to expose the sternocleidomastoid muscle and the posterior part of the parotid gland. (B) The more superficial muscles and the posterior belly of the diagastric have been reflected to expose the internal jugular vein and the attachment of the superior and inferior oblique muscles to the transverse process of C1. A mastoidectomy has been completed to expose the facial nerve, sigmoid sinus, and the semicircular canals. (C) Enlarged view of the mastoidectomy. The jugular bulb is exposed below the semicircular canals. The chorda tympanii arises from the mastoid segment of the facial nerve and passes upward and forward. The tympanic segment of the facial nerve courses below the lateral canal. (D) The external auditory canal has been transected and the middle ear structures have been removed, except the stapes, which remains in the oval window. The lateral edge of the jugular foramen has been exposed by completing the mastoidectomy, transposing the facial nerve anteriorly, and fracturing the styloid process across its base and reflecting it caudally. The petrous carotid is surrounded in the carotid canal by a venous plexus. (E) A segment of the sigmoid sinus, jugular bulb, and internal jugular vein has been removed. The lateral wall of the jugular bulb has been removed while preserving the medial wall and exposing the opening of the inferior petrosal sinus into the jugular bulb. Removing the medial versus wall exposes the portion of the glossopharyngeal, vagus, accessory, and hypoglossal nerves that are hidden deep to the vein. The main inflow from the petrosal confluence is directed between the glossopharyngeal and vagus nerves. (F) The medial venous wall of the jugular bulb has been removed. The intrajugular ridge extends forward from the intrajugular process and divides the jugular foramen between the sigmoid and petrosal parts. The glossopharyngeal, vagus, and accessory nerves enter the dura on the medial side of the intrajugular process, but only the glossopharyngeal nerve courses through the foramen entirely on the medial side of the intrajugular ridge (14). Abbreviations: A., artery; Aur., auricular; Car., carotid; Chor. Tymp., chorda tympani; CN, cranial nerve; Gl., gland; Gr., greater; Inf., inferior; Int., internal; Intrajug., infrajugular; Jug., jugular; Laryn., laryngeal; Lat., lateral; M., muscle; Med., medial; Mid., middle; N., nerve; Obliq., oblique; Pet., petrosal; Petros.; Post., posterior; Proc., process; Semicirc., semicircular; Sig., sigmoid; Sternocleidomast., sternocleidomastoid; Stylo mast., stylomastoid; Sup., superior; Symp., sympathetic; Tr., trunk; Trans., transverse; V., vein.
posterior inferior cerebellar artery (PICA), which courses around the medulla and supplies the suboccipital cerebellar surface. The main branches of the basilar artery are the anterior inferior cerebellar artery (AICA), which passes around thepons and supplies the petrosal cerebellar surface and the nerves entering the internal auditory canal, the superior cerebellar artery (SCA), which encircles the midbrain and upperpons and supplies the tentorial cerebellar surface and dentate nucleus; and the posterior cerebral artery (PCA), which passes to the supratentorial area. The main venous drainage is by way of the petrosal veins, which join the superior and inferior petrosal veins emptying into the superior and inferior petrosal sinuses.

The vascular and neural structures of the posterior fossa can be divided into upper, middle, and lower groups related to the three cerebellar arteries: the upper group is related to the SCA, which encircles the midbrain, courses on the superior cerebellar peduncle and within the cerebel-lomesencephalic fissure, passes below the oculomotor and trochlear nerves and above the trigeminal nerve, and supplies the pontine cerebellar surface; the middle group is related to the AICA, which encircles the pons, courses on the middle cerebellar peduncle, dips in the cerebellopontine fissure passing by and sending branches to the facial and vestibulocochlear nerves, and supplies the petrosal cerebel-lar surface; and the lower group is related to the PICA, which encircles the medulla, passes near or between the rootlets of the lower four cranial nerves to course on the inferior cere- bellar peduncle, dips into the cerebellomedullary fissure, and supplies the suboccipital cerebellar surface (Figs. 12 and 16) (17).

Exocranial Surface

This portion is divided in central and lateral portions (Fig. 14) (14.18,19). The center portion is formed by the basal (circular) part of the occipital bone, which slopes upward from the foramen magnum and has the pharyngeal tubercle for the at-tachment of the superior pharyngeal constrictor on its lower surface and the condyle (os condylogenum) at the anterolateral margin of the foramen magnum. The hy-poglossal foramen, conveying the hypoglossal nerve, crosses above the middle one-third of the long axis of the condyle. The posterior condylar canal carries the posterior condylar vein interconnecting the vertebral venous plexus with the sigmoid sinus. Lateral to the condyle lies the jugular process of the occipital bone, which forms the posterior edge of the jugular foramen, connects the squamosal and basal parts of the occipital bone, and receives the attachment of the rectus capitis lateralis muscle posterior to the jugular foramen and jugular bulb. Two grooves lateral to the jugular process, a medial one for the occipital artery and a lateral one, the digastric groove, for the origin of the posterior belly of the digastric muscle, separate the jugular process from the mas-toid process. The remaining muscles are the longus capitis, the rectus capitis anterior attached in front of the occipital condyle. The nerves of the area are the hypoglossal and C1 nerves. The vertebral artery ascends through the C1 transverse process and crosses me-dially behind the superior articular pillar of the atlas or the atlanto-occipital joint to enter the dura (Figs. 17 and 18). The first segment of the vertebral artery ascends from the sub-clavian artery running up to the transverse foramen of C6. The second segment runs from C6 to C2, where the artery changes to a more lateral direction. The third segment asc-ends laterally to reach the C1 transverse foramen and turns medially and horizontally behind the atlanto-occipital joint to course in the depths of the suboccipital triangle delimited by three muscles: the superior oblique extending from the occipital bone to the C1 transverse process, the inferior oblique extending from the C1 transverse process to the C2 spine, and the rectus capitis posterior major extending from the C2 transverse process to the occipital bone (Figs. 17 and 18). The fourth segment of the vertebral artery extends from the dural entrance to the vertebrobasilar junction. The third segment gives rise to the posterior meningeal and muscular arteries and occasionally the PICA. The other vascular structures in the area are the occipital and ascending pharyngeal arteries, the vertebral venous plexus, and the posterior and anterior condylar veins.

DISCUSSION

With the development of microsurgical techniques and skull base surgical principles, it has become possible to access all parts of the cranial base. Lesions involving the central part of the anterior two-thirds of the cranial base and clivus can be accessed through intracranial routes, such as the orbitozygomatic, transcranial-transbasal, or extended frontal approaches, or by subcranial routes utilizing the vari-ous modifications of the transnasal, transoral, transsphe-noidal, transmandibular, transmaxillary, transcervical, or fa-cial translocation approaches or by a combination of the intracranial and subcranial routes (Figs. 19–23). The ap-proaches can also be extended to the middle skull base by using the orbitozygomatic, preauricular infratemporal fossa, subtemporal anterior petrosectomy, or other extensions of the middle fossa routes (Fig. 24). Further posteriorly, ap-approaches directed through the temporal bone, such as the retrosigmoid, transsphenoidal, translabyrinthine, transcochlear, and com-bined supra-infratentorial parasellar approaches, or a combi-nation of preauricular and postauricular transpetromastoid approach, may be considered (Figs. 25 and 26). Lesions in the posterior fossa and posterior skull base may be reached through the retrosigmoid or subtemporal routes or the far-lateral approach and its transcondylar, supracarotid, and paracarotid modifications (Fig. 24) (19). The jugular fora-men is most often accessed by a postauricular transtemporal ap-proach (Fig. 27). Cranial base tumors frequently invade in-tracranial and subcranial spaces and require innovative com-binations of these transcranial, subcranial, and combined ap-proaches. Thoughtful consideration of skull base anatomy is essential to successful surgery for these tumors.

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