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Anatomic Report

Unilateral Upper and Lower Subtotal Maxillectomy Approaches to the Cranial Base: Microsurgical Anatomy

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ABSTRACT

OBJECTIVE

The relationship of the maxilla, with its thin walls, to the nasal and oral cavities, the orbit, and the infratemporal and pterygopalatine fossae makes it a suitable route for accessing lesions involving both the central and lateral cranial base. In this study, we compared the surgical anatomy and exposure obtained by two unilateral transmaxillary approaches, one directed through an upper subtotal maxillectomy, and the other through a lower subtotal maxillectomy.

METHODS

Cadaveric specimens examined, with 3 to 40× magnification, provided the material for this study.

RESULTS

Both upper and lower maxillectomy approaches open a surgical field extending from the ipsilateral internal carotid artery to the contralateral Eustachian tube; however, they differ in the direction of the access and the areas exposed. The lower maxillectomy opens a combination of the transmaxillary, transnasal, and transoral routes to extra- and intradural lesions of the central cranial base. Performing additional osteotomies of the mandibular coronoid process and the sphenoid pterygoid process provides anterolateral access to the lateral cranial base, including the pterygopalatine and infratemporal fossae, and the parapharyngeal space. The upper maxillectomy opens the transmaxillary and transnasal routes to the central cranial base but not the transoral route. The structures exposed in the lateral cranial base, after removing the coronoid and pterygoid processes, include the pterygopalatine and infratemporal fossae and the parapharyngeal space. Exposure can be extended by a frontotemporal craniotomy, which provides access to the anterior and middle cranial fossae and the basal cisterns.

CONCLUSION

The upper and lower subtotal maxillectomy approaches provide wide but differing access to large parts of the central and lateral cranial base depending on the site of the osteotomies.

Key words: Cranial base, Infratemporal fossa, Maxilla, Maxillectomy, Microsurgical anatomy, Pterygopalatine fossa, Skull base, Transmaxillary

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The maxilla, the largest bone in the facial skeleton, has a unique relationship to the cranial base (Fig. 1). It forms part or all of the floor and lateral wall of the nasal cavity, the roof of the oral cavity, the orbital floor, the upper jaw, and the walls of the infratemporal and pterygopalatine fossae. The relationship of the maxillary sinus, with its thin walls, to all of the above structures makes it a suitable route for accessing large parts of the central and lateral cranial base. Numerous anterior approaches to the cranial base, including those directed through the nasal and oral cavities, sphenoid sinus, mandible, palate, cervical region, and anterior cranial fossa, provide only a limited midline access that is confined to a small part of the central cranial base ([1,4,12,13,23,25,28]). In contrast, approaches directed through a unilateral maxillectomy provide a wide and direct route to lesions involving both the central and lateral cranial base. They also can be flexibly applied to lesions involving a variety of sites by varying the position of the osteotomies, and in selected patients, these approaches may be combined with a craniotomy ([7–9,15,18,19,21]). This adaptability is one of the main advantages of these approaches; however, combining the various osteotomies for exposure of a specific lesion requires an understanding of the complex anatomy of the unilateral maxillectomy approaches.

FIGURE 1.

Osseous relationships. *A*, anterior view of the facial skeleton. The middle one-third of each half of the face is the site of three large cavities. The orbit and nasal cavities open anteriorly, and the maxillary sinus is enclosed by a thin shell of bone. The orbit and nasal cavities are separated from the anterior cranial fossa above by a thin roof, and the nasal cavity and maxillary sinus are bounded below, and separated from, the oral cavity by the hard palate. The orbital rim is formed superiorly by the frontal bone, medially and inferiorly by the maxilla, and laterally by the zygomatic bone. The infraorbital foramen opens below the midpoint of the inferior orbital rim. The supraorbital notch, which may be bridged across to create a foramen, is situated at the junction of the medial one-third and lateral two-thirds of the superior orbital rim. The anterior nasal aperture is formed by the nasal bones above, and the maxillae laterally and below. The nasal cavity is divided sagittally by the nasal septum, and it opens posteriorly through the posterior nasal aperture into the nasopharynx. The clivus is observed through the nasal cavity in the area behind the nasal septum and the middle and inferior conchae. *Ant.,* anterior;*Fiss.,* fissure;*For.,* foramen;*Gr.,* greater;*Horiz.,*horizontal;*Inf.,* inferior;*Infratemp.,* infratemporal;*Lat.,* lateral;*Less.,* lesser;*Med.,* medial;*Mid.,* middle;*Occip.,* occipital;*Post.,* posterior;*Proc.,* process;*Sup.,* superior;*Temp.,* temporal.

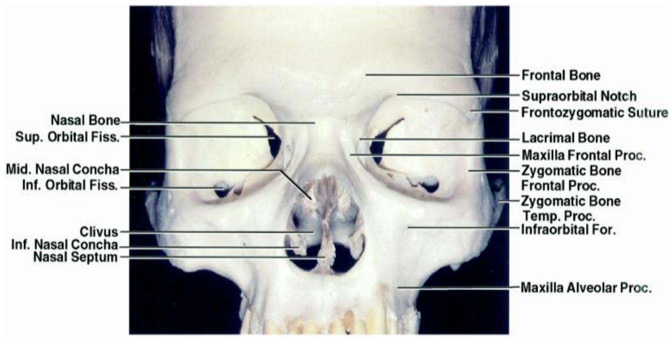


FIGURE 1.

B, anterolateral view of the left orbit. The orbit communicates with the middle cranial fossa through the superior orbital fissure, with the suprasellar area through the optic canal, with the anterior cranial fossa by the anterior and posterior ethmoidal foramina, with the nasal cavity though the nasolacrimal canal, with the infratemporal fossa via the anterolateral part of the inferior orbital fissure, and with the pterygopalatine fossa by the posteromedial end of the inferior orbital fissure. The infraorbital groove arises at the junction of the wider anterolateral and narrow posteromedial parts of the inferior orbital fissure. The anterolateral edge of the inferior orbital fissure is widest at the inferior end of the sphenozygomatic suture, which joins the sphenoid greater wing and the zygomatic frontal process in the area of the thinnest part of the lateral orbital wall. The lacrimal fossa accommodates the lacrimal gland, and the trochlear fossa is the site of attachment of the trochlea of the superior oblique.

FIGURE 1.

C, anterior view of the left half of the sphenoid bone, which has four parts: a body, greater wings, lesser wings, and a pterygoid process. The pterygopalatine fossa is located between the pterygoid process and the posterior maxillary wall below the orbital apex. It communicates with the middle cranial fossa through the foramen rotundum, with the region of the foramen lacerum via the pterygoid canal, with the nasopharynx by the palatovaginal canal, with the infratemporal fossa through the pterygomaxillary fissure, with the nasal cavity via the sphenopalatine foramen, and with the oral cavity by the greater and lesser palatine canals.

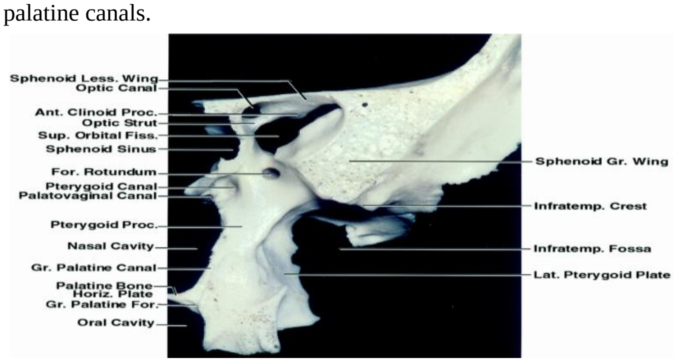


FIGURE 1.

D, lateral view of the middle one-third of the facial skeleton. The nasolacrimal groove, in which the lacrimal sac sits, is located in the anterior part of the medial orbital wall; it is formed anteriorly by the maxillary frontal process and posteriorly by the lacrimal bone. The anterior and posterior lacrimal crests, which form the anterior and posterior edges of the nasolacrimal groove, are ridges on the maxillary and lacrimal bones, respectively. The anterior and posterior ethmoidal foramina, which transmit the anterior and posterior ethmoidal branches of the ophthalmic artery and the nasociliary nerves, are situated in or just above the frontoethmoidal suture at the level of the medially situated cribriform plate.

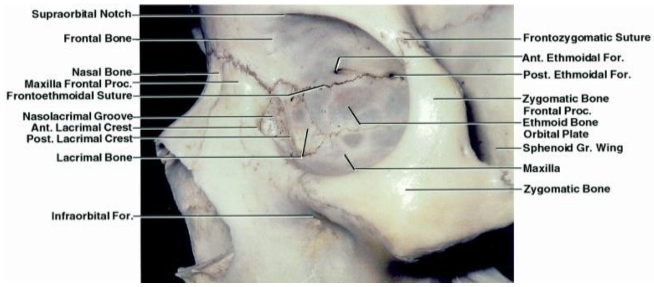


FIGURE 1.

E, lateral view after removal of the lateral wall of both the orbit and maxillary sinus. The medial orbital wall comprises the frontal process of the maxilla, the lacrimal bone, and the orbital plate of the ethmoid (lamina papyracea). The pterygopalatine fossa is bounded anteriorly by the posterior maxillary wall and posteriorly by the pterygoid process, and it and communicates laterally through the pterygomaxillary fissure with the infratemporal fossa. The medial wall of the maxillary sinus forms much of the lateral wall of the nasal cavity.

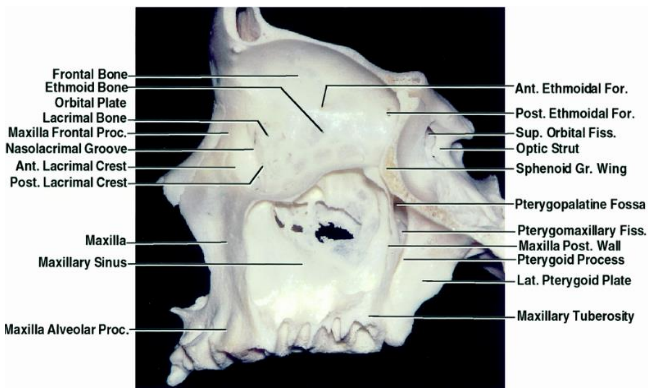
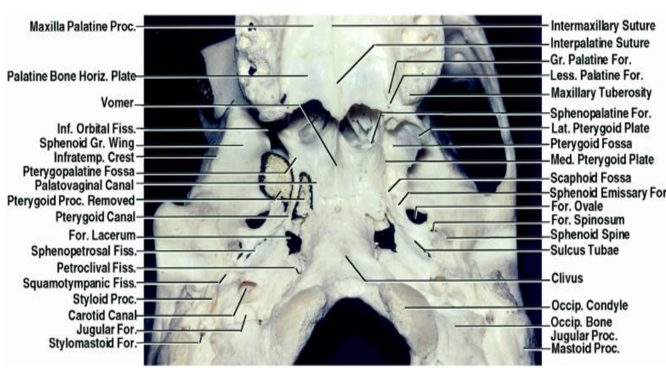


FIGURE 1.

F, inferior view of the cranial base. The right pterygoid process has been sectioned at its junction with the sphenoid greater wing and body and removed to expose the pterygopalatine fossa and the pterygoid and palatovaginal canals. The pterygoid canal, which transmits the vidian nerve formed by the union of the superficial and deep petrosal nerves, passes above the root of the medial pterygoid plate. It opens anteriorly into the medial portion of the pterygopalatine fossa and posteriorly into the anterolateral aspect of the foramen lacerum. The palatovaginal canal transmits the pharyngeal branches of the maxillary nerve and artery. The pterygoid fossa, the site of the attachment of the medial pterygoid, is situated between the medial and lateral pterygoid plates. The scaphoid fossa, the attachment site of the anterior portion of the tensor veli palatini, is located just lateral to the root of the medial pterygoid plate, below the pterygoid canal, and medial to the inconstant sphenoid emissary foramen. 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 foramina ovale and spinosum, and the sphenoid spine. The upper and middle thirds of the clivus are bordered laterally by the foramen lacerum and the petroclival fissure. The lower clivus is bordered by the occipital condyle and the hypoglossal canal, which passes above the condyle. The greater and lesser palatine foramina, which transmit the greater and lesser palatine nerves and vessels, open at the posterolateral edge of the hard palate between the maxillary tuberosity laterally and the horizontal plate of the palatine bone medially.



MATERIALS AND METHODS

Five adult cadaver specimens were dissected using 3 to 40× magnification. Colored silicone was injected into the vascular structures to facilitate their definition. The lower subtotal maxillectomy approach examined in this study resembles the approach described by Cocke and Robertson ([9]) and Cocke et al. ([10]), which they term the *extended unilateral maxillectomy/maxillotomy*. The upper subtotal maxillectomy approach examined resembles the technique described by Arriaga and Janecka ([2]) and Janecka et al. ([18,19]) as the facial translocation approach. The goal was not to replicate these two approaches exactly, but to define the anatomic relationships important in completing these approaches. The mobilized segment of the maxilla was detached from the soft tissues for this study, but in selected patients the maxilla may be mobilized as an osteoplastic maxillotomy hinged to a cheek or palatal soft tissue flap to preserve the blood supply of the mobilized maxilla.

RESULTS

The maxilla has a body and zygomatic, frontal, alveolar, and palatine processes, and it articulates with the zygomatic, frontal, ethmoid, palatine, sphenoid, and nasal bones, as well as the vomer (Fig. 1). The body encloses the maxillary sinus, and it is located above the upper teeth, forming much of the floor of the orbit. The medial surface surrounds the anterior nasal aperture and forms much of the lateral wall of the nasal cavity. The posterior and posterolateral wall of the body forms the anterior wall of the pterygopalatine and infratemporal fossae (Fig. 2). It joins with the lacrimal bone to create an opening through which the nasolacrimal duct descends and serves as the site of inferior nasal concha attachment. It also contains canals and foramina through which numerous branches of the maxillary nerve pass, including the infraorbital branch, as well as the anterosuperior, middle superior, and posterosuperior alveolar nerves. It joins with the palatine bone to complete the bony passages for the greater and lesser palatine nerves.

FIGURE 2.

Inferior views of an axial section of the cranial base. *A*, the infratemporal fossa is surrounded by the maxillary sinus anteriorly, the mandible laterally, the pterygoid process anteromedially, and the parapharyngeal space posteromedially. It contains the mandibular nerve and maxillary artery and their branches, the medial and lateral pterygoid muscles, and the pterygoid venous plexus. The lower part of the nasal cavity and the nasopharynx, both related to the central cranial base, are laterally bounded from front to back by the nasolacrimal duct, the maxillary sinus, the pterygopalatine fossa, the medial pterygoid plate, and the Eustachian tube. The pharyngeal recess (Rosenmüller's fossa) projects laterally from the posterolateral corner of the nasopharynx; its deep edge faces the internal carotid artery laterally and the foramen lacerum above. The posterior nasopharyngeal wall is separated from the lower clivus and the upper cervical vertebra by the longus capitis muscle, and the nasopharyngeal roof rests against the upper clivus and the posterior part of the sphenoid sinus floor. *A.,* artery;*Ant.,* anterior;*Br.,* branch;*Car.,* carotid;*CN*, Cranial Nerve;*Fiss.,* fissure;*For.*, foramen;*Gang.,* ganglion;*Gr.,* greater;*Inf.,* inferior;*Int.,* internal;*Lat.,* lateral;*Less.,* lesser;*Lev.,* levator;*Lig.,* ligament;*M.,* muscle;*Med.,* medial;*Mid.*, middle;*N.,* nerve;*Occip.,* occipital;*Post.,* posterior;*Proc.,* process;*Sup.,* superior;*Superf.,* superficial;*Temp.,* temporal;*Tens.,* tensor;*V.,* vein.

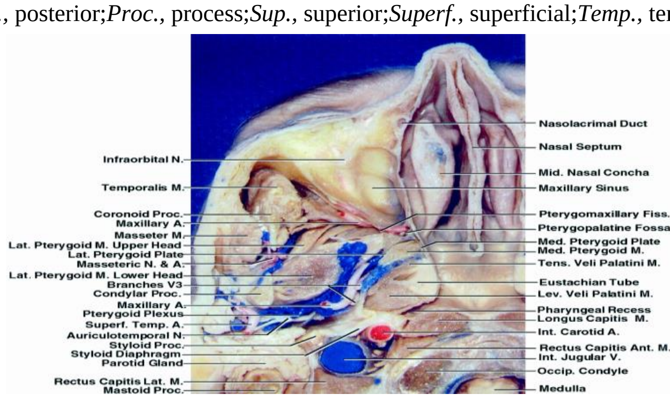


FIGURE 2.

B, enlarged view; note the pre- and poststyloid compartments of the parapharyngeal space (*highlighting*). The styloid diaphragm, which is formed by the anterior part of the carotid sheath, separates the parapharyngeal space into pre- and poststyloid parts. The prestyloid compartment, which is a narrow fat-containing space between the medial pterygoid and tensor veli palatini, separates the infratemporal fossa from the medially located lateral nasopharyngeal region containing the tensor and levator veli palatini and the Eustachian tube. The poststyloid compartment, which is located behind the prestyloid part, contains the internal carotid artery, the internal jugular vein, and Cranial Nerves IX through XII. The pterygopalatine fossa is surrounded by the maxillary sinus anteriorly, the pterygoid process posteriorly, the nasal cavity medially, and the infratemporal fossa laterally.

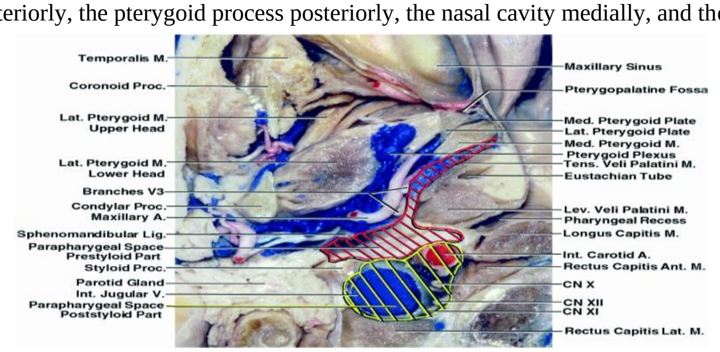


FIGURE 2.

C, enlarged view of the poststyloid part of the parapharyngeal space containing the internal carotid artery, the internal jugular vein, and Cranial Nerves IX through XII descending in the medial part of the interval between the artery and the vein. The styloid diaphragm, which is formed by the anterior part of the carotid sheath, separates the pre- and poststyloid parts of the parapharyngeal space. The styloid process and facial nerve are anterolateral and lateral to the internal jugular vein. The internal carotid artery courses lateral to the longus capitis.

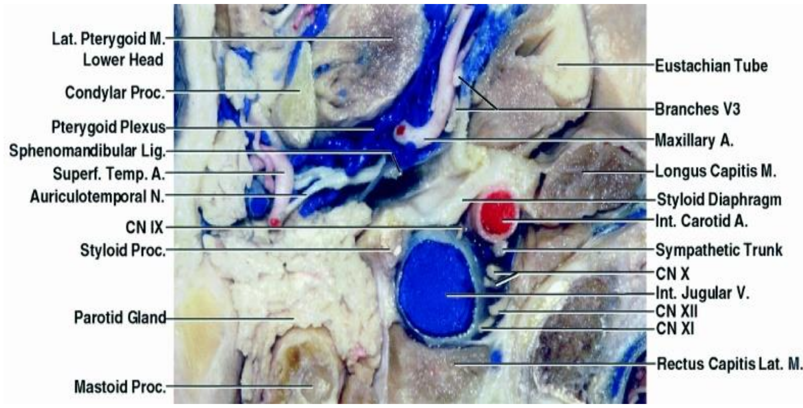


FIGURE 2.

D, the medial pterygoid and part of the lateral pterygoid, some fat in the parapharyngeal space, and the pterygoid venous plexus have been removed. This exposes the otic ganglion and the mandibular nerve and its branches, including the buccal, deep temporal, masseteric, lingual, inferior alveolar, and auriculotemporal nerves, branches to the pterygoids, and the nervus spinosus, which passes through the foramen spinosum.

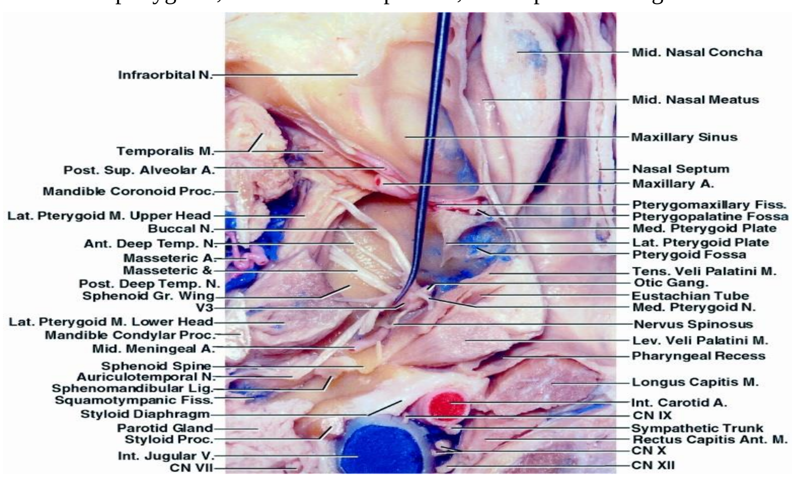


FIGURE 2.

E, the pterygoid process has been removed, further exposing the pterygopalatine fossa containing the terminal part of the maxillary artery and its sphenopalatine, infraorbital, pharyngeal, and greater and lesser palatine branches. The pterygoid canal and the foramen rotundum, which are bounded on the medial side by an extension of the sphenoid sinus, have been opened to expose the vidian and maxillary nerves. The floor of the infraorbital groove, which is located in the roof of the maxillary sinus, has been removed to expose the infraorbital nerve and artery. The cartilage, which fills the lower margin of the foramen lacerum, has been removed to expose the posterior orifice of the pterygoid canal and the internal carotid artery coursing above the foramen.

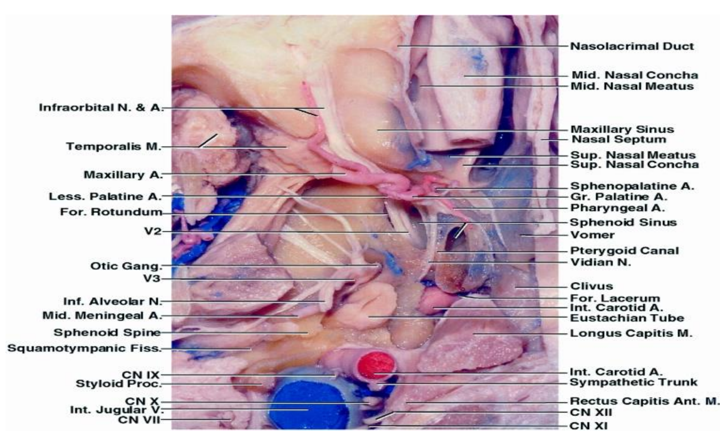


FIGURE 2.

F, the arterial structures in the pterygopalatine fossa have been removed to expose the neural relationships. The pterygopalatine ganglion is situated medial to the maxillary nerve and is connected to it by ganglionic branches. The right half of the sphenoid sinus has been opened, and the petrous carotid has been exposed by removing petrous bone underlying the carotid canal. The Eustachian tube, which has been divided at the root of its cartilaginous part, is situated immediately anterolateral to the petrous carotid. The clivus is bounded laterally by the external surface of the petroclival fissure, in which the inferior petroclival vein courses.

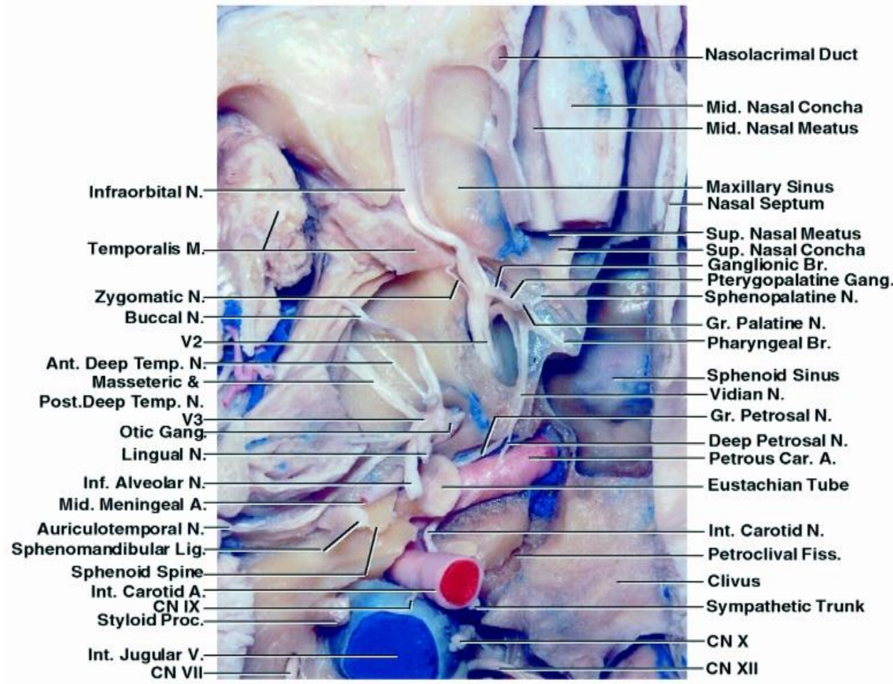
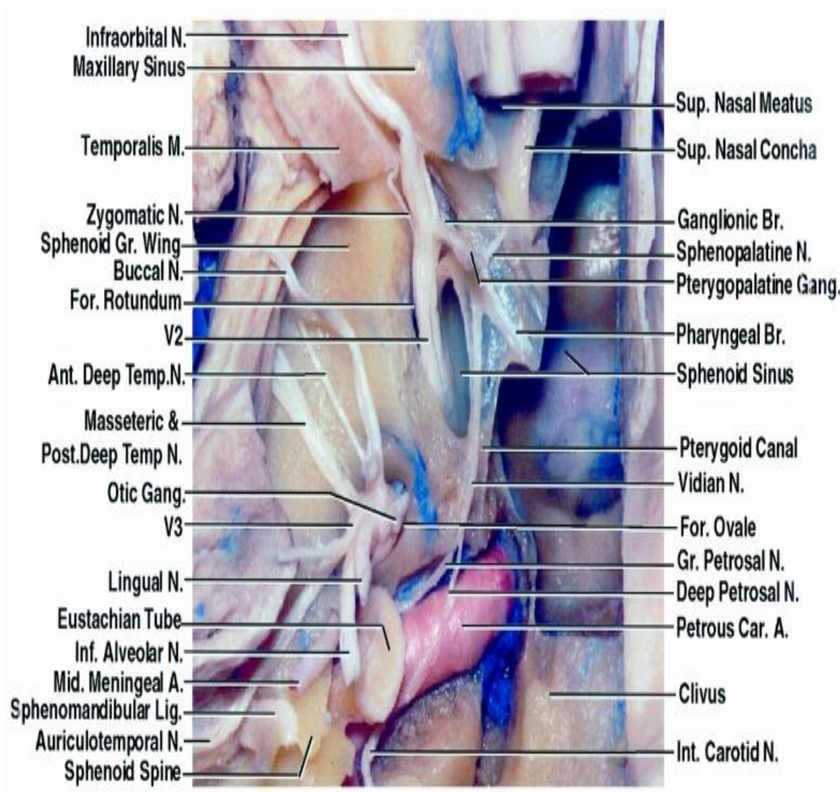


FIGURE 2.

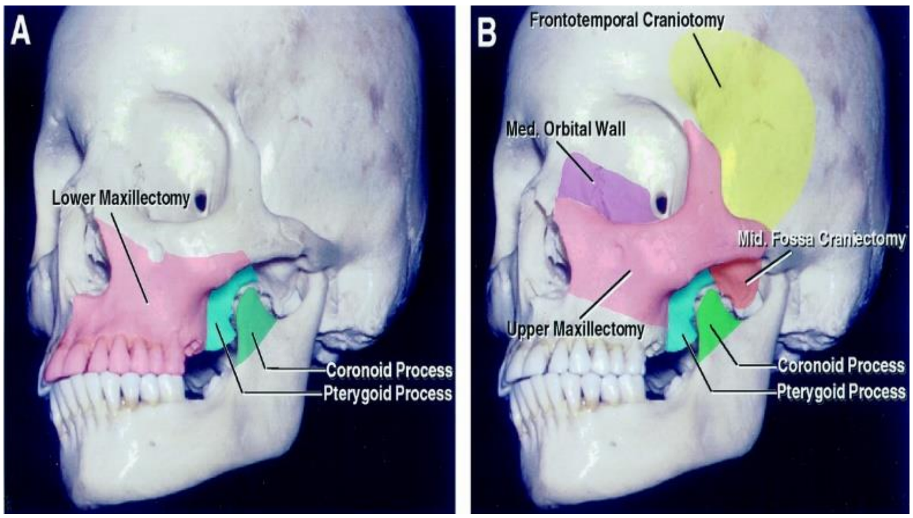
G, enlarged view of the neural structures in the pterygopalatine and infratemporal fossa and the pterygoid canal. The branches joining or emanating from the pterygopalatine ganglion include the greater and lesser palatine, sphenopalatine, vidian, and pharyngeal nerves.



Our results are arranged in the following stages: 1) the facial stage, which includes the skin and soft tissue incisions; 2) the skeletal stage, which focuses on the site of the maxillary and other osteotomies; 3) the retromaxillary stage, which includes exposure of the infratemporal and pterygopalatine fossae and the parapharyngeal space; 4) the central craniocervical stage, which includes accessing the nasal and oral cavities, pharynx, ethmoid and sphenoid sinuses, orbit, clivus, upper cervical vertebra, and pituitary gland and adjacent part of the cavernous sinus; and 5) the intracranial stage, which includes exposure of the anterior and middle cranial fossae, basal cisterns, and lateral wall of the cavernous sinus (Fig. 3).

FIGURE 3.

Basic and extended units for completing the upper and lower subtotal maxillectomies. *A*, the lower maxillectomy is performed by a combination of osteotomies through the maxillary body, hard palate, and pterygomaxillary junction and can be extended by removing the coronoid and pterygoid processes. *B*, the upper maxillectomy is accomplished by performing osteotomies through the maxillary body above the alveolar process, lower orbital rim, and zygomatic arch and can be extended by removing the pterygoid and coronoid processes. The procedure can be combined with a frontotemporal craniotomy and removal of the floor of the middle cranial fossa. An osteotomy in the medial orbital wall is optional for anterior midline access.



Facial stage

Both approaches examined in this study were performed through a Weber-Fergusson facial skin incision, although the lower subtotal maxillectomy may be completed using a degloving technique, in which the incisions are concealed within the nose and mouth ([9]).

Lower maxillectomy

The lower maxillectomy began with an incision extending vertically from the vermilion border of the upper lip, along the philtral ridge, around the nasal ala, and upward to the medial canthal region (Fig. 4). After the vertical incision, an incision was made in the apex of the gingivobuccal gutter extending through the mucoperiosteum from the midline to the tuberosity of the maxilla, which provided access to the posterolateral maxillary wall. In the lower maxillectomy technique, an infraorbital incision is needed infrequently, and the medial palpebral ligament, nasolacrimal duct, and infraorbital nerve usually are preserved because the maxillary osteotomy is located below the infraorbital foramen. If required, however, the incision can be extended horizontally beneath the lower eyelid to the lateral canthus, curving slightly downward to the root of the zygomatic arch; care must be taken to avoid injury to the anterior filaments of the temporal branch of the facial nerve. Ectropion and lymphedema, which are associated with the horizontal skin incision on the cheek below the lower eyelid, can be avoided with the use of a conjunctival incision through the inferior fornix. The cheek flap is elevated by subperiosteal dissection, exposing the anterior and lateral maxilla, nasal and zygomatic bones, anterior nasal aperture, and the masseter muscle. The cheek flap contains the maxillary and zygomatic periostea and the facial muscles. The infraorbital nerve and vessels emerge on the face via the infraorbital foramen, which opens downward and medially between the maxillary attachments of the levator labii superioris above and the levator anguli oris below. The infraorbital neurovascular bundle is usually preserved, but infrequently may be divided if wider lateral exposure is required. If divided, it can be reapproximated at the conclusion of the operation. To expose the oral surface of the hard palate, its mucoperiosteum is incised in an anteroposterior direction lateral to the planned palatal osteotomy, and a palatal flap is elevated. The greater palatine artery descends through its canal at the junction of the maxilla laterally and the palatine bone medially, emerges on the palate's oral surface, and runs forward near the alveolar border of the hard palate.

FIGURE 4.

Lower subtotal maxillectomy approach. *A*, the incision crosses the upper lip and the paranasal, infraorbital, and buccogingival areas. The cheek flap has been reflected laterally by subperiosteal dissection, exposing the maxilla and zygomatic bone and the upper edge of the masseter. The infraorbital nerve and artery have been divided to gain the widest exposure. The approach is commonly completed using only the lateral rhinotomy incision without the lateral infraorbital extension, or by a degloving technique without an incision on the face or transection of the infraorbital nerve, which may be reapproximated at the conclusion of the procedure. *A.*, artery;*Access.*, accessory;*A.I.C.A.*, anteroinferior cerebellar artery;*Ant.*, anterior;*Asc.*, ascending;*Atlanto-occip.*, atlanto-occipital;*Br.*, branch;*Car.*, carotid;*Cav.*, cavernous;*CN*, Cranial Nerve;*Fiss.*, fissure;*For.*, foramen;*Gang.*, ganglion;*Gr.*, greater;*Inf.*, inferior;*Int.*, internal;*Intercav.*, intercavernous;*Intracav.*, intracavernous;*Lat.*, lateral;*Less.;* lesser;*Lev.*, levator;*Lig.*, ligament;*M.*, muscle;*Med.*, medial;*Mid.*, middle;*N.*, nerve;*P.I.C.A.*, posteroinferior cerebellar artery;*Post.*, posterior;*Proc.*, process;*S.C.A.*, superior cerebellar artery;*Sup.*, superior;*Superf.*, superficial;*Temp.*, temporal;*Tens.*, tensor;*TM*, temporomandibular;*V.*, vein.

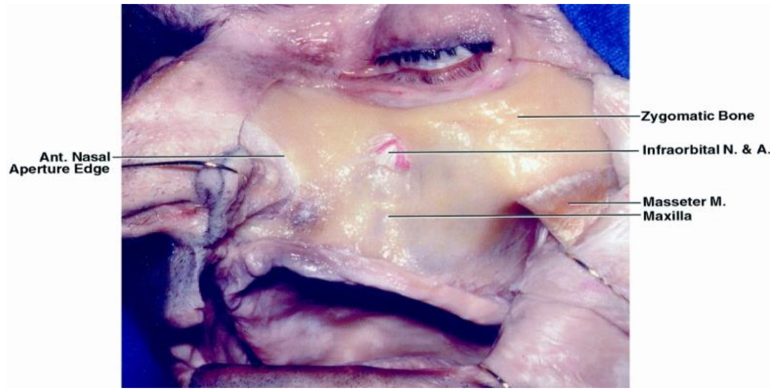


FIGURE 4.

B, the masseter has been detached from the zygoma and retracted laterally, and the inferior part of the zygoma has been removed to expose the coronoid process and the temporalis attachment.

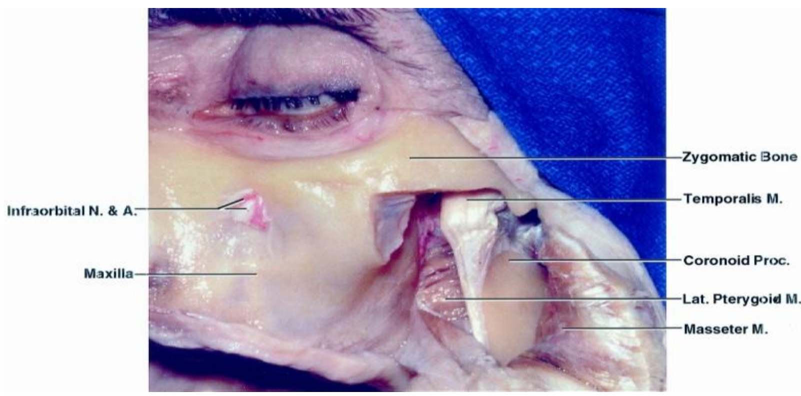


FIGURE 4.

C, the coronoid process and the lower part of the temporalis have been removed to expose the maxillary artery and the lateral and medial pterygoids in the infratemporal fossa. The temporalis attachment and coronoid process can be retracted and reattached at the conclusion of the procedure. A mucosal flap has been elevated from the lower palatal surface using subperiosteal dissection.

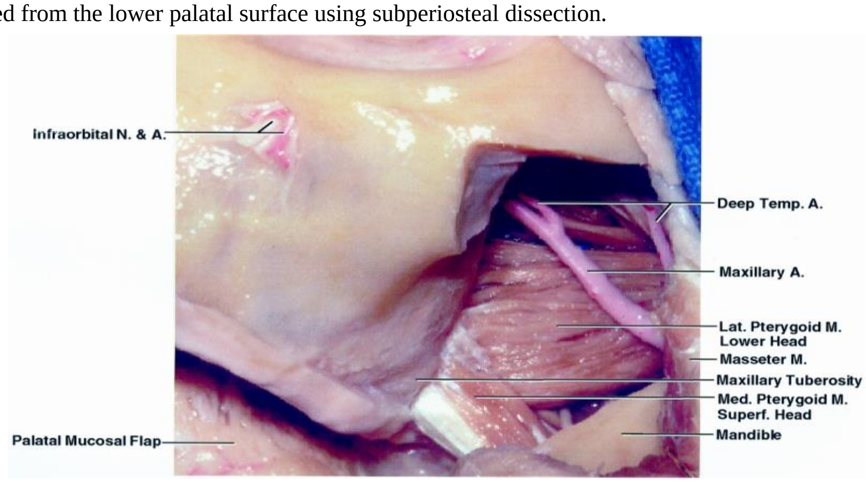


FIGURE 4.

D, anterolateral view of the infratemporal fossa. The pterygoid segment of the maxillary artery passes lateral to the lower head of the lateral pterygoid, which arises from the lateral surface of the lateral pterygoid plate and attaches to the neck of the condylar process and the capsule of the temporomandibular joint. The superficial head of the medial pterygoid arises from the maxillary tuberosity and the palatine pyramidal process and descends superficial to the lower head of the lateral pterygoid where it attaches to the medial surface of the mandibular angle. The upper head of the lateral pterygoid arises from the region of the infratemporal crest and the adjacent part of the greater wing of the sphenoid.

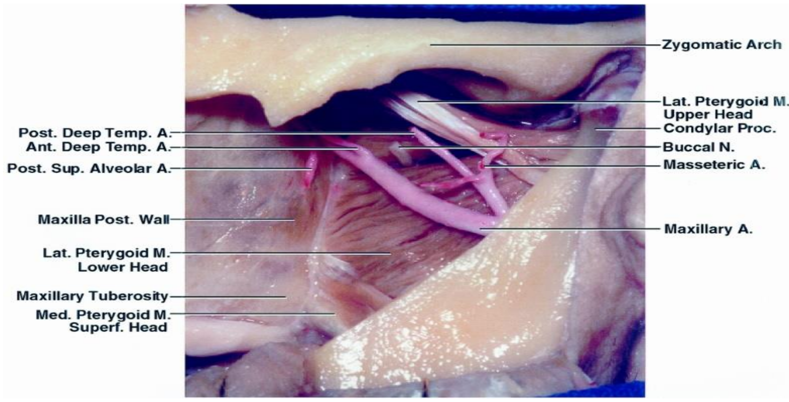


FIGURE 4.

E, the lateral pterygoid has been removed to expose the deep part of the pterygoid venous plexus, which connects with the cavernous sinus by the emissary veins passing through the foramina ovale and spinosum, and occasionally through the inconstant sphenoidal emissary foramen, which if present is located medial to the foramen ovale. The lingual and inferior alveolar nerves descend through the pterygoid venous plexus.

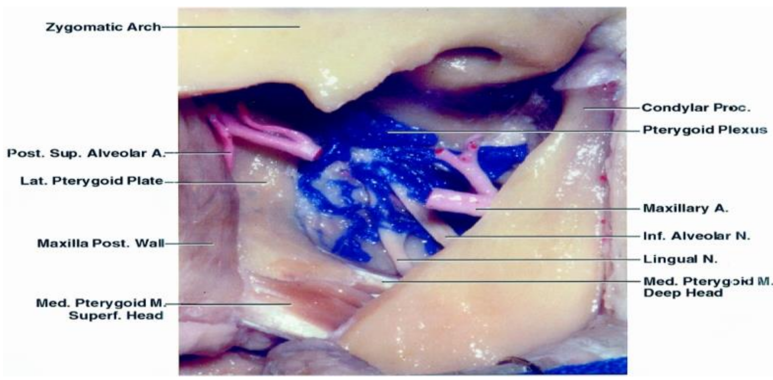


FIGURE 4.

F, the pterygoid plexus has been removed to expose the otic ganglion, as well as the mandibular nerve and its lingual, inferior alveolar, auriculotemporal, buccal, medial pterygoid, deep temporal, and masseteric branches. The chorda tympani nerve passes medial to the middle meningeal artery and the auriculotemporal and inferior alveolar nerves, and joins the lingual nerve to be distributed to the tongue and the sublingual and submandibular glands. The middle meningeal artery ascends between the two rootlets of the auriculotemporal nerve to reach the foramen spinosum, and an accessory meningeal artery ascends medial to the lingual and inferior alveolar nerves to pass through the foramen ovale. The anterior portion of the parapharyngeal space, a narrow fat-containing space bounded by the fascia covering the opposing surfaces of the tensor veli palatini and medial pterygoid, separates the infratemporal fossa from the medially situated lateral nasopharyngeal region, which contains the Eustachian tube and the tensor and levator veli palatini. The anterior portion of the parapharyngeal space has been partially removed to expose the tensor veli palatini, which hides the Eustachian tube located on its posteromedial surface.

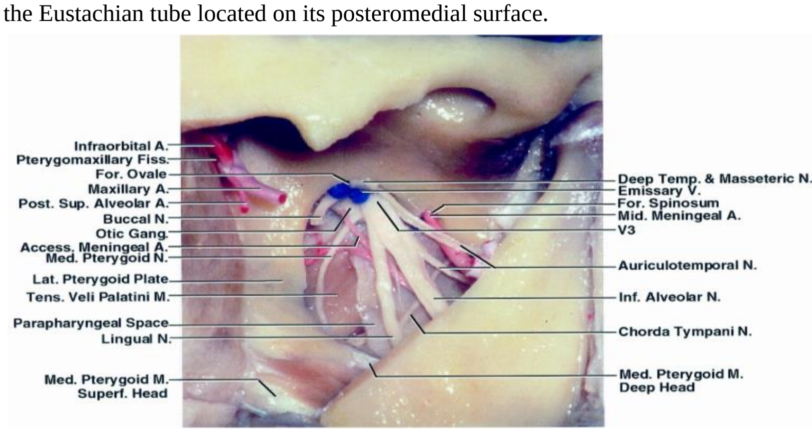


FIGURE 4.

G, anterolateral view before maxillectomy. The infratemporal fossa has been exposed through the space gained by removing the coronoid process and part of the zygoma. The lateral and medial pterygoids have been removed. The mucosal flap on the lower palatal surface is hinged and reflected to the opposite side. The fascial walls of the parapharyngeal space have been removed to expose the tensor and levator veli palatini. The medial pterygoid nerve descends lateral to the tensor veli palatini.

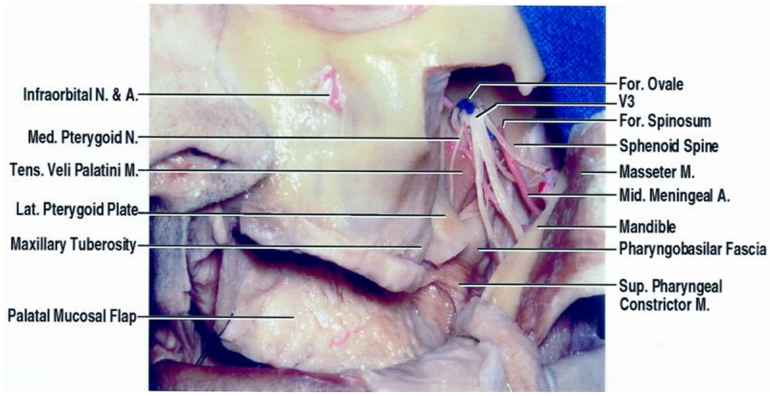


FIGURE 4.

H, the lower subtotal maxillectomy has been completed to expose the lateral wall of the nasal cavity and the retromaxillary region. The mucosal lateral wall and floor of the nasal cavity remain intact. The pterygoid process and plates block access to the central cranial base. The greater palatine nerve and artery arise in the pterygopalatine fossa and descend in front of the sphenoid pterygoid process. The soft palate has been divided for this maxillectomy; however, the maxilla may be hinged to a soft palate pedicle and folded down into the mouth to preserve the maxillary blood supply.

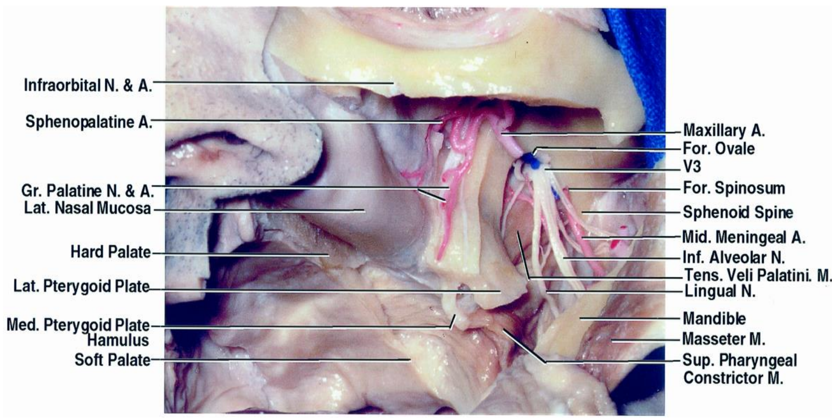


FIGURE 4.

I, enlarged view. The lateral pterygoid plate has been removed to expose the tensor veli palatini, which descends medial to the mandibular nerve on the anterolateral side of the Eustachian tube and lateral to the medial pterygoid plate and the levator veli palatini. The tendon of the tensor veli palatini loops medially around the pterygoid hamulus on the lower edge of the medial pterygoid plate to insert into the soft palate. The foramen ovale is located posterolateral to the base of the lateral pterygoid plate.

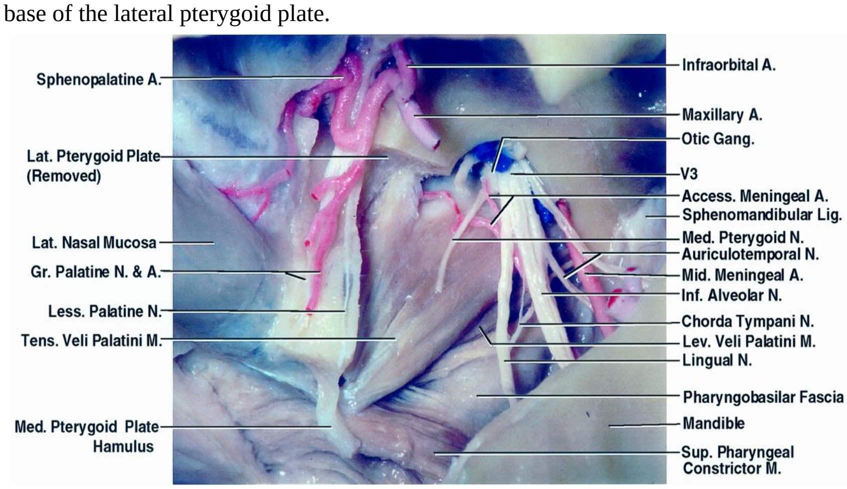


FIGURE 4.

J, the pterygoid process, medial pterygoid plate, and tensor veli palatini have been removed to expose the Eustachian tube, levator veli palatini, and the lateral nasopharyngeal wall, which blends anteriorly into the lateral nasal wall.

FIGURE 4.

K, the lateral membranous portion of the Eustachian tube has been exposed and the lateral wall of the nasopharynx and nasal cavity has been opened. The lateral apex of the pharyngeal recess, which is covered only by the pharyngobasilar fascia, is located below and behind the levator veli palatini and superior to the upper border of the superior pharyngeal constrictor. The cervical carotid, surrounded by the carotid sheath, ascends lateral to the pharyngeal recess. Part of the mandible has been removed to expose the sphenomandibular ligament, a fibrous band extending from the sphenoid spine to the lingula of the mandible. This is located at the medial aspect of the mandibular foramen where the inferior alveolar nerve and artery enter. The structures located between the ligament and the mandible include the mandibular segment of the maxillary artery, the middle and accessory meningeal and inferior alveolar arteries, and the auriculotemporal and inferior alveolar nerves.

FIGURE 4.

L, inferolateral view of the pterygopalatine fossa and its neural contents, including the pterygopalatine ganglion and the maxillary, sphenopalatine, and greater palatine nerves. The root of the pterygoid process has been drilled to expose the pterygoid and palatovaginal canals, which transmit the vidian nerve and the pharyngeal branch of the maxillary nerve, respectively.

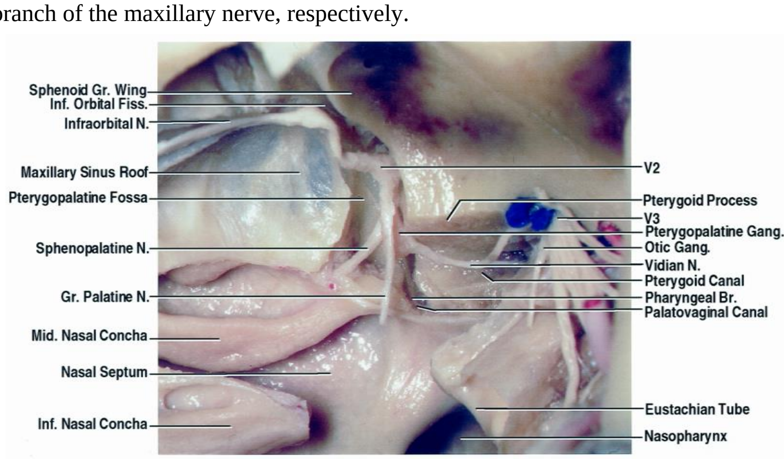


FIGURE 4.

M, the ipsilateral pharyngeal wall between the Eustachian tube and the stylopharyngeus muscle has been retracted to the opposite side to expose the anterior arch of C1 and the longus colli and capitis. Retracting the longus capitis exposes the attachment of the longus colli to the anterior tubercle of C1.

FIGURE 4.

N, the clivus has been exposed by dividing the Eustachian tube and retracting the nasopharyngeal roof to the opposite side. Division of the stylopharyngeus permits retraction of the lower part of the lateral pharyngeal wall to the opposite side and aids in exposing the internal carotid and ascending pharyngeal arteries lateral to the longus capitis.

FIGURE 4.

O, the longus capitis and colli have been retracted laterally to expose the clivus, the anterior arch of C1, and the dens and body of C2.

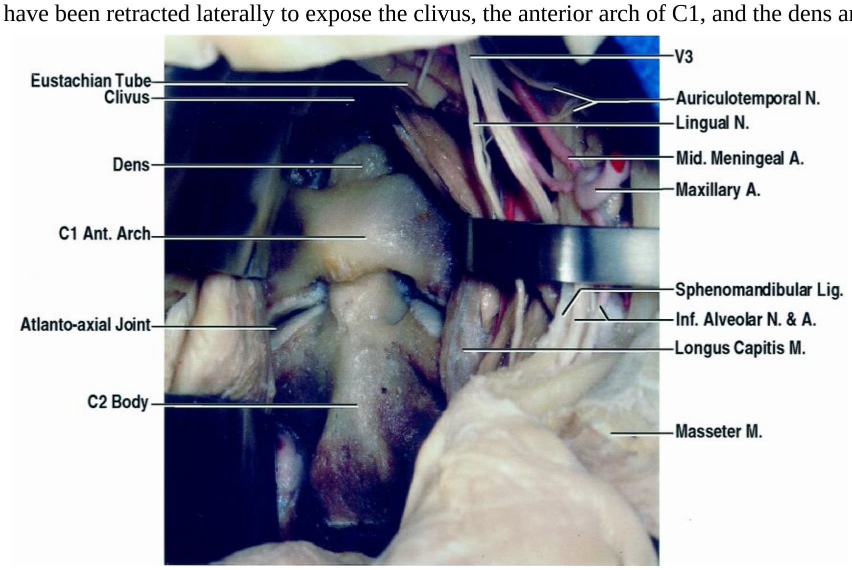


FIGURE 4.

P, the middle and lower thirds of the clivus and the anterior aspect of the foramen magnum have been removed and the dura opened to expose the medulla, the pons, and the basilar and vertebral arteries.

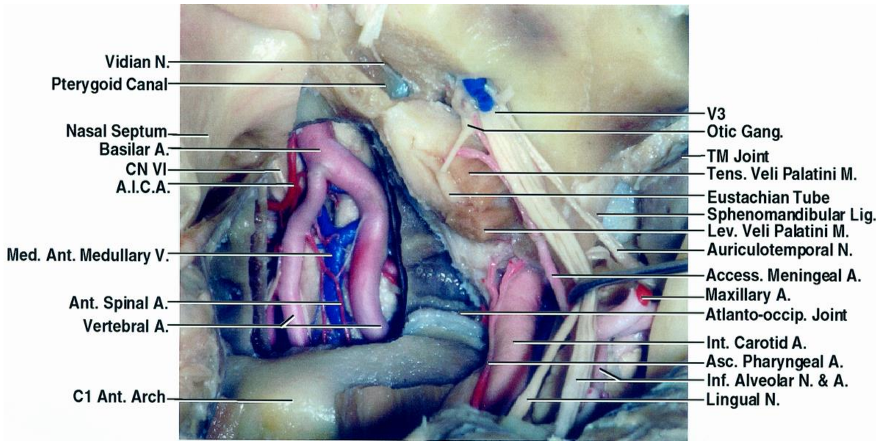


FIGURE 4.

Q, the anterior wall of the sphenoid sinus, the posterior part of the nasal septum, and the base of the medial pterygoid plate have been removed to expose a well-pneumatized sphenoid sinus and the anterior sellar wall.

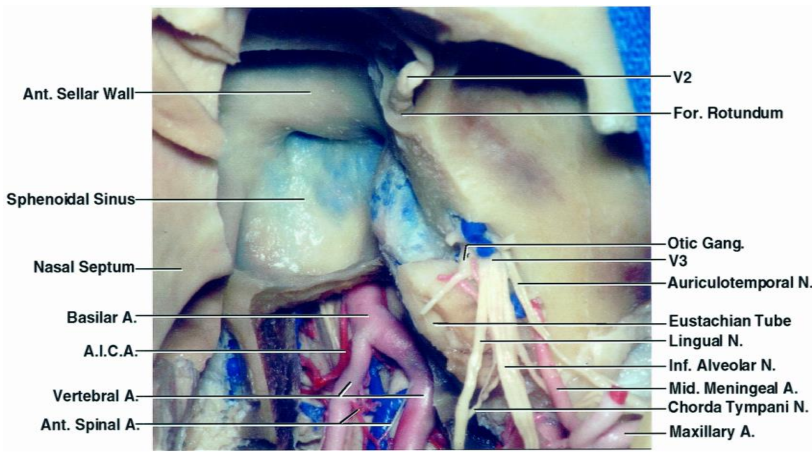


FIGURE 4.

R, the sellar floor and adjacent sinus wall have been removed to expose the pituitary gland, intracavernous carotid arteries, optic nerves, ophthalmic arteries, and intercavernous sinuses. The posterior wall of the sphenoid sinus, which forms the anterior surface of the upper clivus, has been removed to expose the pons and the basilar and superior cerebellar arteries. The short segment of the internal carotid artery (*arrow*) above the Eustachian tube courses on the cartilage of the lower aspect of the foramen lacerum and at this point turns upward to form the posterior vertical segment of the intracavernous carotid. This segment of the internal carotid artery defines the lateral limit of clival exposure.

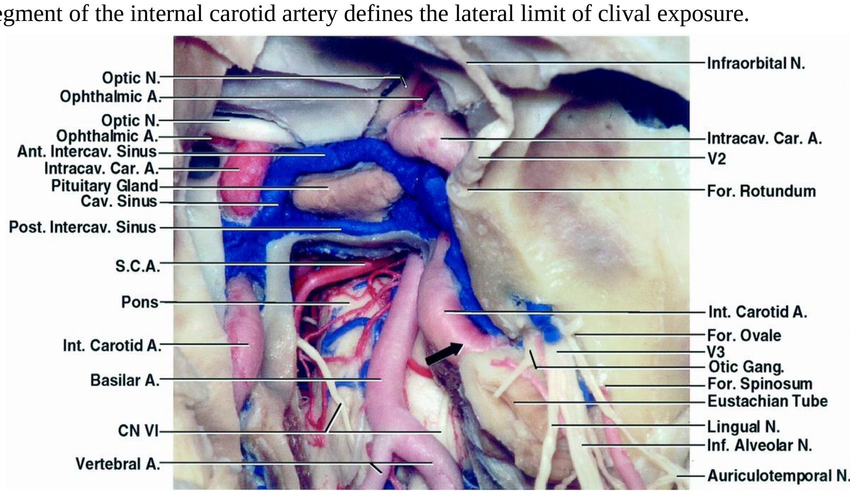
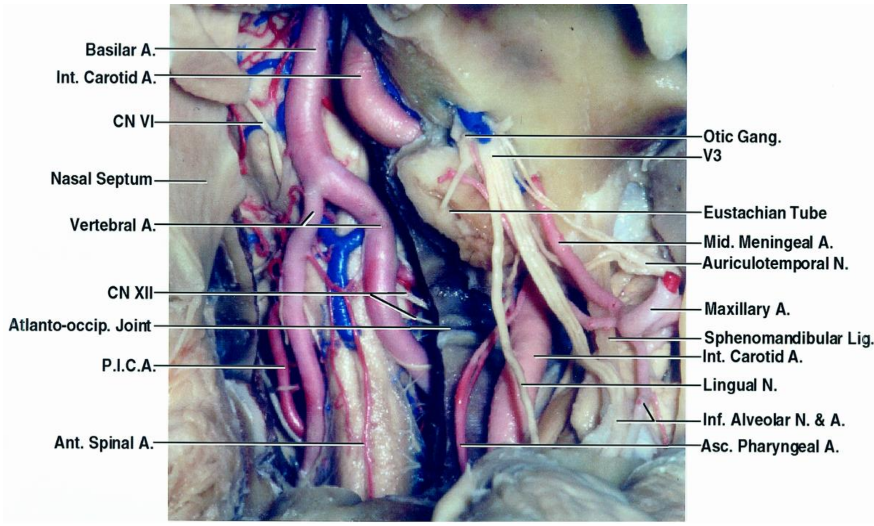


FIGURE 4.

S, the anterior arch of C1 and the dens have been removed to expose the lower medulla, the upper cervical spinal cord, and the vertebral and anterior spinal arteries.



Upper maxillectomy

For the upper maxillectomy, the Weber-Fergusson lateral rhinotomy incision is combined with lower conjunctival, transverse temporal, hemicoronal, and preauricular incisions, as needed (Fig. 5). The cheek flap, which contains the facial muscles, branches of the facial nerve, the parotid gland, and the masseter fascia, is reflected as far as the maxillary attachment of the buccinator inferiorly, the level of the hard palate anteriorly, and the trunk of the facial nerve exiting the stylomastoid foramen posteriorly. The temporal branch of the facial nerve runs within the temporoparietal fascia, a continuation of the galeal layer that is usually thin, loose, and mixed with the adipose tissue around the zygomatic arch; it supplies the frontalis, corrugator supercilii, and orbicularis oculi. An upper lip split, gingivobuccal incisions, and palatal mucoperiosteal incisions are performed only when a hard palate osteotomy is required.

FIGURE 5.

Upper subtotal maxillectomy. *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, each layer of the cheek flap was dissected separately to illustrate the structures in the flap. This exposes the facial muscles, the facial nerve branches, and the parotid gland. The temporal branch of the facial nerve, which is divided in completing the temporal incision, is tagged in preparation for reapproximation at closure. *A.*, artery;*Access.*, accessory;*Ant.*, anterior;*Br.*, branch;*Cav.*, cavernous;*CN*, Cranial Nerve;*For.*, foramen;*Gang.*, ganglion;*Gr.*, greater;*Inf.*, inferior;*Infratemp.*, infratemporal;*Int.*, internal;*Lat.*, lateral;*Less.*, lesser;*Lev.*, levator;*Lig.*, ligament;*M.*, muscle;*Med.*, medial;*Mid.*, middle;*N.*, nerve;*Post.*, posterior;*Proc.*, process;*Sup.*, superior;*Superf.*, superficial;*Temp.*, temporal;*Tens.*, tensor;*TM*, temporomandibular;*Transv.*, transverse;*V.*, vein.

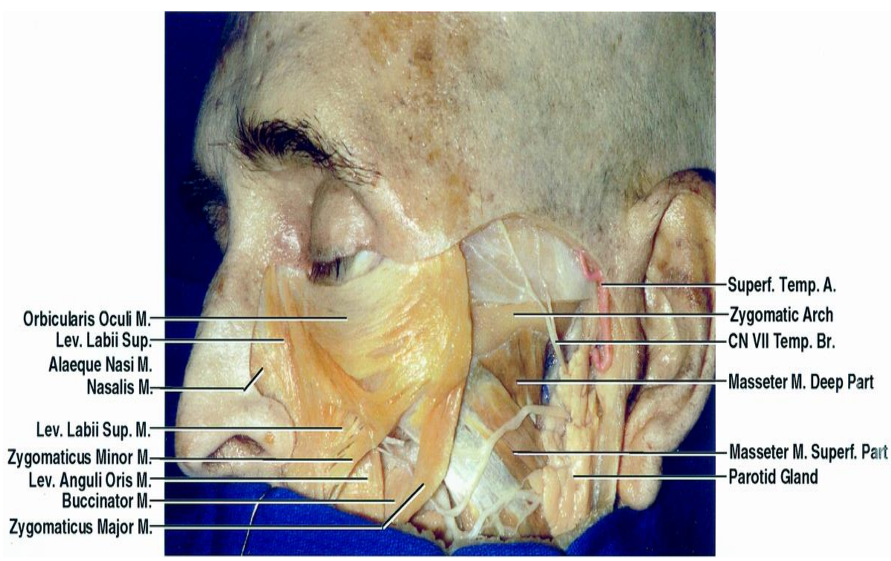


FIGURE 5.

B, the parotid gland has been removed to expose the facial nerve at the stylomastoid foramen. The infraorbital part of the orbicularis oculi has been removed to expose the underlying muscles. The infraorbital nerve and vessels exit the infraorbital foramen beneath the levator labii superioris. The masseter, which is crossed by the parotid duct, attaches along the lower margin of the zygomatic arch.

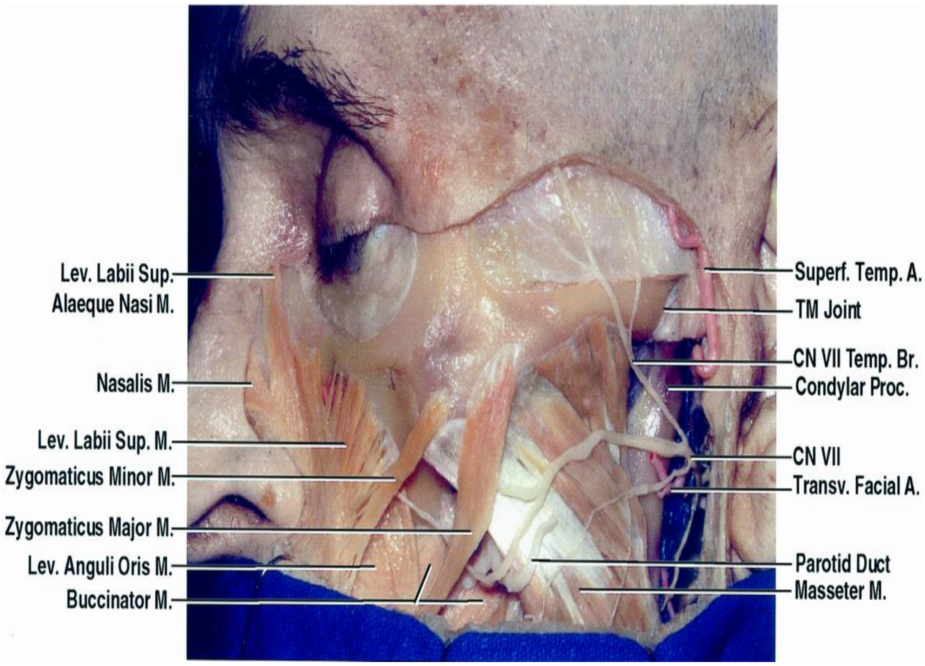


FIGURE 5.

C, the hemicoronal incision and reflection of the frontotemporal scalp flap expose the lateral orbital rim, frontal bone, and the temporalis muscle. The cheek flap, containing the facial muscles, branches of the facial nerve, the parotid gland, and the masseter fascia has been reflected inferiorly to the level of the maxillary attachment of the buccinator muscle.

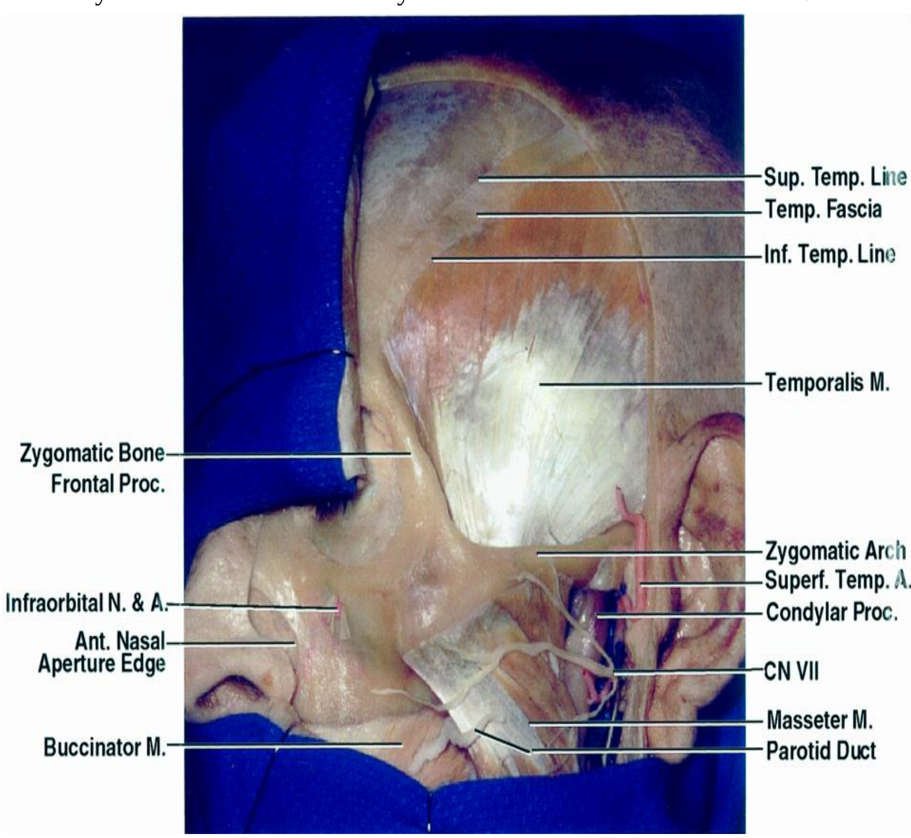


FIGURE 5.

D, the masseter has been detached from the zygoma and retracted downward to expose the maxillary tuberosity and temporalis attachment to the coronoid process. The upper edge of the buccinator attaches to the maxilla.

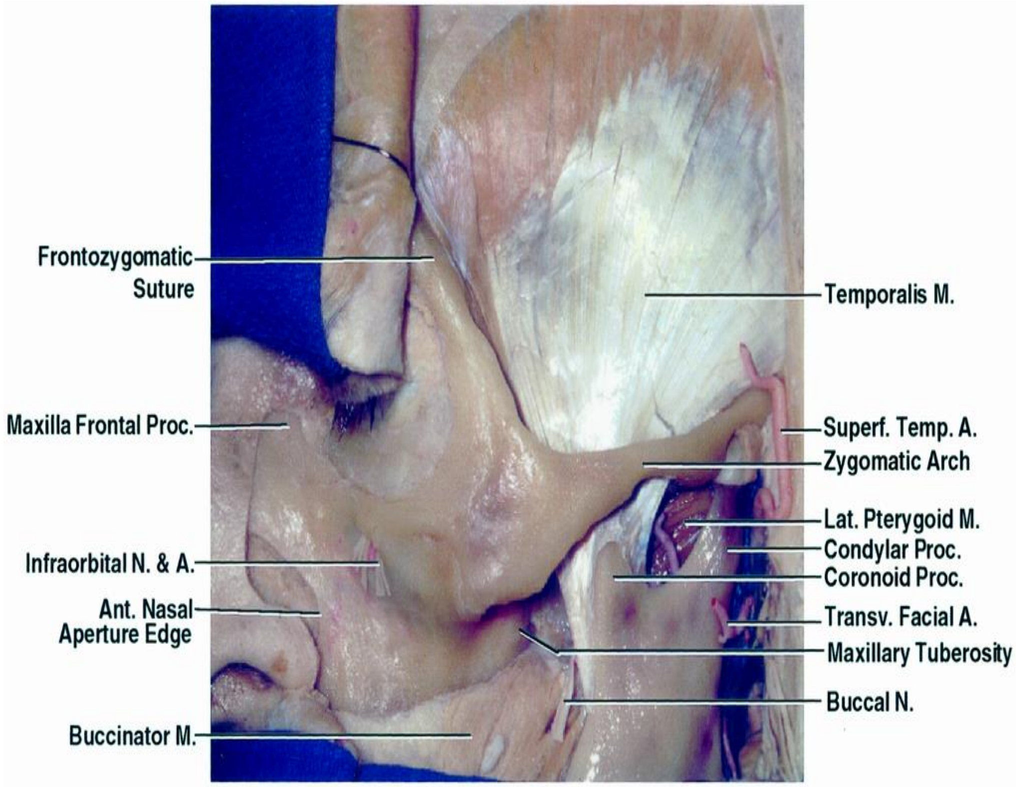


FIGURE 5.

E, the periorbita has been elevated from the orbital floor. The infraorbital nerve and artery proceed across the orbital floor. The lacrimal sac has been exposed above the orbital opening of the nasolacrimal canal.

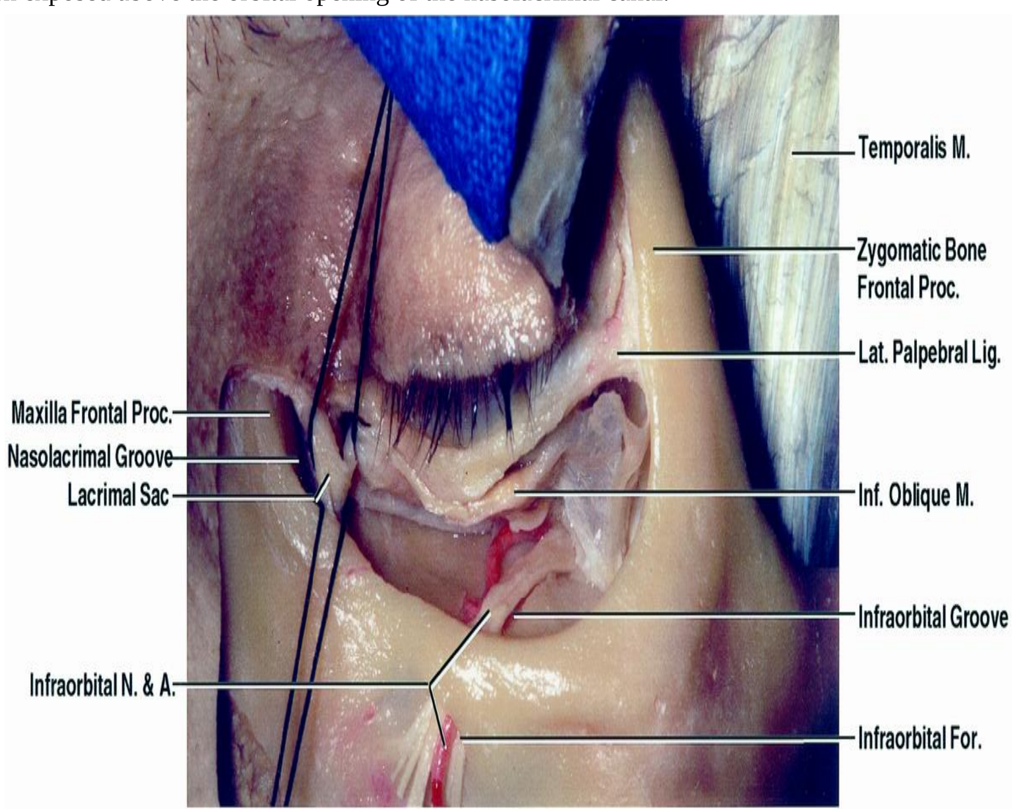


FIGURE 5.

F, the orbital, maxillary, and zygomatic osteotomies have been compiled and the lower half of the orbital rim, the anterior, medial, and lateral walls of the maxillary body, and the zygomatic arch have been removed. The lower horizontal cut, located at Le Fort I level, extends above the apical roots and hard palate, along the inferior nasal meatus medially, and above the maxillary attachment of the buccinator laterally. The maxillectomy does not include the posterior maxillary wall or cross the greater and lesser palatine canals. The lateral nasal mucosa wall was included with the maxillectomy, which exposed the nasal cavity. The infraorbital nerve may be preserved for reconstruction when this exposure is closed.

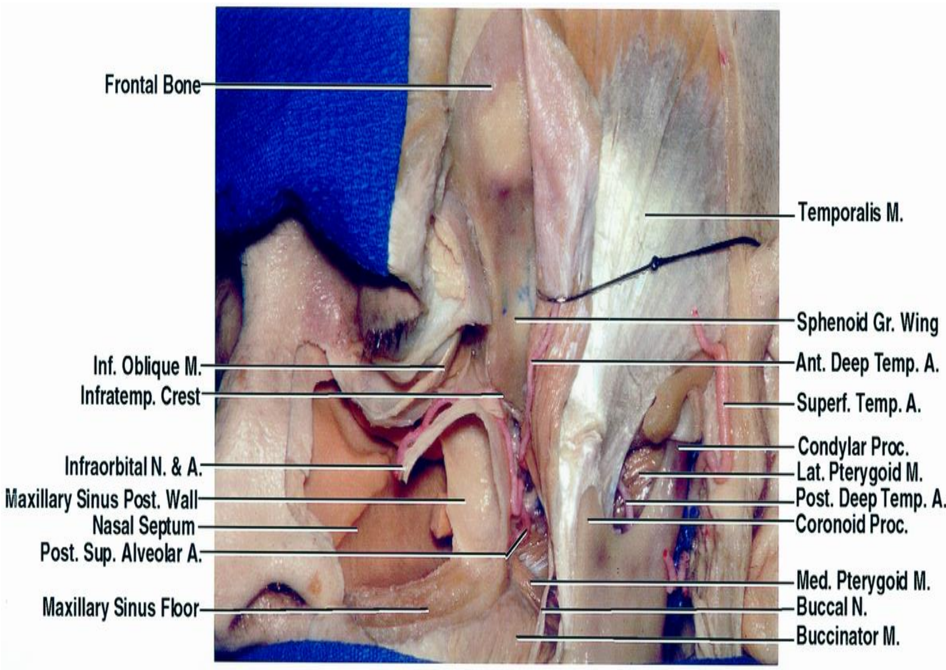


FIGURE 5.

G, the posterior sinus wall has been removed to expose the pterygopalatine fossa and the greater and lesser palatine nerves and arteries. The base of the coronoid process was divided, and the temporalis was reflected downward to expose the infratemporal fossa. The lateral pterygoid has two heads: an upper head arising from the greater sphenoid wing along the infratemporal crest, and a lower head arising from the lateral pterygoid plate. The buccal nerve passes between the upper and lower heads. The maxillary artery, which in this case ascends forward lateral to the lateral pterygoid, may also pass medial to this muscle.

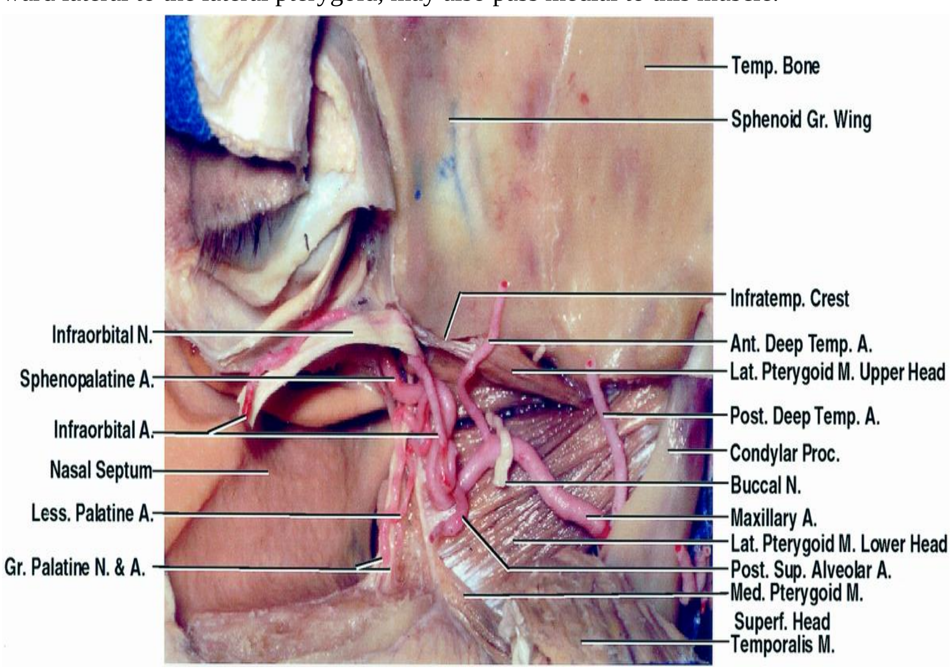


FIGURE 5.

H, the maxillary artery has been divided distal to the origin of the deep temporal arteries that supply the temporalis. The lateral pterygoid has been removed to expose the deep head of the medial pterygoid, which arises from the opposing surfaces of the medial and lateral pterygoid plates facing the pterygoid fossa. Removal of the lateral pterygoid also exposes the mandibular nerve and branches below the foramen ovale and the middle meningeal artery below the foramen spinosum.

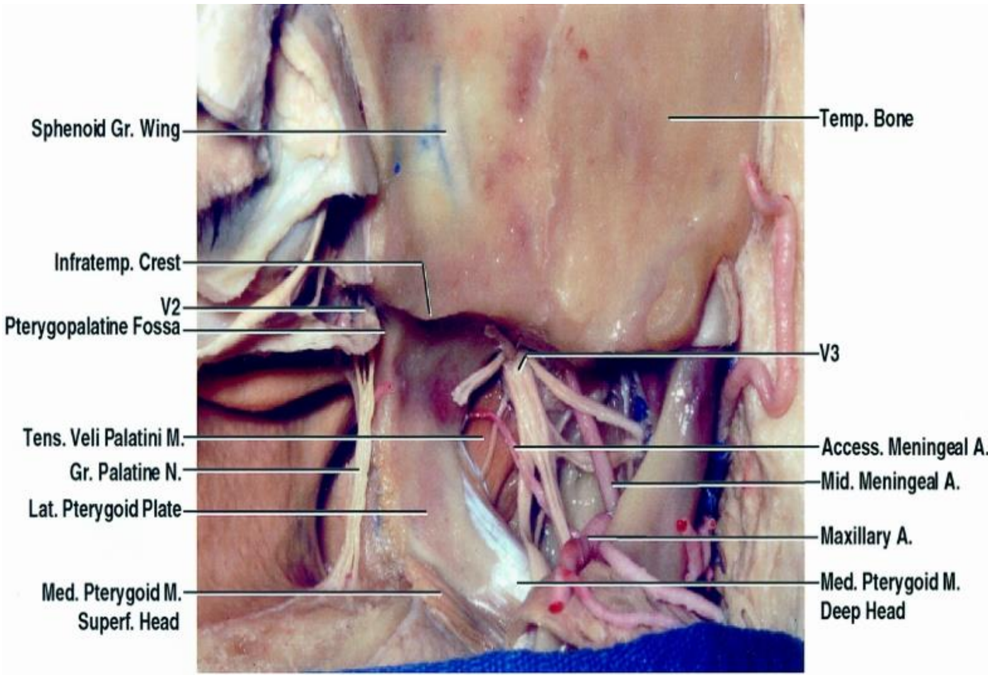


FIGURE 5.

I, the lateral pterygoid plate has been removed to expose the origin of the deep head of the medial pterygoid. The auriculotemporal nerve usually splits into two roots that encircle the middle meningeal artery. The chorda tympani exits the temporal bone, enters the infratemporal fossa on the medial side of the sphenoid spine, and descends medial to the middle meningeal artery and the branches of the mandibular nerve to join the lingual nerve coursing anterior to the inferior alveolar nerve. The medial pterygoid nerve arises from the medial surface of the mandibular nerve near the otic ganglion and descends on the lateral surface of the tensor veli palatini to reach the deep surface of the medial pterygoid. The upper part of the parapharyngeal space extends into the thin fat-containing plane between the medial pterygoid and the tensor veli palatini.

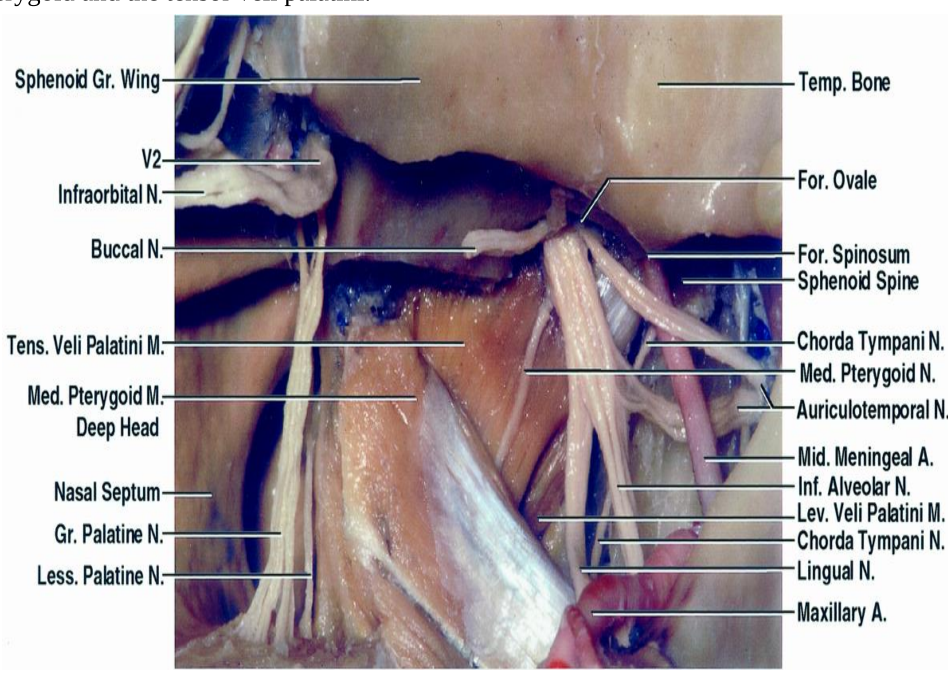


FIGURE 5.

J, the medial pterygoid has been removed to expose the tensor and levator veli palatini and the medial pterygoid plate. The tensor veli palatini has a long narrow origin, which extends backward from the scaphoid fossa at the root of the medial pterygoid plate and medial to the foramina ovale and spinosum and the sphenoid spine. The lateral wall of the pharyngeal recess (Rosenmüller's fossa), which is covered by the pharyngobasilar fascia, is a lateral extension of the nasopharynx behind the Eustachian tube and the levator veli palatini.

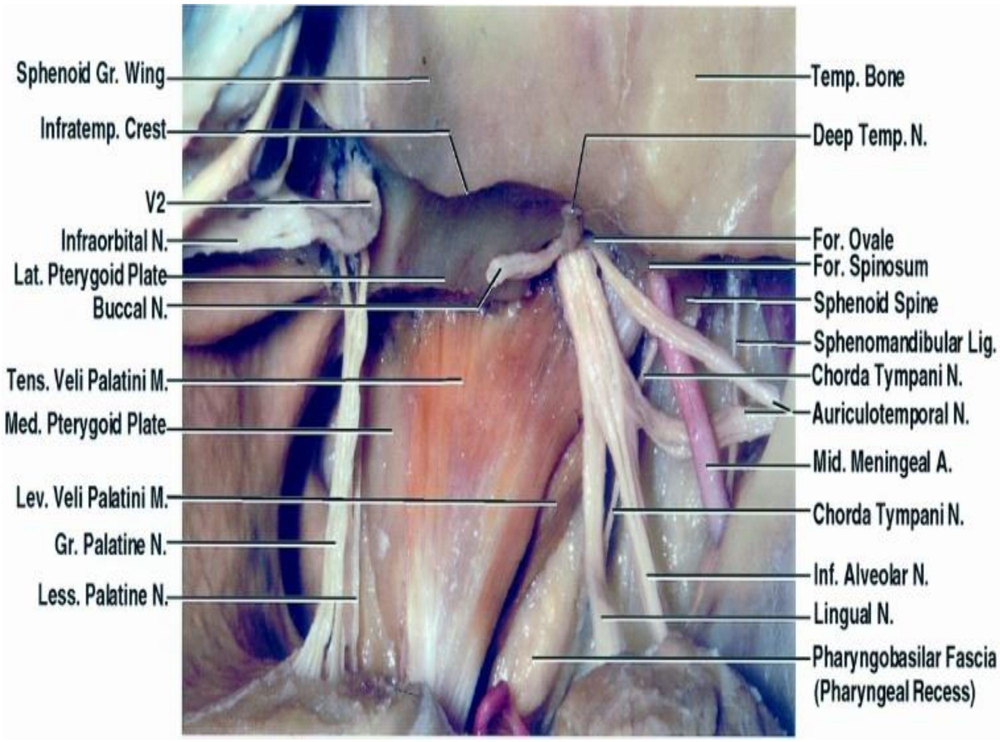


FIGURE 5.

K, the tensor veli palatini and the medial pterygoid plate have been removed to expose the Eustachian tube. The levator veli palatini is situated below and behind the Eustachian tube. The pharyngeal orifice of the Eustachian tube hugs the posterior edge of the medial pterygoid plate. The internal carotid ascends lateral to the pharyngobasilar fascia covering the pharyngeal recess.

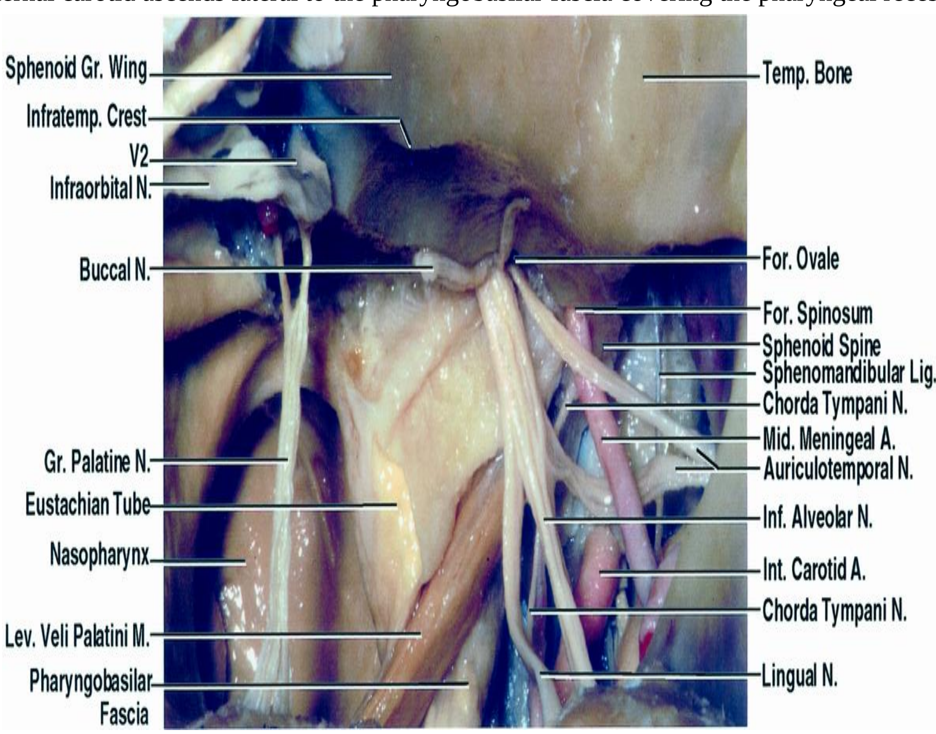


FIGURE 5.

L, a frontotemporal craniotomy has been completed.

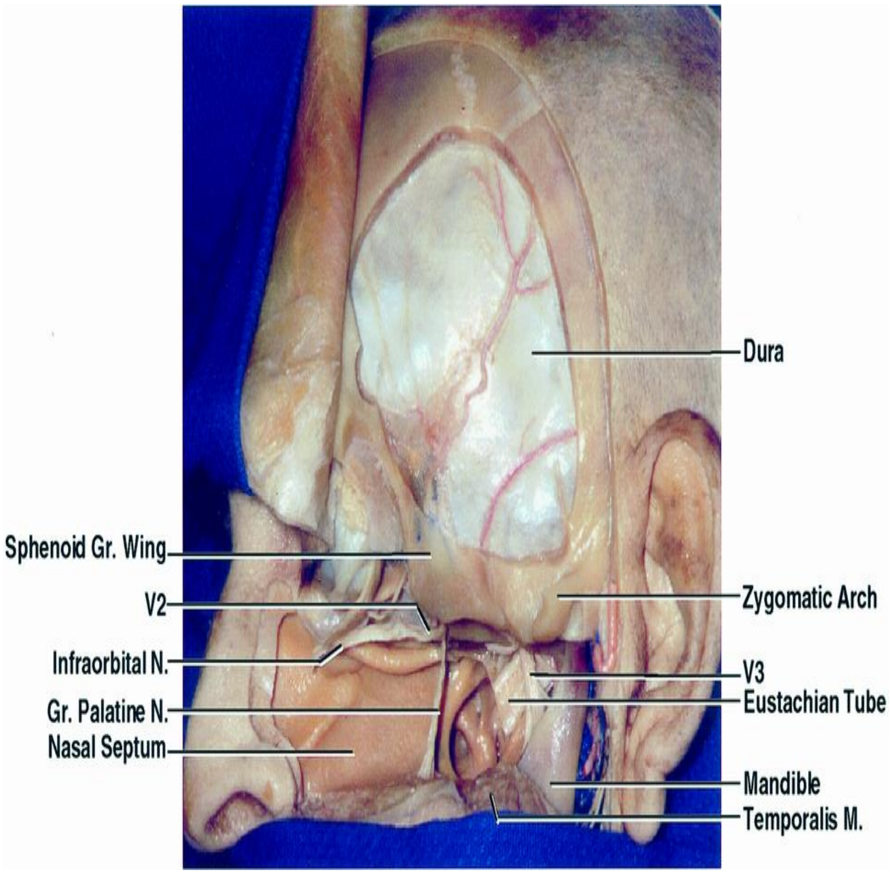


FIGURE 5.

M, the removal of the greater sphenoid wing has been extended medially to open the lateral orbit, the superior orbital fissure, and the foramina ovale and rotundum. The periorbita has been opened to expose the lacrimal gland and extraocular muscles. The contralateral Eustachian orifice and pharyngeal recess are exposed behind the nasal septum.

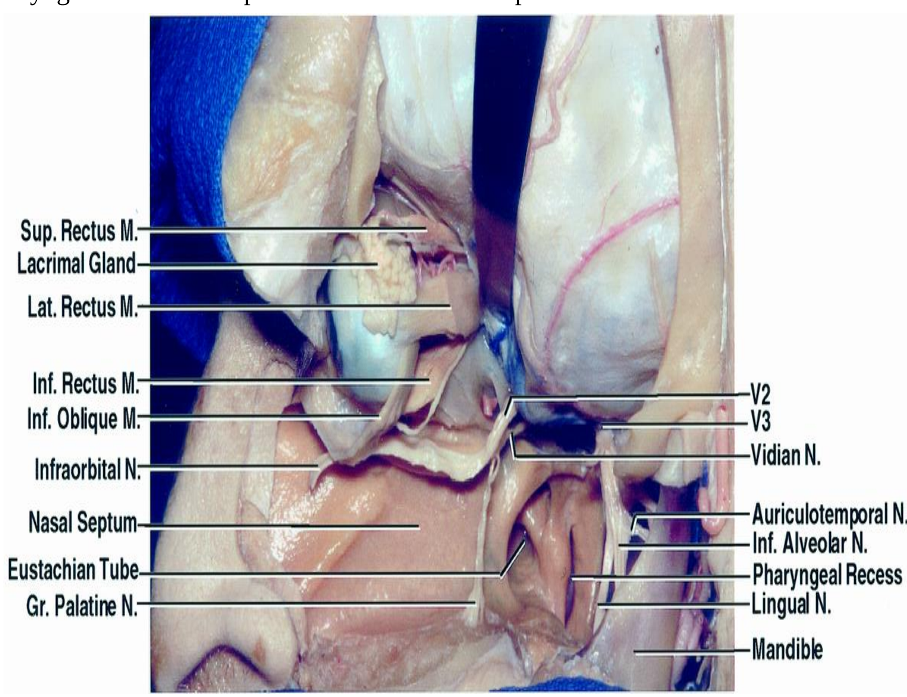


FIGURE 5.

N, the removal of the floor of the middle fossa formed by the greater sphenoid wing opens the foramina rotundum, ovale, and spinosum, and the pterygoid canal. The pterygoid canal, through which the vidian nerve courses, crosses the base of the medial pterygoid plate and extends from the anterolateral edge of the foramen lacerum posteriorly to the pterygopalatine fossa anteriorly. Its anterior end is situated medial to and below the foramen rotundum.

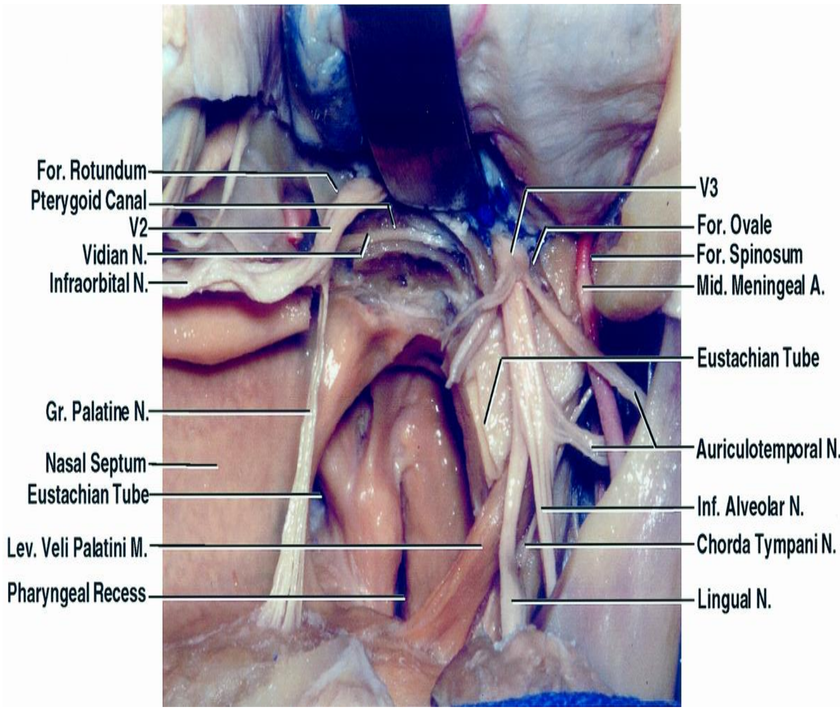


FIGURE 5.

O, the left half of the posterior nasopharyngeal wall and the levator veli palatini have been removed to expose the retropharyngeal region, where the longus capitis ascends in front of the anterior arch of the atlas and attaches above to the clivus. The cervical carotid ascends behind the Eustachian tube and lateral to the longus capitis.

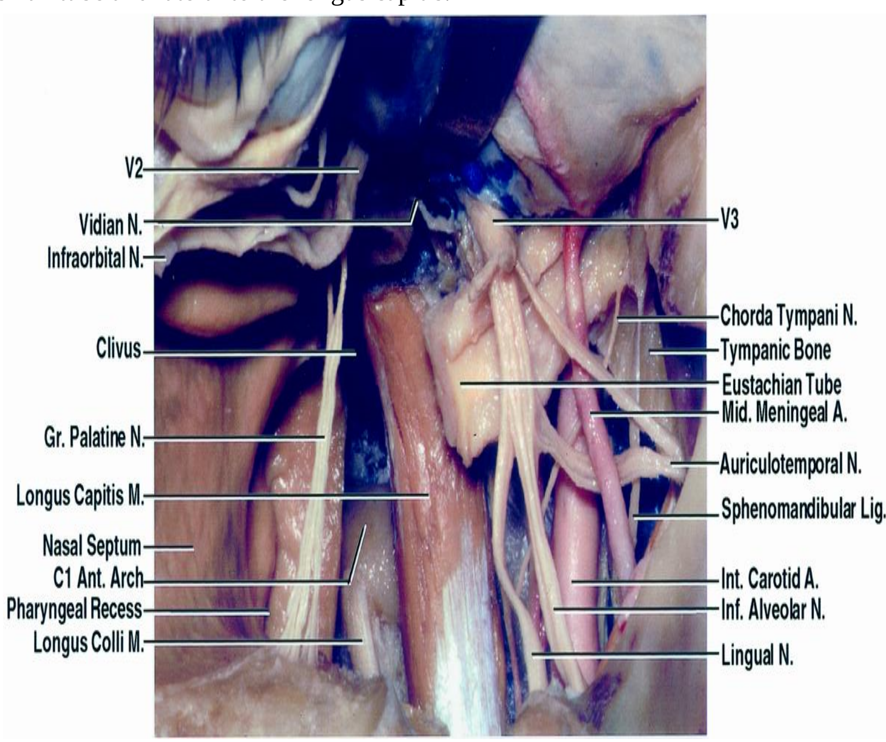


FIGURE 5.

P, the longus capitis has been removed to expose the clivus and the anterior arch of C1.

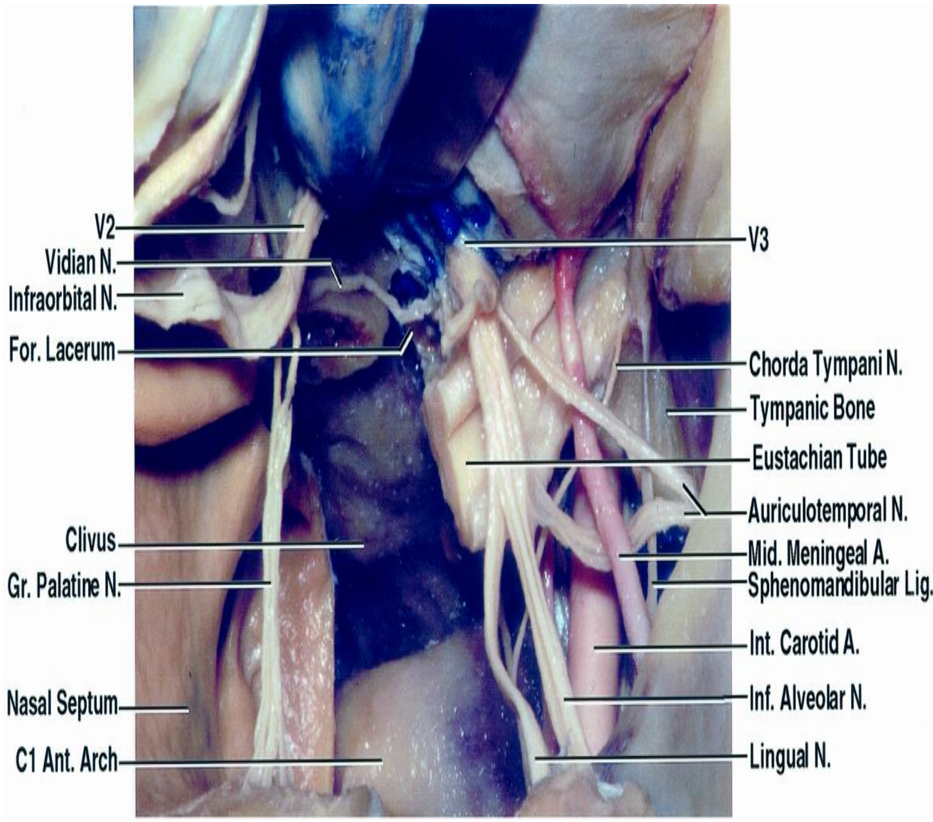


FIGURE 5.

Q, the temporal lobe has been elevated, and the dura covering the frontal and temporal lobes and lateral wall of the cavernous sinus has been opened.

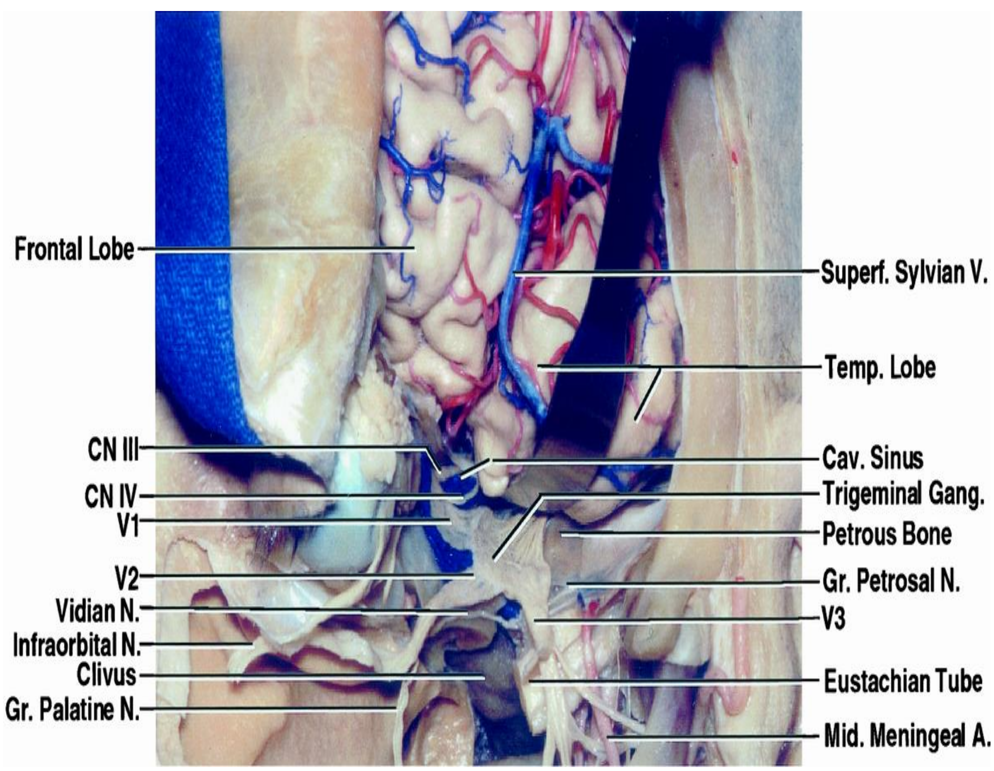


FIGURE 5.

R, magnified view of the structures passing through the cavernous sinus, superior orbital fissure, and the foramina rotundum and ovale. The oculomotor, trochlear, and ophthalmic nerves are exposed in the lateral wall of the cavernous sinus. The supraclinoid portion of the internal carotid artery is exposed above the tentorial edge.

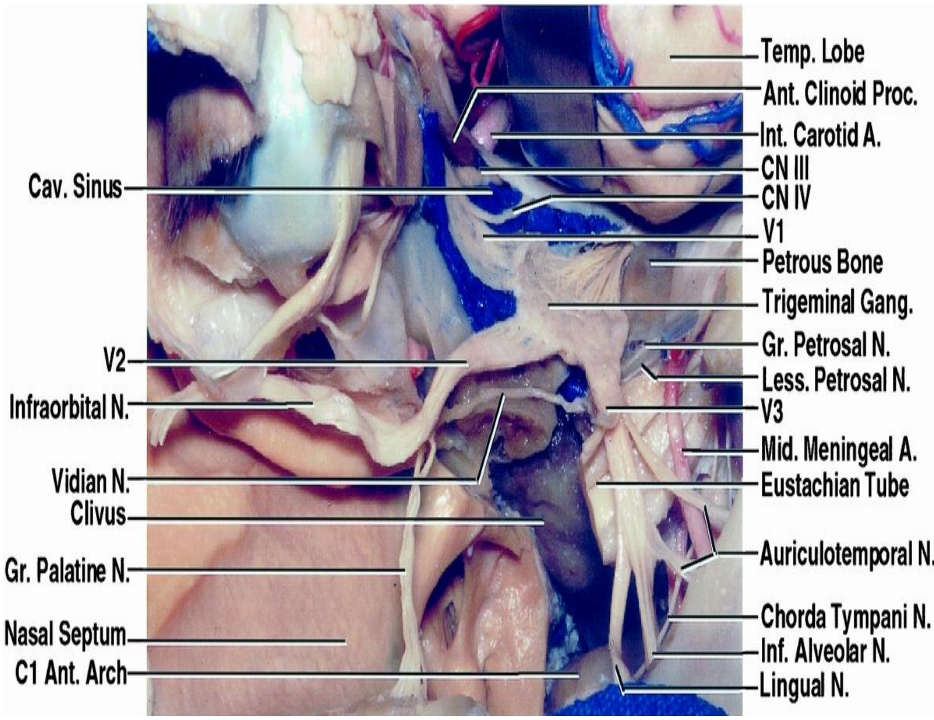
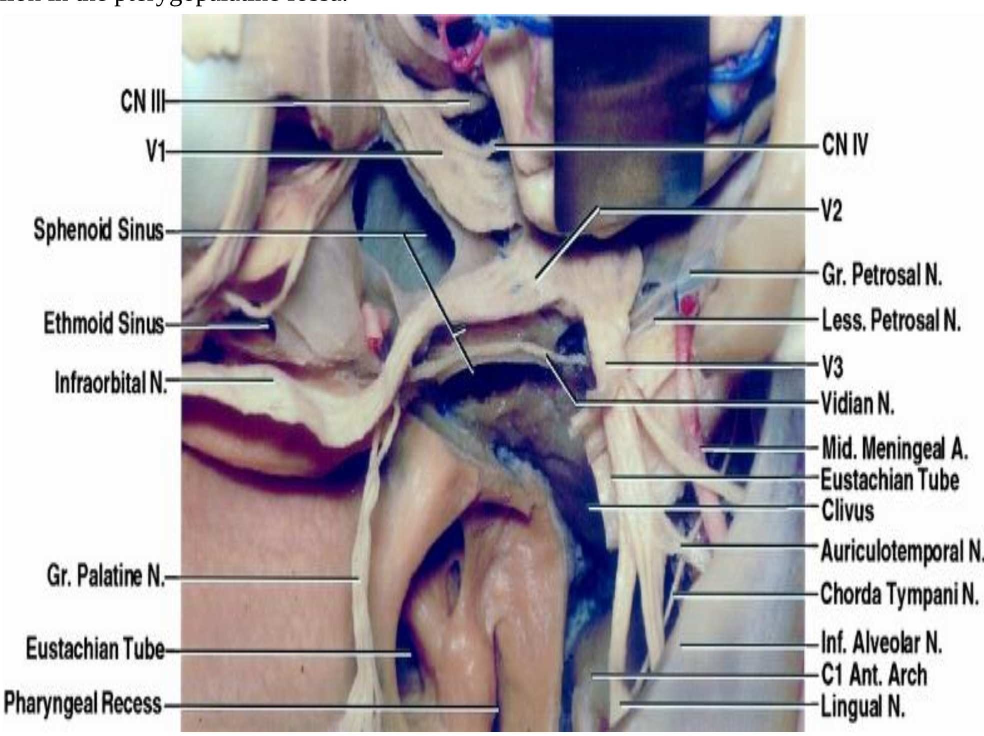


FIGURE 5.

S, the lateral wall of the sphenoid sinus between the ophthalmic and maxillary nerves, and above and below the anterior part of the vidian nerve, has been opened to expose a well-pneumatized sphenoid sinus. The greater and lesser petrosal nerves (the former behind) cross the upper surface of the petrous temporal bone. The vidian nerve, formed at the edge of the foramen lacerum by the union of the greater and deep petrosal nerves, runs forward through the pterygoid canal in the base of pterygoid process to reach the pterygopalatine ganglion in the pterygopalatine fossa.



As the temporal incision in a patient is completed, an attempt is made to identify the temporal branch of the facial nerve before it is transected in preparation for reapproximation during closure, although the small size of this branch may make its identification and reapproximation difficult or impossible. The remaining branches of the facial nerve are contained in the cheek flap and are preserved. A lower conjunctival incision is incorporated to achieve a better cosmetic result than that obtained with a transverse incision across the upper cheek. The infraorbital nerve, which is crossed in elevating the cheek flap, is marked for reconstruction in closing. The hemicoronal incision exposes the lateral orbital rim and the temporalis. After reflection of the frontotemporal scalp flap, the masseter is detached from the zygoma and retracted inferiorly to expose the maxillary tuberosity and the mandibular coronoid process, and the temporalis is elevated from the temporal squama.

If access to the medial orbit or ethmoid sinus is needed, the vertical limb of the paranasal incision can be extended upward in a curvilinear manner to the inferomedial edge of the eyebrow, just medial to the palpable supraorbital notch or foramen, as for a lateral rhinotomy or medial maxillectomy approach (Fig. 6). The medial orbit is exposed by detaching the medial palpebral ligament, mobilizing the lacrimal sac from the nasolacrimal groove, and displacing the periorbita laterally. The medial palpebral ligament is separated into two leaves, anterior and posterior, by the lacrimal sac. The anterior leaf, a strong tendinous band, crosses in front of the lacrimal sac and attaches to the maxillary frontal process in front of the nasolacrimal groove (Fig. 6). This ligament is transected and tagged so that it can be reapproximated precisely at the time of closure, preserving canthal balance. The thinner posterior leaf located behind the lacrimal sac is weakly attached to the lacrimal bone, together with the lacrimal part of the orbicularis oculi and the medial check ligament. Laterally, the medial palpebral ligament divides into upper and lower parts, each attached to the medial end of the corresponding tarsus.

FIGURE 6.

Exposure along the medial maxilla and orbit. *A,* the left paranasal incision extends to the lower edge of the eyebrow. The flap has been reflected using subperiosteal dissection to expose the maxillary frontal process and the attachment of the medial palpebral ligament. *A.,* artery;*A.I.C.A.,* anteroinferior cerebellar artery;*Ant.,* anterior;*Br.,* branch;*Car.,* carotid;*For.,* foramen;*Gang.,* ganglion;*Gr.,* greater;*Inf.,* inferior;*Intracav.,* intracavernous;*Lat.,* lateral;*Lig.,* ligament;*M.,* muscle;*Med.,* medial;*Mid.,* middle;*N.,* nerve;*Post.,* posterior;*Proc.,* process;*Sup.,* superior.

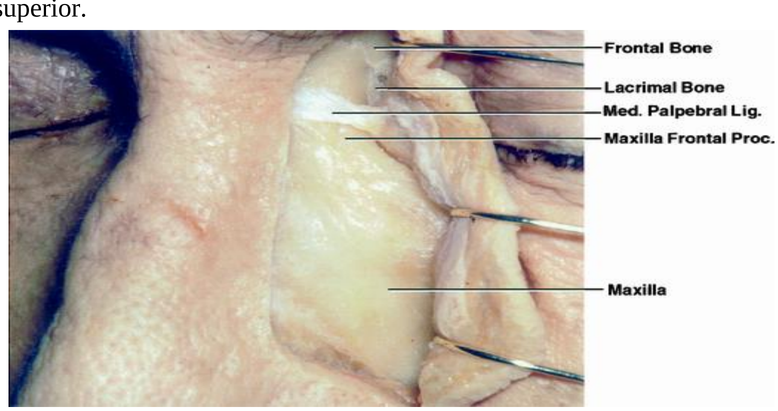


FIGURE 6.

B, the medial palpebral ligament has been divided and retracted laterally to expose the lacrimal canaliculi and the underlying lacrimal sac, which sits in the nasolacrimal groove.

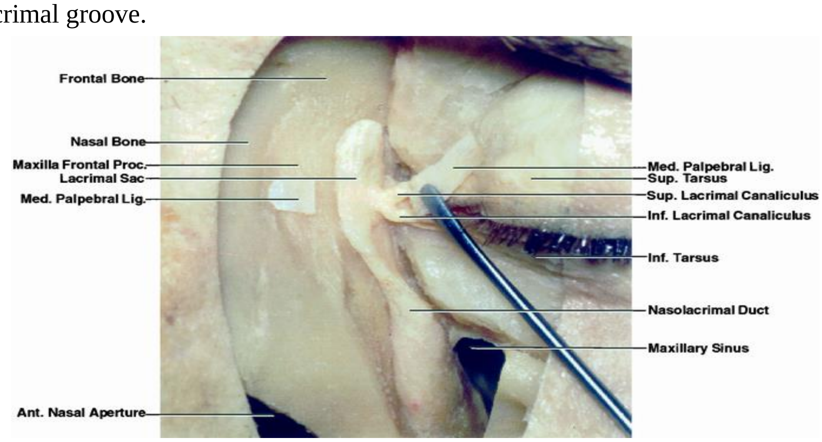


FIGURE 6.

C, the anteromedial maxilla has been opened to show the relationship among the nasal cavity, maxillary sinus, and nasolacrimal duct. The part of the maxillary frontal process to which the medial palpebral ligament attaches has been preserved. The inferior concha is a bone that projects medially and inferiorly from the maxilla. The majority of the maxillary sinus is situated lateral to the inferior meatus; however, the sinus opens into the middle meatus.

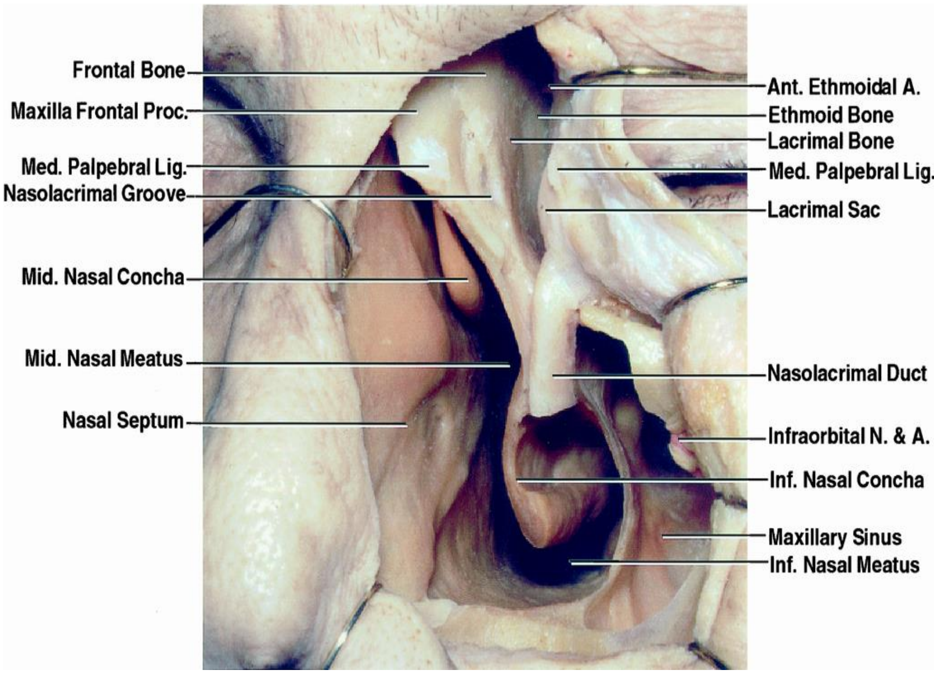


FIGURE 6.

D, the medial wall of the orbit, which is formed by the lacrimal and ethmoid bones, has been exposed. Dividing the lacrimal sac or nasolacrimal duct and the anterior and posterior ethmoidal arteries and nerves allows lateral retraction of the orbital contents to expose the medial orbital wall as far posterior as the orbital apex and optic canal.

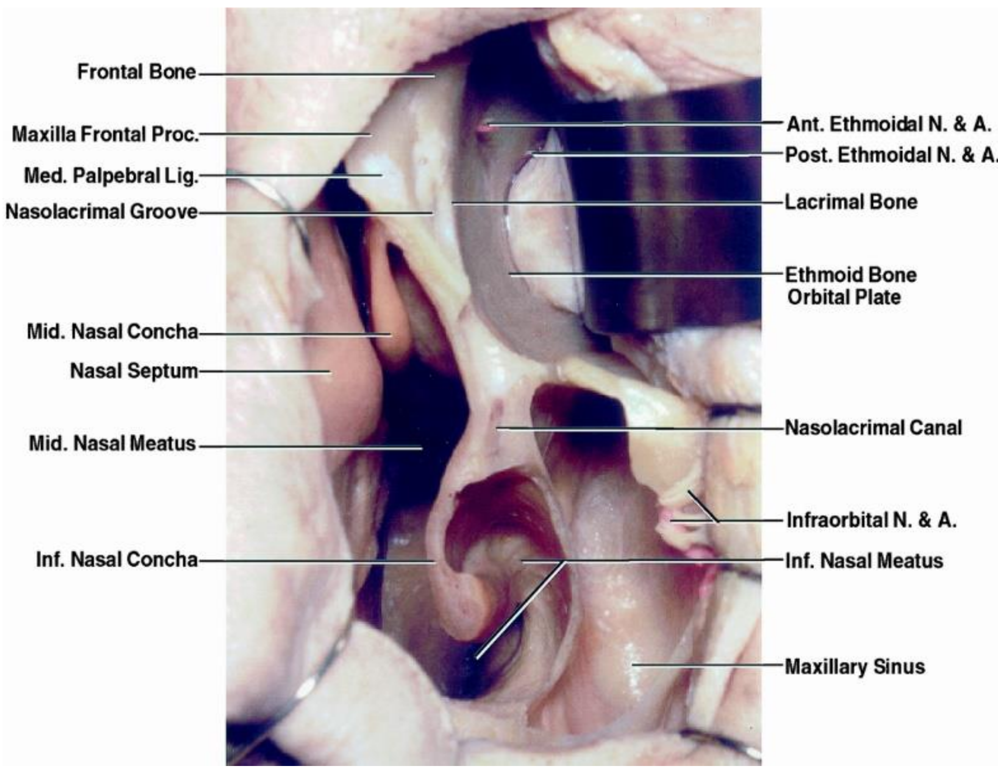


FIGURE 6.

E, the medial part of the posterior maxillary wall has been removed to expose the pterygopalatine ganglion, which is located behind the sinus in the medial part of the pterygopalatine fossa and in front of the sphenoid pterygoid process and pterygoid canal. The maxillary nerve enters the pterygopalatine fossa through the foramen rotundum, which is located lateral and superior to the pterygoid canal, and it communicates with the pterygopalatine ganglion by ganglionic branches. The pterygopalatine ganglion and related branches, including the sphenopalatine, greater and lesser palatine, orbital, and pharyngeal branches, usually are located behind the maxillary artery, which has been retracted downward. The greater palatine canal descends along the posteromedial wall of the maxilla in the groove between the maxilla and the palatine perpendicular plate. The pharyngeal orifice of the Eustachian tube hugs and is attached to the posterior edge of the medial pterygoid plate. The maxillary artery enters the pterygopalatine fossa by passing through the pterygomaxillary fissure. It gives rise to numerous branches, including the infraorbital, posterosuperior alveolar, sphenopalatine, greater and lesser palatine, and vidian arteries, which usually are located in front of the pterygopalatine ganglion and its branches. The medial and inferomedial orbital walls also have been removed to expose the posterior ethmoid air cells and the anterior face and ostium of the sphenoid sinus.

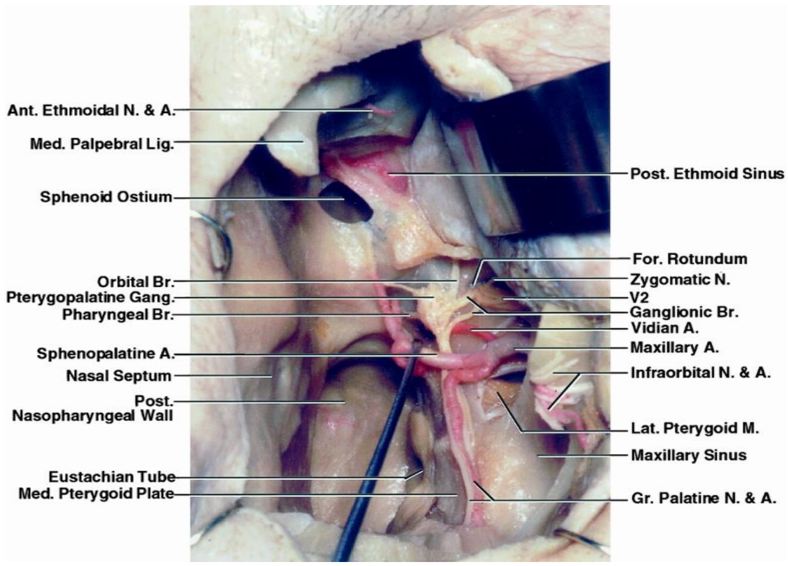


FIGURE 6.

F, the approach has been redirected toward the midline to expose the posterior nasopharyngeal wall. The anterior face of the sphenoid sinus has been opened to expose several septa within the sinus. Access to the central cranial base is limited bilaterally by the pterygoid processes and the Eustachian openings into the nasopharynx along the posterior edge of the medial pterygoid plates. The sphenopalatine artery sends branches across the face of the sphenoid, which may result in troublesome bleeding when the face of the sphenoid is opened.

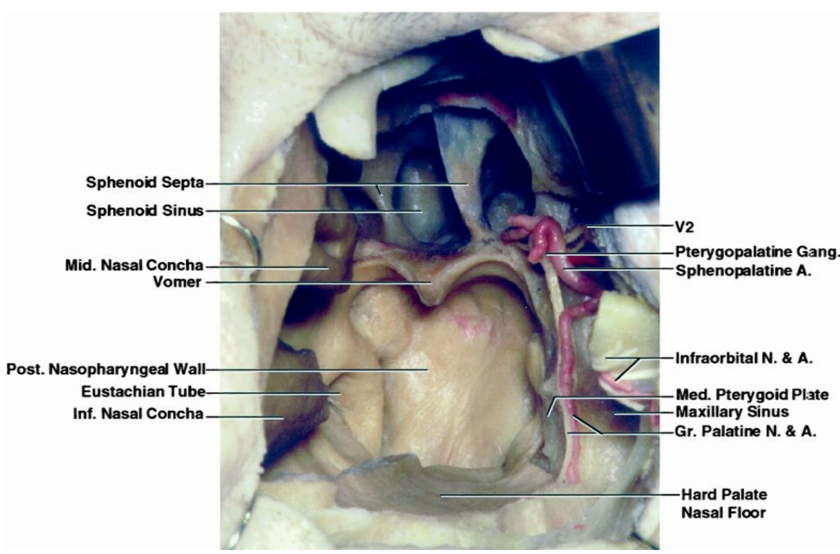


FIGURE 6.

G, the sphenoid septi and the anterior sellar wall have been removed to expose the pituitary gland. The nasopharyngeal mucosa has been opened in the midline, and the longus capitis attachments to the lower half of the clivus have been reflected laterally in preparation for clival opening.

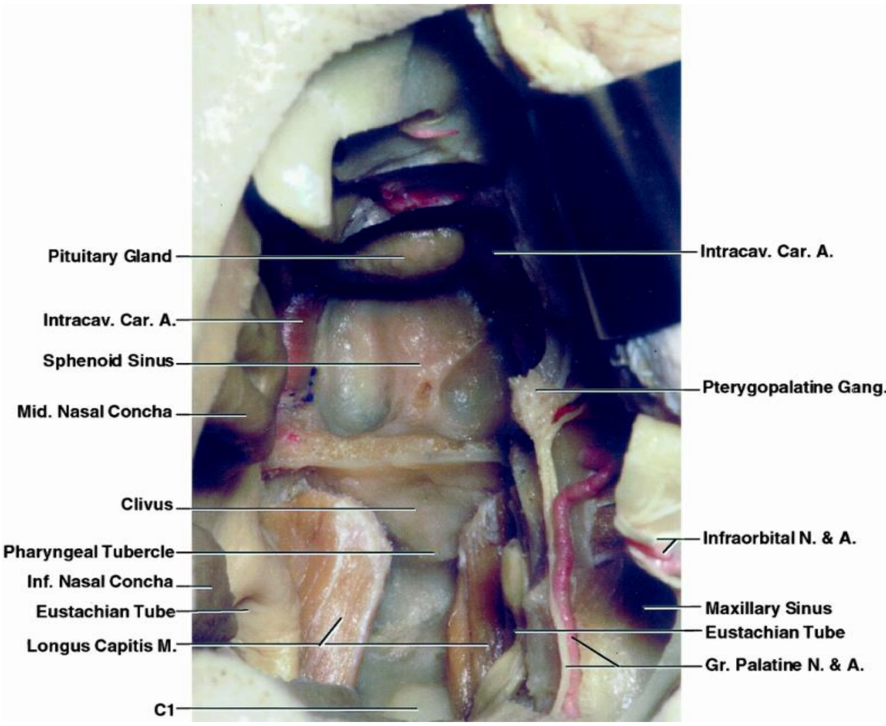
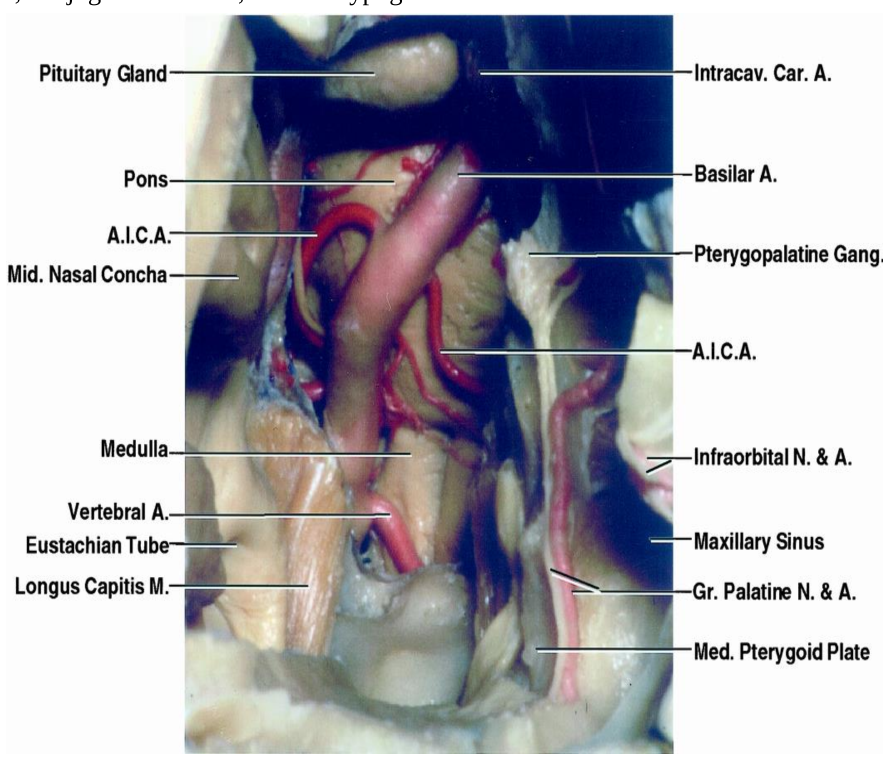


FIGURE 6.

H, the clivus and dura have been opened to expose the anterior pontine and medullary surfaces and the basilar artery. The exposure is limited bilaterally by the intracavernous carotid arteries, the pterygopalatine ganglion, the medial pterygoid plates, and the Eustachian tubes. Further posteriorly, if the pterygoid process and the medial part of the Eustachian tube are resected, the exposure is limited by the cervical carotid arteries, the jugular foramen, and the hypoglossal canals.



The lacrimal drainage pathway includes the superior and inferior lacrimal canaliculi, the lacrimal sac, and the nasolacrimal duct. The superior and inferior lacrimal canaliculi begin at the puncta in the eyelids and open into the lateral wall of the lacrimal sac beneath the anterior leaf of the medial palpebral ligament. The lacrimal sac lies in the nasolacrimal groove, formed anteriorly by the thick maxillary frontal process and posteriorly by the thin lacrimal bone (Fig. 6, B and C). The anterior lacrimal crest, located at the anterior margin of the nasolacrimal groove, is palpable as a small tubercle that serves as a guide to the lacrimal sac (Fig. 1, B, D, and E). The closed upper end of the lacrimal sac is situated below the frontomaxillary and frontolacrimal sutures. The nasolacrimal duct descends from the lacrimal sac through the nasolacrimal canal and opens in the inferior nasal meatus under the inferior nasal concha (Fig. 6, B and C). Transecting the lacrimal sac at its lower end, and ligating the anterior and posterior ethmoidal arteries just proximal to the anterior and posterior ethmoidal canals, allows displacement of the orbital contents laterally for exposure of the medial orbital apex (Fig. 6D). The nasolacrimal duct and lacrimal sac may be reconstructed at the conclusion of the procedure.

Skeletal stage

For both the upper and lower maxillectomy, the anterior and lateral aspects of the maxilla, part of the zygoma, and the anterior nasal aperture are exposed; however, the approaches differ in that the lower maxillectomy requires exposure of the oral surface of the hard palate, whereas the upper maxillectomy requires exposure of the orbital floor and the zygomatic arch (Figs. 3–5). Before completion of the osteotomy, miniplate sites are carefully marked for restoration of skeletal contour and occlusion during closure.

Lower maxillectomy

To perform the lower maxillectomy, the upper level of the osteotomy is extended just beneath the infraorbital foramen anteriorly, which disconnects the lower two-thirds, including the hard palate and alveolar ridge, from the upper one-third, leaving the orbital floor formed by the roof of the maxillary sinus and the zygomatic arch intact. The anterior portion of the masseter is detached from the zygoma. Partial removal of the inferior edge of the zygomatic body then exposes the mandibular coronoid process and the pterygomaxillary area for proximal exposure of the maxillary artery and control of bleeding from its more distal branches during the osteotomy (Fig. 4, A and B). The coronoid process and temporalis may be divided to provide wider access to the maxillary artery in the infratemporal fossa (Fig. 4C).

The hard palate osteotomy begins with a vertical cut in the alveolar ridge between the central and lateral incisors, then proceeds backward in a parasagittal plane on the ipsilateral side of the nasal septum, parallel to the intermaxillary and interpalatine sutures to the posterior edge of the hard palate. Avoiding division of the soft palate allows the maxilla to be hinged to a pedicle, which preserves some blood supply to the maxilla. The osteotomy is completed with a horizontal cut through the lateral maxillary wall and a vertical cut extending across the front of the posterior maxillary wall and through the retromolar region, reaching the medial maxillary wall and the perpendicular plate of the palatine bone, which is wedged into the lateral nasal wall between the maxilla and the sphenoid pterygoid process. The bone cut continues forward through the inferior or middle nasal meatus to the anterior nasal aperture, possibly leaving a shell of posterior maxillary wall attached to the pterygoid process. The posterior wall of the maxillary sinus is thin, difficult to cut precisely, and easily fractured, which creates the possibility of leaving some of it in place as the maxilla is mobilized.

The greater palatine canal, which is approximately 10 mm long, is bounded laterally by the posteromedial maxillary wall and medially by the palatine perpendicular plate. It transmits the corresponding nerve and vessels, which descend from the pterygopalatine fossa to reach the oral surface of the hard palate at the greater palatine foramen medial to the molar tooth, approximately 6 to 7 mm in front of the pterygomaxillary suture (Figs. 1, C and F, and 4I). The greater palatine artery is sectioned during the last osteotomy, unless the artery is freed from the bony canal or unless the retromolar osteotomy, through the pterygomaxillary suture, is situated in front of the canal. Brisk bleeding from the artery may be controlled by occlusion of the maxillary artery at the pterygomaxillary fissure or by preoperative embolization.

The osteotomy may extend behind the posterior maxillary wall, in which case the posterior limit of the exposure is the pterygopalatine fossa located between the maxilla and pterygoid process, or it can be extended behind the pterygopalatine fossa and through the pterygoid process if necessary. The lower maxilla can be hinged to a pedicle of soft palate to preserve some of the maxilla's blood supply, but in this study the maxilla was completely detached to provide a better display of the anatomic detail. After mobilizing the lower maxilla, the reachable areas include the nasal and oral cavities, the oro- and nasopharynx, and the anterior part of the infratemporal fossa, which at this stage is covered by the buccal fat pad underlying the cheek and may be very prominent (Fig. 4H).

Upper maxillectomy

To perform the upper maxillectomy, the upper osteotomy is extended through the orbital rim and floor, and the lower cut is directed above the level of the alveolar process along the inferior meatus medially and just above the maxillary attachment of the buccinator laterally, leaving the hard palate intact (Fig. 5F). It includes a cut in the orbital floor behind and parallel to the inferior orbital rim, extending from the anterolateral edge of the inferior orbital fissure toward the medial and lateral orbital walls, after the infraorbital nerve is unroofed and elevated from the floor with the orbital contents (Fig. 5E). The infraorbital nerve, which is a branch of the maxillary nerve, enters the orbit through the inferior orbital fissure and passes forward successively in the infraorbital groove, canal, and foramen to reach the cheek. The anterolateral end of the inferior orbital fissure, which usually is wider than the medial part, provides communication between the orbit and the anterosuperior aspect of the infratemporal fossa, and is covered posteriorly by the most anterior part of the temporalis (Figs. 1, A and B, and 2). Reflection of a frontotemporal scalp flap allows the temporalis to be detached from the anterior part of the temporal fossa, exposing the lateral orbital rim for osteotomy.

The lateral orbital osteotomy begins at the anterolateral edge of the inferior orbital fissure, extends upward along the lateral wall near the suture between the orbital surface of the greater sphenoid wing and the zygomatic frontal process, where the wall is thinnest, and finally turns anteriorly to cross the lateral orbital rim. After a cut of the zygomatic arch, osteotomy is performed at the posterior wall of the maxillary sinus. Pterygomaxillary separation in the retromolar region is not necessary for the upper maxillectomy; thus, the neurovascular contents of the greater palatine canal and the osseous connection between the hard palate, posterior maxilla, and pterygoid process are preserved. At this point, the exposure includes the nasal cavity by opening the lateral nasal wall, and the periorbita covering the lower and lateral orbit. The posterior pharyngeal wall facing the clivs is visible through the nasal cavity from the anterior midline; however, the exposure is limited laterally by the pterygoid process and below by the hard palate. Lateral access to the infratemporal fossa is still blocked by the mandible and the temporalis.

The lacrimal apparatus is not transected unless medial orbital or ethmoidal dissection is required (Fig. 6). The anterior and lateral walls of the nasolacrimal canal are formed by the maxilla and the posteromedial wall by the lacrimal bone superiorly and the inferior nasal concha inferiorly. The lateral wall of the nasolacrimal canal is formed by the most anterior part of the medial wall of the maxillary sinus. To preserve the entire nasolacrimal canal and duct, the osteotomy along the orbital floor extends laterally to the upper opening of the nasolacrimal canal, then crosses the lower orbital rim laterally to the medial wall of the maxillary sinus, and continues obliquely to the anterior nasal aperture at the level of the inferior nasal meatus. If access to the ethmoid sinus and medial orbit is required after the above cuts, an osteoplastic flap consisting of the nasal bone and maxillary frontal process can be elevated. If the oblique cut along the anterior maxillary wall is directed more horizontally to a higher point on the anterior nasal aperture (at the level of the middle nasal meatus between the middle and inferior nasal conchae), the nasolacrimal duct must be divided during the osteotomy.

After transecting the lacrimal sac at the entrance to the canal, the osteotomy can be extended up the medial orbital wall as high as the suture with the frontal bone (Fig. 6D). The anterior border of the medial orbital wall, formed by the anterior lacrimal crest of the maxillary frontal process, joins posteriorly with the lacrimal bone to complete the nasolacrimal groove. The posterosuperior part of the nasolacrimal groove faces the anterior ethmoid sinus, and the anteroinferior part is related medially to the middle nasal meatus. The medial orbital osteotomy, if it is necessary, should be performed below the frontoethmoidal suture line at the site of the anterior and posterior ethmoidal canals, which are located lateral to and at the level of the intracranial surface of the cribriform plate (Fig. 6, D and E).

Retromaxillary stage

The retromaxillary area accessed during lower and upper maxillectomy includes the infratemporal and pterygopalatine fossae and the parapharyngeal space (Fig. 2). The difference in exposure with the two approaches will be discussed after reviewing the anatomy of these areas.

Infratemporal fossa (

Figs. 1F;Fig. 2;Fig. 4, D–G; and Fig. 5, G–K)

Removal of the lateral part of the posterior maxillary wall, which is performed in both the upper and lower maxillectomy, exposes the anterior part of the infratemporal fossa. Visualization of the infratemporal fossa is improved by dividing the coronoid process above the level of the mandibular foramen, at the site where the inferior alveolar nerve and artery enter the mandibular canal. The mandibular foramen or canal is not violated if the cut at the root of the coronoid process is located above a line extending obliquely downward from the mandibular incisura.

The osseous boundaries of the infratemporal fossa are the posterolateral maxillary surface anteriorly, the lateral pterygoid plate anteromedially, the mandibular ramus laterally, and the tympanic part of the temporal bone and the styloid process posteriorly. The fossa is domed anteriorly by the infratemporal surface of the greater sphenoid wing, at the site of the foramina ovale and spinosum, and posteriorly by the squamous part of the temporal bone (Figs. 1F and 2, F and G). The inferior, posteromedial, and superolateral aspects are open without bony walls.

The lateral pterygoid muscle crosses the upper part of the infratemporal fossa taking origin from upper and lower heads: the upper head arises from the infratemporal surface and infratemporal crest of the greater sphenoid wing, and the lower originates from the lateral surface of the lateral pterygoid plate (Fig. 2;Fig. 4, C and D; and Fig. 5G). Both heads pass posterolaterally, inserting on the neck of the mandibular condylar process and the articular disc of the temporomandibular joint. The medial pterygoid muscle crosses the lower part of the infratemporal fossa and arises with superficial and deep heads; the superficial head arises from the lateral aspect of the palatine pyramidal process and the maxillary tuberosity, and it passes superficial to the lower head of the lateral pterygoid. The deep head originates from the medial surface of the lateral pterygoid plate and the pterygoid fossa between the two pterygoid plates, and it passes deep to the lower head of the lateral pterygoid (Fig. 2, A and B;Fig. 4, C–F; and Fig. 5, G–I). Both heads descend backward and laterally to attach to the medial surface of the mandibular ramus below the mandibular foramen. The anterior part of the lower head of the lateral pterygoid is situated between the anterior part of the two heads of the medial pterygoid. The sphenomandibular ligament, located medially to the mandibular condylar process, descends from the sphenoid spine to attach to the lingula of the mandibular foramen. The structures located or passing between the sphenomandibular ligament and the mandible are the lateral pterygoid and the auriculotemporal nerve superiorly, and the inferior alveolar nerve, the parotid gland, the maxillary artery, and its inferior alveolar branch inferiorly (Figs. 2C, and 4, K and N).

The maxillary artery is divided into three segments: mandibular, pterygoid, and pterygopalatine (Figs. 4D and 5G). The mandibular segment arises from the external carotid artery near the posterior border of the condylar process, passes between the process and the sphenomandibular ligament along the inferior border of the lower head of the lateral pterygoid, and gives rise to the deep auricular, anterior tympanic, middle and accessory meningeal, and inferior alveolar arteries. The middle meningeal ascends medial to the lateral pterygoid to enter the foramen spinosum, the accessory meningeal arises from the maxillary or middle meningeal to enter the foramen ovale, and the inferior alveolar descends to enter the mandibular foramen (Figs. 4F and 5H). The pterygoid segment usually courses lateral to, but occasionally medial to, the lower head of the lateral pterygoid and gives rise to the deep temporal, pterygoid, masseteric, and buccal arteries. The pterygopalatine segment courses between the two heads of the lateral pterygoid and enters the pterygopalatine fossa by passing through the pterygomaxillary fissure. Its branching will be described with the pterygopalatine fossa.

The pterygoid venous plexus is located in the infratemporal fossa and has two parts: a superficial part located between the temporalis and lateral pterygoid, and a deep part situated between the lateral and medial pterygoids anteriorly and between the lateral pterygoid and the parapharyngeal space posteriorly (Figs. 2, A–C, and 4E). The deep part is more prominent and connects with the cavernous sinus by emissary veins passing through the foramina ovale and spinosum and occasionally through the sphenoidal emissary foramen (foramen of Vesalius) (Fig. 1F). The main drainage of the pterygoid plexus is through the maxillary vein to the internal jugular vein.

The mandibular nerve enters the infratemporal fossa by passing through the foramen ovale on the lateral side of the parapharyngeal space, where it gives rise to several smaller branches, and then divides into smaller anterior and a larger posterior trunks (Fig. 2, D–G;Fig. 4, F–K; and Fig. 5, H–J). The anterior trunk gives rise to the deep temporal and masseteric nerves, which supply the temporalis and the masseter, respectively, and the nerve to the lateral pterygoid, all of which run anterolaterally to reach these muscles. The buccal nerve, which conveys sensory fibers, passes anterolaterally between the two heads of the lateral pterygoid and descends lateral to the lower head to reach the buccinator and the buccal mucosa. The nerve to the lateral pterygoid occasionally runs with the buccal nerve. The posterior trunk gives off the lingual, inferior alveolar, and auriculotemporal nerves, which descend medial to the lateral pterygoid. These nerves are predominantly sensory with the exception of the mylohyoid nerve, which arises from the inferior alveolar nerve above the mandibular foramen and supplies the anterior belly of the digastric and the mylohyoid.

The lingual and inferior alveolar nerves, the former coursing anterior to the latter, pass between the lateral and medial pterygoids. The auriculotemporal nerve usually splits to encircle the middle meningeal artery and passes posterolaterally between the mandibular ramus and the sphenomandibular ligament. The chorda tympani nerve, which contains the taste fibers from the anterior two-thirds of the tongue and the parasympathetic secretomotor fibers to the submandibular and sublingual salivary glands, enters the infratemporal fossa through the petrotympanic fissure at the medial edge of the sphenoid spine. It descends medial to the auriculotemporal and inferior alveolar nerves and joins the lingual nerve. The otic ganglion is situated immediately below the foramen ovale on the medial side of the mandibular nerve (Figs. 2, D–G, and 4F). The ganglion receives the lesser petrosal nerve, which courses along the floor of the middle fossa anterolateral to the greater petrosal nerve to exit through the foramen ovale or the more posteriorly situated canaliculus innominatus, and it conveys parasympathetic secretomotor fibers to the parotid gland via the auriculotemporal nerve (Fig. 5, Q--S). The medial pterygoid nerve arises from the medial aspect of the mandibular nerve close to the otic ganglion and descends to supply the medial pterygoid and tensor veli palatini. The nervus spinosus, a meningeal branch, also arises near the otic ganglion and ascends through the foramen spinosum to innervate the middle fossa dura.

Parapharyngeal space

Both the upper and lower maxillectomy access the upper part of the parapharyngeal space (Figs. 2B and 4F). The space, overall, is shaped like an inverted pyramid, with its base on the cranial base superiorly and its apex at the hyoid bone inferiorly. It is subdivided into prestyloid and poststyloid compartments by the styloid diaphragm, a fibrous sheet that also constitutes the anterior part of the carotid sheath. The prestyloid part, situated anteriorly between the fascia covering the opposing surfaces of the medial pterygoid and tensor veli palatini, is a thin fat-filled compartment separating the structures in the infratemporal fossa from the Eustachian tube and tensor and levator veli palatini in the lateral nasopharyngeal wall. The upper portion of the prestyloid part is situated between two fascial sheets, which are oriented in a sagittal plane. The lateral sheet arises from the medial surface of the medial pterygoid, and it passes upward, backward, and medial to the mandibular nerve and the middle meningeal artery, incorporating the sphenomandibular ligament posteriorly and reaching the retromandibular deep lobe of the parotid gland.

The medial sheet is formed by the fascia overlying the lateral surface of the tensor veli palatini and is continuous inferiorly with the fascia over the superior pharyngeal constrictor and posteriorly with the thick styloid diaphragm, which envelopes the stylopharyngeus, styloglossus, and stylohyoid and blends into the carotid sheath. The superior border is located where the two fascial sheets fuse together and insert in the cranial base along a line extending backward from the pterygoid process lateral to the origin of the tensor veli palatini, and medial to the foramina ovale and spinosum to the sphenoid spine and the posterior margin of the glenoid fossa. The sharply angled inferior boundary is situated at the junction of the posterior digastric belly and the greater hyoid cornu. The poststyloid part, which contains the internal carotid artery, internal jugular vein, and the initial extracranial segment of Cranial Nerves IX through XII, is separated from the infratemporal fossa by the posterolateral portion of the prestyloid part. The parapharyngeal space has been included in the infratemporal fossa in some descriptions of this region ([3,26]).

Pterygopalatine fossa

Both the upper and lower maxillectomies expose the pterygopalatine fossa (Fig. 1, C, E, and F;Fig. 2, A, B, and D–G;Fig. 4, I–L;Fig. 5G; and Fig. 6E). The posterior wall of the maxillary sinus, which forms the anterior wall of the fossa, is so thin and fragile that it may fracture from the mobilized maxilla and require separate removal to expose the anterior face of the fossa. The fossa is bounded posteriorly by the sphenoid pterygoid process, medially by the palatine perpendicular plate, which bridges the interval between the maxilla and pterygoid process, and it opens superiorly through the medial part of the inferior orbital fissure into the orbital apex. The fossa contains the maxillary nerve, pterygopalatine ganglion, maxillary artery and their branches, all embedded in fat tissue. Its lateral boundary, the pterygomaxillary fissure, opens into the infratemporal fossa and allows passage of the maxillary artery from the infratemporal into the pterygopalatine fossa where the artery gives rise to its terminal branches. The lower part of the fossa is funnel-shaped with its inferior apex opening into the greater and lesser palatine canals, which transmit the greater and lesser palatine nerves and vessels, and communicate with the oral cavity. The sphenopalatine foramen, located in the upper part of the fossa's medial wall, conveys the sphenopalatine nerve and vessels, and it opens into the superior nasal meatus just above the root of the middle nasal concha. The foramen is formed anteriorly by the palatine bone's orbital process, posteriorly by the sphenoidal process, and inferiorly by the upper end of the perpendicular plate, which also forms the medial wall of the fossa. The foramen rotundum opens just below the superior orbital fissure through the superior part of the posterior wall of the fossa (Figs. 1, B and C, and 2, E–G).

The pterygoid canal opens through the pterygoid process inferomedial to the foramen rotundum, and conveys the vidian nerve carrying autonomic fibers to the pterygopalatine ganglion. After entering the fossa, the maxillary nerve gives off ganglionic branches to the pterygopalatine ganglion, then deviates laterally just beneath the inferior orbital fissure, giving rise to, in order, the zygomatic and posterosuperior alveolar nerves outside the periorbita. It then turns medially as the infraorbital nerve passing through the inferior orbital fissure to enter the infraorbital groove, where the anterosuperior and middle superior alveolar nerves arise, finally exiting the infraorbital foramen to terminate on the cheek.

The pterygopalatine ganglion, located in front of the pterygoid canal and inferomedial to the maxillary nerve, receives communicating rami from the maxillary nerve and gives rise to the greater and lesser palatine nerves from the lower surface of the ganglion, the sphenopalatine nerve and pharyngeal branch from the medial surface, and the orbital branch from the superior surface. The vidian nerve is formed by the union of the greater petrosal nerve, which conveys parasympathetic fibers arising from the facial nerve at the level of the geniculate ganglion, and the deep petrosal nerve, which conveys sympathetic fibers from the carotid plexus, to reach the lacrimal gland and nasal mucosa. The parasympathetic fibers synapse in the pterygopalatine ganglion, whereas the sympathetic fibers synapse in the superior cervical sympathetic ganglion.

The third or pterygopalatine segment of the maxillary artery enters the pterygopalatine fossa by passing through the pterygomaxillary fissure (Fig. 2E;Fig. 4, H and I;Fig. 5G; and Fig. 6E). This segment courses in an anterior, medial, and superior direction and gives rise to the infraorbital artery, which passes through the inferior orbital fissure and courses with the infraorbital nerve; the posterosuperior alveolar artery, which descends to pierce the posterolateral wall of the maxilla; the recurrent meningeal branches, which pass through the foramen rotundum; the greater and lesser palatine arteries, which descend through the greater and lesser palatine canals; the vidian artery to the pterygoid canal; the pharyngeal branch to the palatovaginal canal; and finally the sphenopalatine artery, which passes through the sphenopalatine foramen to reach the nasal cavity and is considered the terminal branch of the maxillary artery because of its large diameter. The arterial structures in the pterygopalatine fossa are located anterior to the neural structures. Identification of the arteries in the middle of the fossa is difficult because of their tortuosity and the variability of branching. The venous component of the fossa usually is scarce, and at times no significant veins are found with the exception of the sphenopalatine vein, which runs in the periosteum of the anterior wall of the fossa and empties laterally into the pterygoid venous plexus.

Summary of the retromaxillary exposure

Upper maxillectomy

The upper maxillectomy, with removal of the coronoid process and zygomatic arch, provides anterior, anterolateral, and lateral accesses to the pterygopalatine and infratemporal fossae and the parapharyngeal space (Fig. 5, G–K). The lateral view of the upper part of the infratemporal fossa using this approach is shorter and wider than that provided by the lower maxillectomy. The lateral route to the lower part of the infratemporal fossa is limited by the inferiorly reflected temporalis and the mandibular ramus. Anterior access to the lower portion of the fossa and the more posteriorly located poststyloid area is deep, and it is limited below by the remaining hard palate. Resection or mobilization of the mandibular condylar process provides an even wider lateral view of the fossa, particularly its posterior portion.

Lower maxillectomy

The lower maxillectomy offers anterior and anterolateral access to the pterygopalatine and infratemporal fossae and the parapharyngeal space from below, in combination with the transoral route (Fig. 4, H–L). The internal carotid artery, internal jugular vein, and lower cranial nerves in the poststyloid region can be accessed by opening the styloid diaphragm. However, lateral access is limited, and anterior exposure of the upper part of the infratemporal fossa is deeper and more restricted than the lateral exposure afforded by the upper maxillectomy.

Central craniocervical stage

Both the lower and upper maxillectomy provide access to the posterior nasopharyngeal wall for direct incision in the midline with exposure of the clivus down to C1, but only the lower maxillectomy provides oropharyngeal access for midline exposure as low as C4 (Fig. 4, M–S;Fig. 5, N–P; and Fig. 6, G and H). However, the midline exposure in both maxillectomies is restricted by the pterygoid process, the Eustachian tube, and the lateral pharyngeal wall. Removing the pterygoid process, the adjacent part of the Eustachian tube, and the tensor and levator veli palatini, then retracting the ipsilateral pharyngeal wall toward the opposite side widens the anterior and anterolateral access extending from the nasopharynx, sphenoid sinus, and clivus to the upper cervical region.

The pterygoid process, which may be removed in either of the two approaches, is formed by the medial and lateral plates, which fuse anteriorly (Fig. 1, C and F;Fig. 2D;Fig. 3;Fig. 4H; and Fig. 5H). The process faces the pterygopalatine fossa anteriorly, the infratemporal fossa laterally, and the posterior nasal aperture at the junction of the nasal cavity and nasopharynx medially. It is attached above to the junction of the greater wing and sphenoid body. The root of the lateral plate is located below the foramen rotundum and the medial portion of the middle cranial fossa. The base of the medial plate is usually bounded above by the sphenoid sinus, depending on the degree of pneumatization of the sinus. The pterygoid canal is located in the root of the medial plate inferomedial to the foramen rotundum and below the lateral wing of the sphenoid sinus. The posterior edge of the root of the lateral plate projects backward to the foramen ovale. The posterior border of the root of the medial plate, which is located below the posterior opening of the pterygoid canal and the anterolateral aspect of the foramen lacerum, attaches to the anterior margin of the pharyngeal edge of the Eustachian tube.

Removing the pterygoid process increases access to the lateral nasopharyngeal region, which includes the Eustachian tube and the tensor and levator veli palatini. The Eustachian tube descends anteromedially from the tympanic cavity to the nasopharynx (Fig. 2;Fig. 4, J–L; and Fig. 5, K and N–Q). The initial segment adjoining the tympanic cavity has solid walls formed by the temporal bone. Further anteromedially, the tube has a combination of fibrous and cartilaginous parts; the former forms only the lateral wall, and the latter forms the superior, medial, and inferior walls. The cartilaginous part is fused above to the extracranial groove (the sulcus tubae) between the petrous temporal bone and the sphenoid greater wing. The Eustachian tube is bounded laterally by the tensor veli palatini, posteriorly and inferiorly by the levator veli palatini, and medially by the nasopharyngeal mucosa and pharyngobasilar fascia. The horizontal segment of the petrous carotid courses along the posteromedial margin of the Eustachian tube, and these structures usually are separated by a thin layer of bone.

The tensor veli palatini lies lateral to the Eustachian tube, the levator veli palatini, and the medial pterygoid plate (Fig. 2, A–D;Fig. 4I; and Fig. 5J). Its broad thin attachment to the cranial base extends backward and laterally from the scaphoid fossa at the medial aspect of the root of the medial pterygoid plate, between the foramina ovale laterally and the lacerum medially, and then between the foramen spinosum laterally and the orifice of the bony part of the Eustachian tube medially to end behind the sphenoid spine. It descends narrowing anteriorly to become a small tendon, which turns medially and crosses beneath the medial pterygoid hamulus to insert in the soft palate. The levator veli palatini attaches to the extracranial surface of the petrous temporal bone just in front of the lower opening of the carotid canal and partly to the lower aspect of the cartilaginous part of the Eustachian tube. It then descends below and behind the Eustachian tube, posteromedial to the tensor veli palatini, and lateral to the nasopharynx to insert in the soft palate.

Posterior to the levator veli palatini, the nasopharynx has a blind lateral wing, the pharyngeal recess (Rosenmüller's fossa), which is bounded posteriorly by the longus capitis and laterally by the pharyngobasilar fascia (Fig. 2, A–D). The apex of the posterolaterally projecting fossa faces the internal carotid and the ascending pharyngeal arteries. The pharyngobasilar fascia lines the lateral and posterior walls of the nasopharyngeal mucosa, and it attaches to the cranial base superiorly, the posterior edge of the medial pterygoid plate anteriorly, and the superior pharyngeal constrictor below and behind. The fascia tightly attaches above to the fibrocartilaginous tissue covering the extracranial surface of the petroclival fissure. Posteriorly, the fascia attaches to the clivus immediately anterior to the prevertebral fascia overlying the longus capitis, and in the midline it joins the pharyngeal raphe of the superior pharyngeal constrictor, which is attached to the pharyngeal tubercle on the lower clival surface approximately 1 cm above the foramen magnum.

Summary of central craniocervical exposure

Lower maxillectomy

The lower maxillectomy produces an excellent anterior exposure of the posterior part of the central cranial base through the combined transnasal, transoral, and transmaxillary routes, which is enhanced by removing the pterygoid process (Fig. 4, M–R). The exposure can be increased by retracting the pharyngeal mucomuscular flap, which is composed of the pharyngobasilar fascia, the superior pharyngeal constrictor, the soft palate, the tonsillar pillars, the palatal tonsil, and the divided retromolar buccal mucosa to the opposite side. The pharyngeal dissection is directed in front of the prevertebral fascia overlying the longus capitis and the longus colli, and it requires opening the posterior part of the parapharyngeal space and detaching the stylopharyngeus as well as the tensor and levator veli palatini from the pharyngeal wall and soft palate. The main obstacle to accessing the clivus is the cartilaginous part of the Eustachian tube. Pharyngeal retraction below the Eustachian tube exposes the anterior arch of C1 and the C2 to C4 vertebral bodies (Fig. 4M). Transection of the Eustachian tube and detachment of the pharyngobasilar fascia from the cranial base expose the posterior portion of the sphenoid body and the entire clivus (Fig. 4N). Exposing the lower half of the clivus requires retraction of the longus capitis on each side of the midline (Fig. 4O).

After these maneuvers, the internal carotid artery, internal jugular vein, and Cranial Nerves IX through XII define the lateral limit of the exposure. Removing the posterior nasal septum, above or in combination with removal of the pterygoid process, allows for wide opening of the sphenoid sinus and the ipsilateral posterior ethmoid sinus (Fig. 4Q). The septal mucosa, if elevated as a pedicled flap, can be reflected to provide a vascularized layer that reinforces the closure of the clival dura. The structures that can be exposed through the sphenoid sinus are the medial wall of the cavernous sinus, including the intracavernous carotid artery, the optic nerve and ophthalmic artery in the optic canal, and the pituitary gland (Fig. 4R). The roof of the nasal cavity, lower surface of the cribriform plate, and anterior and middle ethmoid sinuses usually can be accessed without performing an additional osteotomy of the medial or inferior orbital rim.

Upper maxillectomy

The upper maxillectomy yields anterior access to the posterior part of the central cranial base that is limited by the Eustachian tube superiorly and the hard palate inferiorly, even after the pterygoid process is removed (Fig. 5, N–P). Retracting the ipsilateral pharyngeal wall to the opposite side with division of the Eustachian tube produces somewhat limited access to the clivus and C1.

Intracranial stage

Upper maxillectomy

Combining the upper maxillectomy with a frontotemporal craniotomy provides intradural access to the anterior and middle cranial fossae, the frontal and temporal lobes, and the basal cisterns by the subfrontal, pterional, pretemporal, and subtemporal routes (Fig. 5, L and Q). Removal of the greater sphenoid wing and floor of the middle cranial fossa opens the superior orbital fissure, foramina rotundum, ovale, and spinosum, and it accesses the lateral wall of the cavernous sinus (Fig. 5, M–R). Drilling the base of the pterygoid plate exposes the pterygoid canal inferomedial to the foramen rotundum. Entry to the sphenoid sinus is obtained by drilling its lateral wall between the ophthalmic and maxillary nerves, or by drilling the anterior part of the root of the pterygoid process above the pterygoid canal. However, the space between the pterygoid canal and foramen rotundum is limited (Fig. 5S). Continued extradural dissection to the posterior part of the middle cranial fossa exposes the anterior surface of the petrous temporal bone, the trigeminal ganglion in Meckel's cave, and the greater and lesser petrosal nerves in their grooves on the floor of the middle fossa. Drilling the apex of the petrous temporal bone behind the petrous carotid with opening of the dura accesses the anterolateral aspect of the upper brainstem, although the exposure is very limited. Anterior transposition of the petrous carotid is required to reach the central part of the clivus from this lateral exposure. The lateral access is best suited to exposing lesions at the petroclival junction rather than those centrally located in the clivus.

Lower maxillectomy

The lower maxillectomy, with removal of the clivus and anterior elements of the upper cervical vertebrae, provides reasonable intradural access to the front of the pons, the medulla, and the cervical spinal cord above C4 as well as the basilar and vertebral arteries (Fig. 4, P–S). The vital structures that provide the lateral limits to the extradural bone removal and the intradural exposure include the petrous and intracavernous carotid, especially the artery on the ipsilateral side; the abducent nerve in Dorello's canals, particularly the contralateral nerve located at the anterosuperior end of the petrous apex; and the hypoglossal canals and occipital condyles. Opening the basilar venous plexus, which crosses behind the upper clivus and the posterior wall of the sphenoid sinus, may result in profuse hemorrhaging.

DISCUSSION

Among the various anterior routes to the central cranial base, the route most frequently selected for lesions involving the lower clivus and adjacent vertebral bodies has been the transoral approach ([12,13]). The upper and middle portions of the clivus are also accessible by the Le Fort I transverse maxillotomy, and the additional median section of either the hard or both the hard and soft palates increases the clival exposure, although Cocke and Robertson ([9]) and Cocke et al. ([10]) conclude that the unilateral maxillectomy provides a more extensive exposure than some bilateral approaches, such as the Le Fort I ([1,4,23,28]). The hemimaxillectomy approach described by Hernández-Altemir ([16]) accessed both the transmaxillary and transoral routes. Subsequent modifications and extensions have provided added exposure of both the central and the lateral cranial base, permitting en bloc excision of large neoplasms by selecting and combining the osteotomies on the basis of the extent of disease ([7,8,10,15,18,19,21]).

The osteotomies for completing the upper and lower maxillectomy approaches are divided into four basic units: maxillary body, orbital rim, hard palate, and zygomatic arch; and three extended units: coronoid process, pterygoid process, and frontotemporal craniotomy (Fig. 3). The maxillary sinus is a core space for these approaches through which the retromaxillary area can be reached without violating any vital structure, although the transantral route alone provides very limited exposure ([11]). Removal of the medial orbital rim provides access to the ethmoid and frontal sinuses, cribriform plate, and the anterior face of the sphenoid sinus through the medial orbital route as in the lateral rhinotomy or medial maxillectomy approach; however, temporary sectioning of the medial palpebral ligament and the nasolacrimal duct usually is necessary ([27]). If the osteotomy involves the lower orbital rim and floor, the infraorbital nerve must be transected. A palatal osteotomy combined with a cut through the maxillary body below the orbital floor enables transmaxillary access to be combined with transoral access, and increases the anterior exposure of the central cranial base. Zygomatic arch osteotomy facilitates the lateral exposure of the upper part of the infratemporal fossa and the middle cranial fossa by allowing reflection of division of the temporalis muscle. Transection of the coronoid process opens the lateral aspect of the infratemporal fossa and allows early exposure of the maxillary artery for control of bleeding, which is common during the maxillary osteotomy. The sphenoid pterygoid process separates the central from the lateral cranial base and blocks anterolateral access to the central cranial base. Removing the pterygoid process provides exposure extending from the central to the lateral cranial base and allows for wide anterolateral access to the clivus and upper cervical spine. The frontotemporal craniotomy, when combined with an orbitozygomatic osteotomy and removal of the floor of the middle cranial fossa, provides lateral access to the cavernous sinus, the sphenoid sinus, and the petrous apex extradurally, and the frontal and temporal lobes and the basal cisterns intradurally.

The lower maxillectomy is performed by a combination of osteotomies through the maxillary body, the hard palate, and the pterygomaxillary junction, and it may be extended by cuts through the pterygoid and coronoid processes (Fig. 3A). Through a combination of the transmaxillary, transnasal, transoral, and transpalatal routes, this approach offers excellent upwardly directed anterior access to the central cranial base, as well as anterolateral access to the lateral cranial base after removal of the coronoid process. The structures accessed by this approach in the central cranial base include the nasal cavity, the lower surface of the cribriform plate, the nasopharynx, the ethmoid and sphenoid sinuses, the optic canal, the pituitary fossa, the medial cavernous sinus, the entire clivus and the upper cervical spine to C4 extradurally, the pons, the medulla, and the upper spinal cord, and the whole length of the basilar artery and the vertebral arteries intradurally. In the lateral cranial base, the structures accessed by this approach include the pterygopalatine and infratemporal fossae and the parapharyngeal space and its poststyloid region. This approach includes neither osteotomy in the orbital rim or zygomatic arch nor craniotomy, and it preserves the facial and infraorbital nerves, nasolacrimal duct, and the medial palpebral ligament. The entire ethmoid sinus, as well as the roof of the nasal cavity including the cribriform plate, can be reached by the lower maxillectomy without an additional osteotomy of the medial or inferior orbital rim. A maxillotomy pedicled either on a palatal or cheek flap is preferable, if possible, to maxillectomy because the pedicle aids in preserving blood supply to the maxilla and teeth ([6,8,10,16]). The sublabial midfacial degloving technique eliminates the facial scar, although the exposure is limited if the oral commissure is small, and it may not provide the more extensive access obtained with the Weber-Fergusson incision ([9]).

The upper maxillectomy, accomplished by a combination of osteotomies through the maxillary body above the alveolar process, lower orbital rim, and zygomatic arch, and extended by cuts through the base of the pterygoid or coronoid processes, provides a more lateral route to the central and lateral cranial base. It may be combined with a frontotemporal craniotomy for intracranial exposure (Fig. 3B). In this study, the structures adequately exposed by this approach in the central cranial base included the nasal cavity, the lateral and inferior aspects of the orbit, the posterior ethmoid sinus, the nasopharynx, the sphenoid sinus, the lateral cavernous sinus, the entire clivus, and the C1 anterior arch extradurally, as well as the anterolateral aspect of the lower brainstem and upper cervical cord intradurally; and in the lateral cranial base, the pterygopalatine and infratemporal fossae, the parapharyngeal space and its poststyloid area, the anterior and middle cranial fossae, and the petrous apex extradurally. This approach also provides intradural access by the subfrontal, pterional, pretemporal, and/or subtemporal routes to the areas below the frontal and temporal lobes and to the basal cisterns. An additional osteotomy in the medial orbital wall allows for anterior midline access to the entire ethmoid sinus, cribriform plate, and anterior aspect of the sphenoid sinus.

The lateral approaches, such as the preauricular subtemporal/infratemporal approach and the Fisch Type C postauricular approach provide lateral access to the cranial base, including the infratemporal fossa, petrous apex, clivus, nasopharynx, and sphenoid sinus without facial incisions. However, they provide limited access to the central cranial base, and anterior midline access is severely restricted compared with the more anterior route through the maxilla ([14,24]). The Fisch Type C approach also requires facial nerve transposition, which often results in temporary or permanent facial weakness. A palatal osteotomy is not included in the upper maxillectomy; however, it can be combined, as in the lower maxillectomy approach, to gain greater access to the central cranial base.

The lower maxillectomy provides more anterior and inferior access to the cranial base, whereas the upper maxillectomy approach yields a more lateral and superior opening. However, these two techniques are complementary and their osteotomy units can be combined to provide a wider exposure. The upper maxillectomy potentially can be combined with even more extended procedures such as the presigmoid transpetrosal approach posteriorly, the midline mandibular osteotomy inferiorly, and/or contralateral transfacial access ([17,21]). Exposure from the upper clivus down to the level of C4 can be achieved by the transmandibular approach alone; however, from our preliminary examination, it is improbable that the median mandibulotomy improves the exposure achieved by the lower maxillectomy approach ([5,20]).

Disadvantages and complications associated with these approaches include facial scarring, transection of the infraorbital nerve and the temporal branch of the facial nerve, impaired lacrimal drainage, medial canthus and dental misalignment, Eustachian tube dysfunction and serous otitis, disturbed mastication, facial deformity, and temporal depression secondary to the use of temporalis flap. The facial incisions usually do not irreversibly sacrifice any structure of functional and esthetic importance ([8,16,19]). The lower conjunctival incision overcomes the problems of visible infraorbital scar, ectropion, and lymphedema ([19,22]). A peripheral neurorrhaphy after transection of the temporal branch of the facial nerve usually results in recovery ([19]). Reconstruction of the infraorbital nerve, placement of nasolacrimal stents, reapproximation of the medial palpebral ligament, placement of ventilating tubes in the Eustachian tube, and careful manipulation of the osteotomies in the maxilla, zygoma, and possibly the mandibular coronoid or condylar processes aid in minimizing permanent side effects.

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COMMENTS

The authors present another article that over time will become a classic in a long line of works from Professor Rhoton and his laboratory. These approaches are relatively unfamiliar territory to the majority of neurosurgeons. An article such as this goes far in enhancing our understanding of the anatomy in the infratemporal fossa and retropharyngeal region.

Both approaches presented provide good alternatives to a Fisch Type C approach, because with these approaches facial nerve mobilization is unnecessary. At a minimum, temporary facial nerve morbidity is expected with the Fisch Type C procedure. The lower subtotal maxillectomy approach is best suited to the treatment of extradural lesions. There are certainly alternatives for lesions that are also located intradurally and that do not traverse the oro- and nasopharyngeal spaces. I use every possible means to avoid traversing the oropharyngeal space to reach the intradural compartment. The reader should keep in mind that a communication between the oropharynx or nasopharynx is also possible using the upper approach presented here. When using this type of approach for an invasive cancer in the infratemporal fossa, there can be extension to the upper airway and violation of this region during surgery. Communication is then possible to the intradural compartment, if the tumor extends intracranially and is resected from that compartment. If the upper airway does come into communication with the intracranial compartment, it is probably best to perform some type of airway diversion procedure to prevent a tension pneumocephalus. This can be accomplished either by tracheostomy or temporarily by passing nasal airways.

Hitotsumatsu and Rhoton have presented a very detailed and useful monograph on the anatomy of the subtotal maxillectomy approaches. This will be added to the body of work that Dr. Rhoton has provided, which I consider a primary reference for contemporary cranial base surgery.

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This excellent article is an anatomic study of upper and lower subtotal maxillectomy approaches to the cranial base. Readers must understand the division between anatomic studies and clinical experience. Anatomic studies form the basis of a surgical approach or allow the surgeon to refine the operation; however, they do not provide actual information regarding issues such as intraoperative bleeding, postoperative complications, and healing. During maxillectomy exposure, bleeding from the pterygoid venous plexus can be significant. If the internal carotid or extracranial vertebral arteries become exposed to the nasopharyngeal secretions, rupture of the artery can occur postoperatively as a result of infected arteries. If the dura mater is breached, postoperative cerebrospinal fluid leakage and infection may be difficult to control. Postoperative trismus, soft tissue and bone loss with facial deformity, and numbness of the teeth also may be observed after maxillectomy exposure. Before using these complex cranial base exposures in their practice, surgeons would be well advised to observe other surgeons who perform these operations commonly.

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Hitotsumatsu and Rhoton provide a detailed anatomic description of transmaxillary approaches to the cranial base and the infratemporal and pterygopalatine fossa in particular. However, as the authors mention, these approaches may carry considerable side effects related to dental occlusion, lacrimal function, and so forth. Any such approach requires considerable experience and should be undertaken by cranial base teams with interdisciplinary cooperation of neurosurgeons, otorhinolaryngologists, and maxillofacial surgeons.

My concern with such demanding cranial base approaches always centers on the right indications for use. Certainly, a wide exposure of the cranial base is provided with the approaches described here. However, when do we really need such extensive approaches? Surgeons with little experience may be tempted to "overexpose" a lesion and subject the patient to unnecessary risks. In most instances, we can use much simpler techniques, such as a transethmoidal or pterional approach to follow the disease into the neighboring structures. In those patients in whom a transmaxillary approach is indeed indicated, this article by Hitotsumatsu and Rhoton will be of fundamental importance for understanding the microsurgical anatomy of this region.

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This article contains beautiful pictures that the authors must have expended great effort to obtain. It is worthwhile not only for neurosurgeons, but also for maxillofacial surgeons and head and neck surgeons. The current anatomic presentations on the transmaxillary approach have differed because the maxilla occupies a large space in the face. In this article, the approach was classified into two categories: the lower and the upper maxillary approaches. The lower approach covers the same surgical area as the Le Fort I approach. The upper approach covers a wider area, which is accessed around the orbit. According to the authors, the upper maxillary approach was more manageable if divided into medial and lateral approaches. Because the deep craniobasal structures are clearly separated by the remarkable wall consisting of the pterygoid plates, the Eustachian tube, and the attached muscles, it is difficult to obtain a combined surgical field from the pharynx to the infratemporal fossa, as shown in Figure 4H–S, without incurring a loss of function. Figures 5 and 6 demonstrate more practical anatomy, presented clinically by the transfacial approach and orbitozygomatic infratemporal approach, respectively.

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