5 Brainstem

CHAPTER OBJECTIVES

- To review the anatomy of the brainstem
- To develop a three-dimensional picture of the interior of the brainstem
- To know the positions of several of the cranial nerve nuclei, the olivary nuclear complex, and the paths taken by the various ascending and descending nerve tracts as they ascend to the higher brain centers or descend to the spinal cord
- To assess the signs and symptoms presented by a patient and identify the exact location of a structural lesion

A 58-year-old woman is referred to a neurologist because of recent onset of difficulty with walking. The neurologist notes that she stands and walks with her left arm flexed at the elbow and the left leg extended (left hemiparesis). While walking, she has difficulty flexing the left hip and knee and dorsiflexing the ankle; the forward motion is possible by swinging the left leg outward at the hip to avoid dragging the foot on the ground. Her left arm remains motionless.

Neurologic examination shows no signs of facial paralysis, but tongue weakness is evident. On protrusion, the tongue deviates toward the right side (right hypoglossal nerve palsy). Cutaneous sensations are found to be normal, but muscle joint sense, tactile discrimination, and vibratory sense on the left side of the body are impaired.

Based on the neurologic findings, a diagnosis of right-sided medial medullary syndrome is made. The medial part of the right side of the medulla oblongata receives its arterial supply from the right vertebral artery. Occlusion of this artery or its branch to the medulla results in destruction of the right pyramid (left hemiparesis), destruction of the right hypoglossal nucleus and nerve (right hypoglossal palsy), and destruction of the medial lemniscus on the right side (left-sided loss of muscle joint sense, vibratory sense, and tactile discrimination). The absence of facial palsy showed that the facial nerve nuclei, the facial nerves, and the corticobulbar fibers to the facial nuclei were intact. The sparing of the sensations of touch, pain, and temperature showed that the spinal lemniscus was intact.

This diagnosis is possible as the result of carefully sorting out the neurologic findings. A clear knowledge of the position and function of the various nerve tracts and nuclei in the medulla oblongata is essential before a clinician can reach a diagnosis in this case.

SKULL ANATOMY

Head injuries from blunt trauma and penetrating missiles are associated with a high mortality and disabling morbidity. Because of the close relationship that exists between the skull and the underlying brain and cranial nerves (CNs), as well as their common involvement in many diseases, a brief review of the anatomy of the skull will first be considered.

Adult Skull

The skull is composed of several separate bones united at immobile joints called **sutures**. The connective tissue between the bones is called a **sutural ligament**. The mandible is an exception, united to the skull by the mobile temporomandibular joint.

The bones of the skull can be divided into those of the **cranium** and those of the face. The **vault** is the upper part of the cranium, and the **base of the skull** is the lowest part of the cranium (Fig. 5-1).

The skull bones are made up of **external** and **internal tables** of compact bone separated by a layer of spongy bone called the **diploë** (Fig. 5-2). The internal table is thinner and more brittle than the external table. The bones are covered on the outer and inner surfaces with periosteum.

The **cranium** consists of the following bones, two of which are paired (Fig. 5-3; also see Fig. 5-1):

- Frontal bone 1
- Parietal bones 2
- Occipital bone 1
- Temporal bones 2
- Sphenoid bone 1
- Ethmoid bone 1

The **facial bones** consist of the following, two of which are single:

- Zygomatic bones 2
- Maxillae 2
- Nasal bones 2
- Lacrimal bones 2
- Vomer 1
- Palatine bones 2
- Inferior conchae 2
- Mandible 1

Although students do not need to know the detailed structure of each individual skull bone, they should be familiar with the skull as a whole. If possible, have a dried skull available for reference as you read the following description.

Anterior View

The **frontal bone**, or forehead bone, curves downward to make the upper margins of the orbits (see Fig. 5-1). The **superciliary arches** can be seen on either side, and the **supraorbital notch**, or **foramen**, can be recognized. Medially, the frontal bone articulates with the frontal

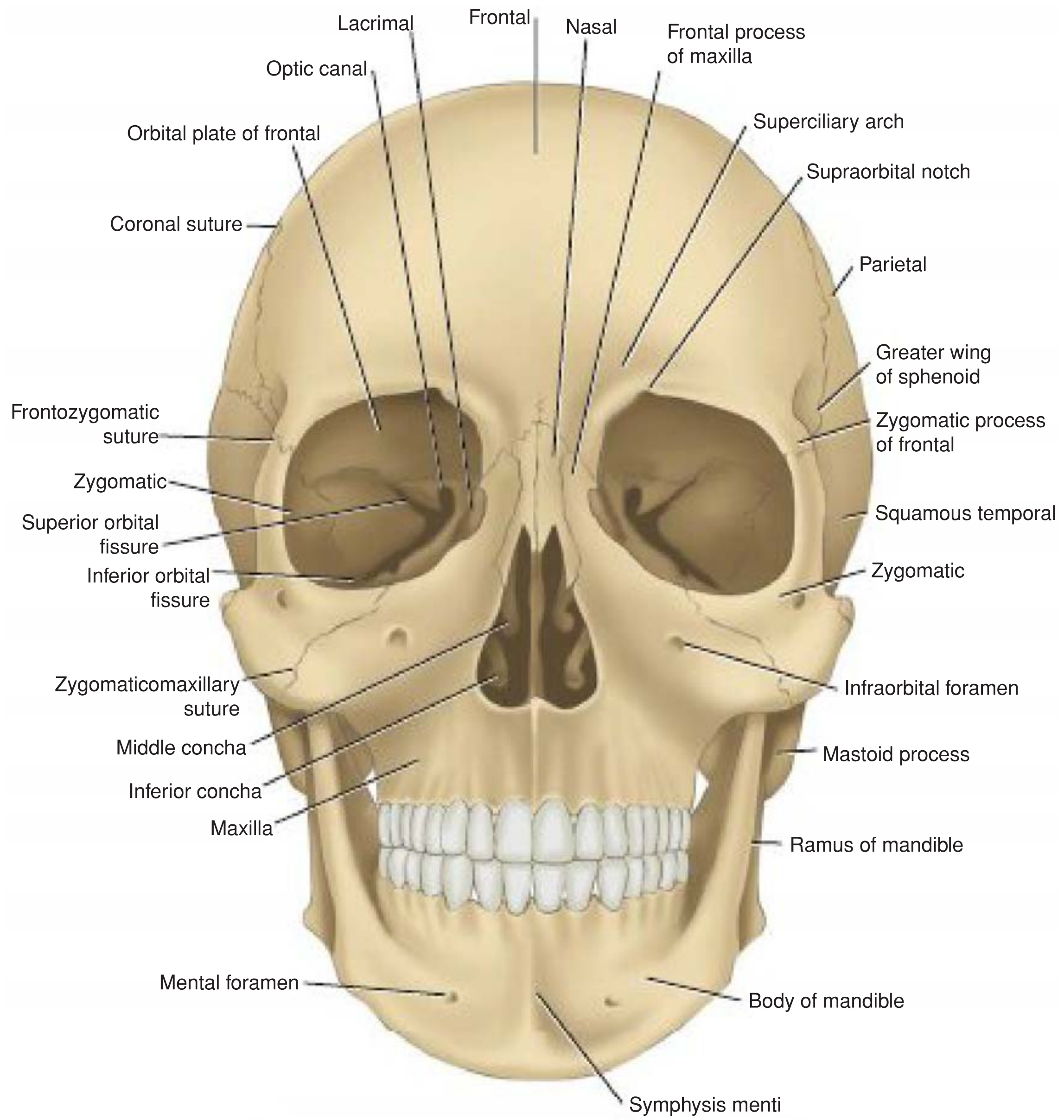

Figure 5-1 Bones of the anterior aspect of the skull.

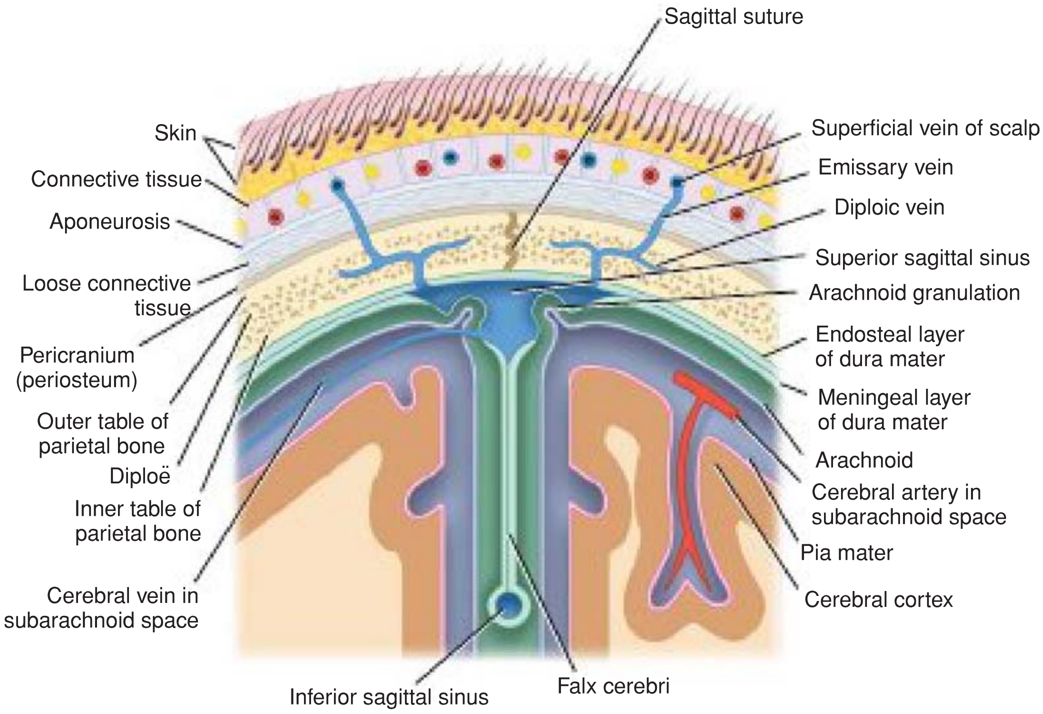

Figure 5-2 Coronal section of the upper part of the head showing the layers of the scalp, the sagittal suture of the skull, the falx cerebri, the superior and inferior sagittal venous sinuses, the arachnoid granulations, the emissary veins, and the relation of cerebral blood vessels to the subarachnoid space.

processes of the maxillae and with the nasal bones. Laterally, the frontal bone articulates with the zygomatic bone.

The **orbital margins** are bounded by the frontal bone superiorly, the zygomatic bone laterally, the maxilla inferiorly, and the processes of the maxilla and frontal bone medially.

Within the **frontal bone**, just above the orbital margins, are two hollow spaces lined with mucous membrane called the **frontal air sinuses**. These communicate with the nose and serve as voice resonators.

The two **nasal bones** form the bridge of the nose. Their lower borders, with the maxillae, make the **anterior nasal aperture**. The nasal cavity is divided into two by the bony nasal septum, which is largely formed by the **vomer**. The **superior** and **middle conchae** are shelves of bone that project into the nasal cavity from the **ethmoid** on each side; the **inferior conchae** are separate bones.

The two **maxillae** form the upper jaw, the anterior part of the hard palate, part of the lateral walls of the nasal cavities, and part of the floors of the orbital cavities. The two bones meet in the midline at the **intermaxillary** suture and form the lower margin of the nasal aperture. Below the orbit, the maxilla is perforated by the **infraorbital** foramen. The **alveolar process** projects downward and, together with the fellow of the opposite side, forms the **alveolar** arch, which carries the upper teeth. Within each maxilla is a large, pyramid-shaped cavity lined with mucous membrane called the **maxillary** sinus. This communicates with the nasal cavity and serves as a voice resonator.

The **zygomatic bone** forms the prominence of the cheek and part of the lateral wall and floor of the orbital cavity. It articulates with the maxilla medially and with the zygomatic process of the temporal bone laterally to form the **zygomatic arch**. The zygomatic bone is perforated by two foramina for the zygomaticofacial and zygomaticotemporal nerves.

The **mandible**, or lower jaw, consists of a horizontal **body** and two vertical **rami**.

Lateral View

The **frontal bone** forms the anterior part of the side of the skull and articulates with the parietal bone at the **coronal suture** (see Fig. 5-3).

The **parietal bones** form the sides and roof of the cranium and articulate with each other in the midline at the **sagittal suture**. They articulate with the occipital bone behind, at the **lambdoid suture**.

The skull is completed at the side by the squamous part of the **occipital bone**; parts of the **temporal bone**, namely, the **squamous**, **tympanic**, **mastoid process**, **styloid process**, and **zygomatic process**; and the **greater wing of the sphenoid**. Note the position of the external

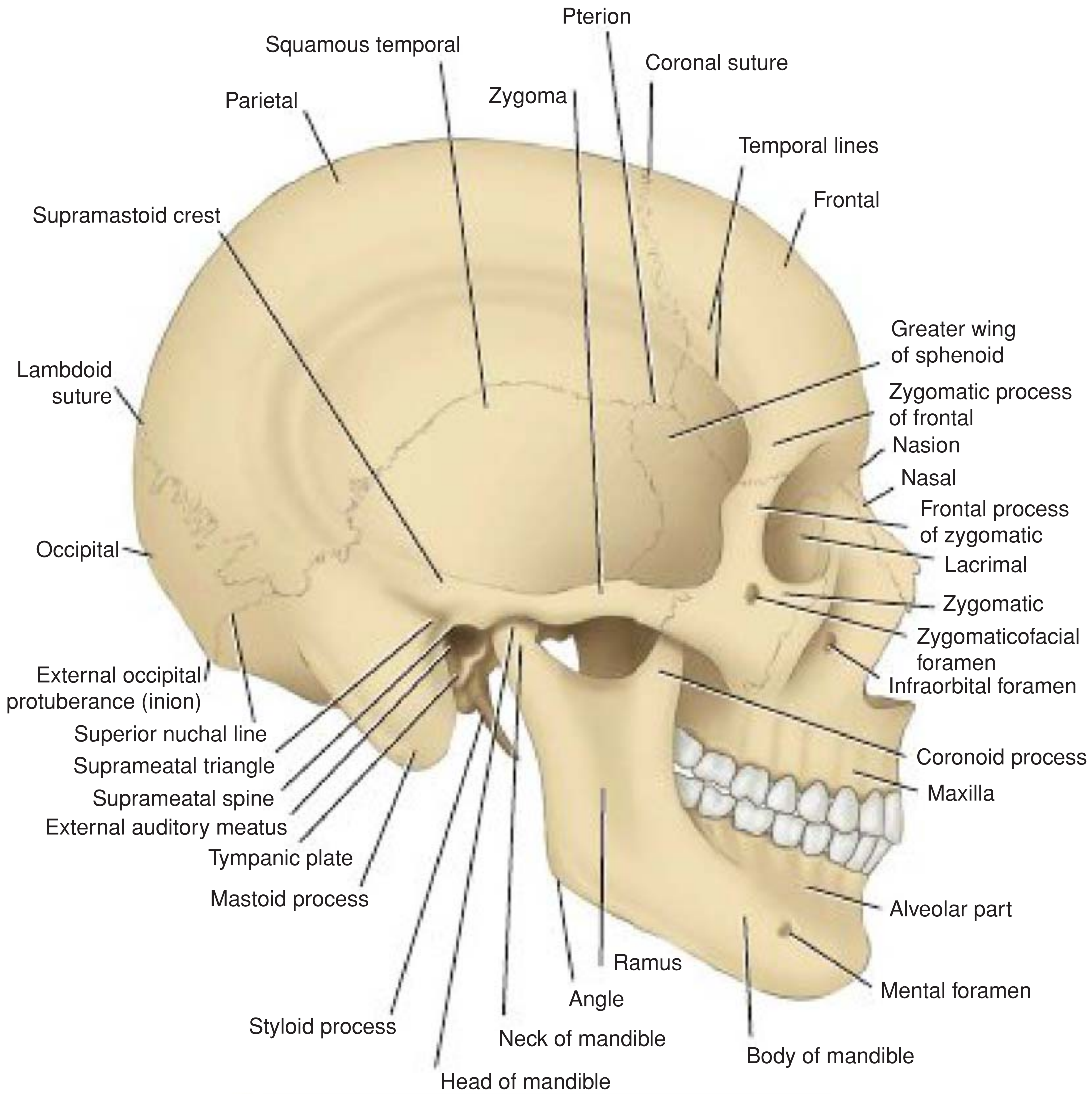

Figure 5-3 Bones of the lateral aspect of the skull.

auditory meatus. The ramus and body of the mandible lie inferiorly.

Note that the thinnest part of the lateral wall of the skull is where the anteroinferior corner of the parietal bone articulates with the greater wing of the sphenoid; this point is referred to as the **pterion**.

Clinically, the pterion is an important area because it overlies the anterior division of the **middle meningeal artery** and **vein**.

Identify the **superior** and **inferior temporal lines**, which begin as a single line from the posterior margin of the zygomatic process of the frontal bone and diverge as they arch backward. The **temporal fossa** lies below the inferior temporal line.

The **infratemporal fossa** lies below the **infratemporal crest** on the greater wing of the sphenoid. The **pterygomaxillary fissure** is a vertical fissure that lies within the fossa between the pterygoid process of the sphenoid bone and back of the maxilla. It leads medially into the **pterygopalatine fossa**.

The **inferior orbital fissure** is a horizontal fissure between the greater wing of the sphenoid bone and the maxilla. It leads forward into the orbit.

The **pterygopalatine fossa** is a small space behind and below the orbital cavity. It communicates laterally with the infratemporal fossa through the pterygomaxillary fissure, medially with the nasal cavity through the **sphenopalatine foramen**, superiorly with the skull through the **foramen rotundum**, and anteriorly with the orbit through the **inferior orbital fissure**.

Posterior View

The posterior parts of the two parietal bones (Fig. 5-4A) with the intervening **sagittal** suture are seen above. Below, the parietal bones articulate with the squamous part of the occipital bone at the **lambdoid** suture. On each side, the occipital bone articulates with the temporal bone. In the midline of the occipital bone is a roughened elevation called the **external** occipital

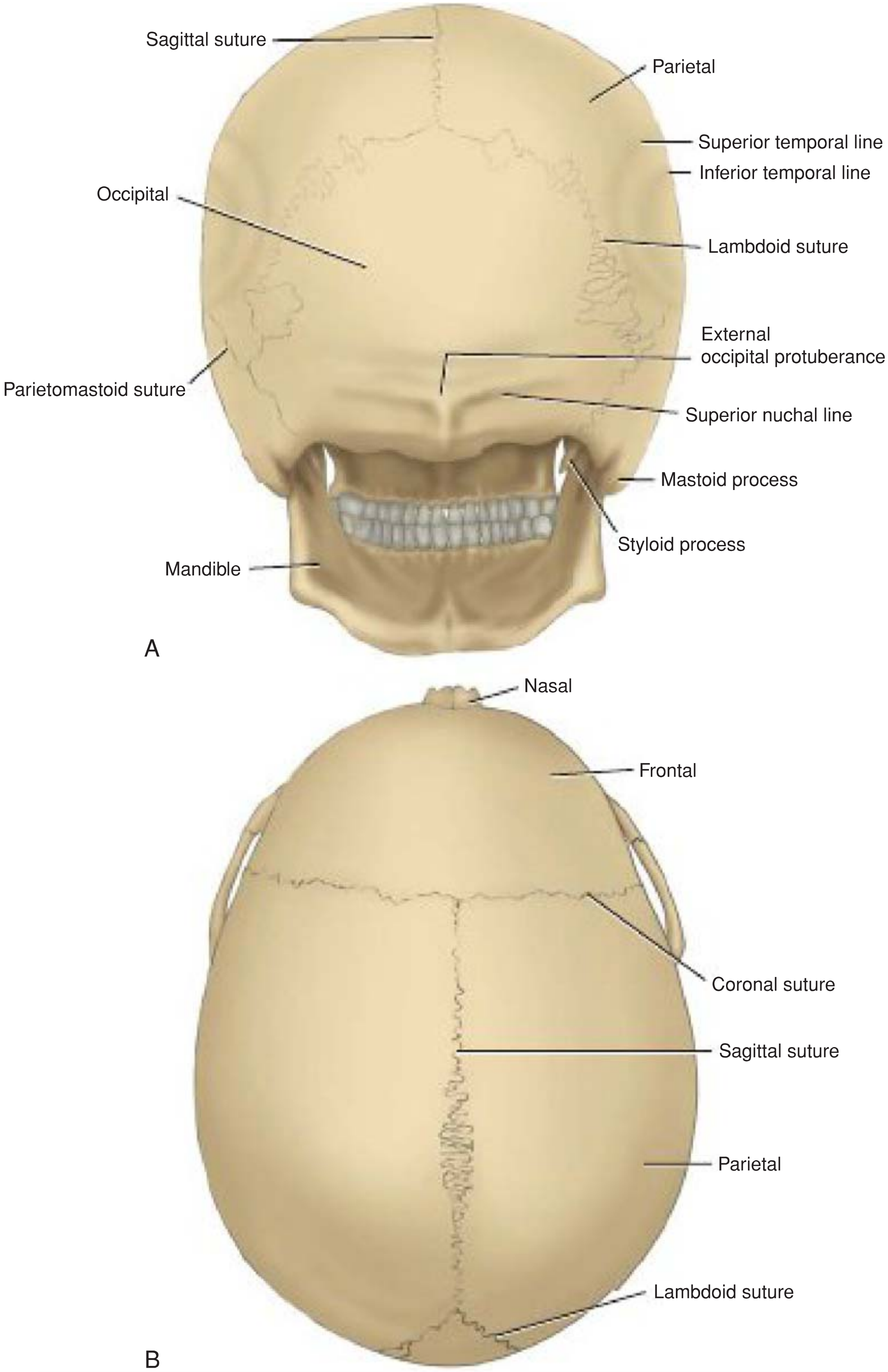

Figure 5-4 Bones of the skull viewed from the posterior (**A**) and superior (**B**) aspects.

protuberance, which gives attachment to muscles and the ligamentum nuchae. On either side of the protuberance, the **superior** nuchal lines extend laterally toward the temporal bone.

Superior View

Anteriorly, the frontal bone (see Fig. 5-4B) articulates with the two parietal bones at the **coronal suture**. Occasionally, the two halves of the frontal bone fail to fuse, leaving a midline **metopic suture**. Behind, the two parietal bones articulate in the midline at the **sagittal suture**.

Inferior View

If the mandible is discarded, the anterior part of this aspect of the skull is seen to be formed by the **hard palate** (Fig. 5-5).

The **palatal processes of the maxillae** and the **horizontal plates of the palatine bones** can be identified. In the midline anteriorly is the **incisive fossa** and **foramen**. Posterolaterally are the **greater** and **lesser palatine foramina**.

Above the posterior edge of the hard palate are the **choanae** (posterior nasal apertures). These are separated from each other by the posterior margin of the **vomer** and

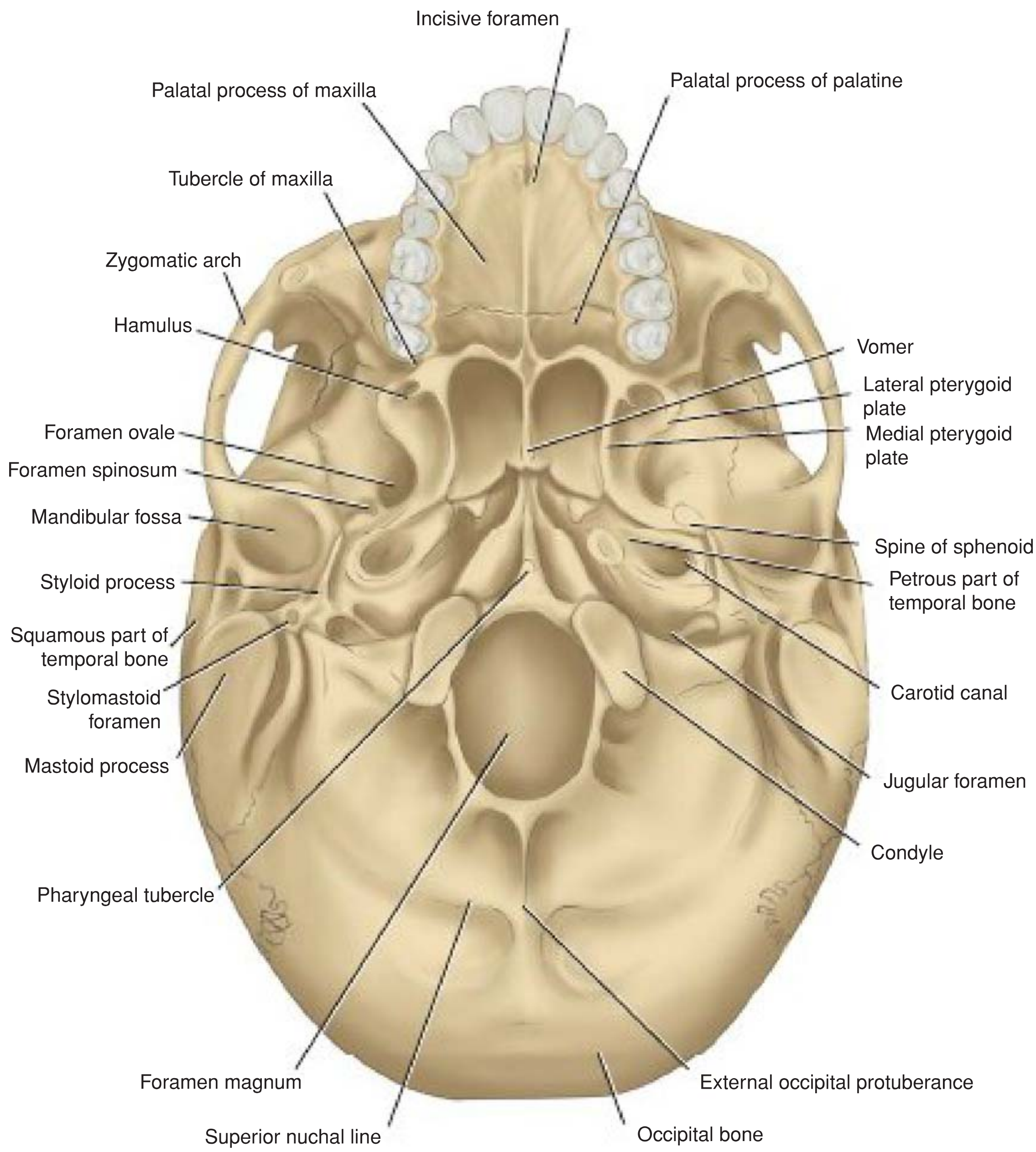

Figure 5-5 Inferior surface of the base of the skull.

are bounded laterally by the **medial pterygoid plates** of the sphenoid bone. The inferior end of the **medial pterygoid plate** is prolonged as a curved spike of bone, the **pterygoid hamulus**.

Posterolateral to the **lateral pterygoid plate**, the greater wing of the sphenoid is pierced by the large **foramen ovale** and the small **foramen spinosum**. Posterolateral to the foramen spinosum is the **spine of the sphenoid**.

Behind the spine of the sphenoid, in the interval between the greater wing of the sphenoid and the petrous part of the temporal bone, is a groove for the cartilaginous part of the **auditory tube**. The opening of the bony part of the tube can be identified.

The **mandibular fossa** of the temporal bone and the **articular tubercle** form the upper articular surfaces for the temporomandibular joint. Separating the mandibular fossa from the tympanic plate posteriorly is the **squamotympanic fissure**, through the medial end of which the chorda tympani exits from the tympanic cavity.

The **styloid process** of the temporal bone projects downward and forward from its inferior aspect. The opening of the **carotid canal** can be seen on the inferior surface of the petrous part of the temporal bone.

The medial end of the petrous part of the temporal bone is irregular and, together with the basilar part of the occipital bone and the greater wing of the sphenoid, forms the **foramen lacerum**. During life, the foramen lacerum is closed with fibrous tissue, and only a few small vessels pass through this foramen from the cavity of the skull to the exterior.

The **tympanic plate**, which forms part of the temporal bone, is C shaped on section and forms the bony part of the **external auditory meatus**. While examining this region, identify the **suprameatal crest** on the lateral surface of the squamous part of the temporal bone, the **suprameatal triangle**, and the **suprameatal spine**.

In the interval between the styloid and mastoid processes, the **stylomastoid foramen** can be seen. Medial to the styloid process, the petrous part of the temporal bone has a deep notch, which, together with a shallower notch on the occipital bone, forms the **jugular foramen**.

Behind the posterior apertures of the nose and in front of the foramen magnum are the sphenoid bone and the basilar part of the occipital bone.

The **occipital condyles** should be identified; they articulate with the superior aspect of the lateral mass of the first cervical vertebra, the atlas. Superior to the occipital condyle is the **hypoglossal canal** for transmission of the hypoglossal nerve (Fig. 5-6).

Posterior to the foramen magnum in the midline is the external occipital protuberance.

Neonatal Skull

The newborn skull (see Fig. 5-6), compared with the adult skull, has a disproportionately large cranium relative to the face. In childhood, the growth of the mandible, the maxillary sinuses, and the alveolar processes of the maxillae results in a great increase in length of the face.

The bones of the skull are smooth and unilaminar, there being no diploë present. Most of the skull bones are ossified at birth, but the process is incomplete, and the bones are mobile on each other, being connected by fibrous tissue or cartilage. The bones of the vault are not closely knit at sutures, as in the adult, but are separated by unossified membranous intervals called **fontanelles**. Clinically, the anterior and posterior fontanelles are most important and are easily examined in the midline of the vault.

The **anterior fontanelle** is diamond shaped and lies between the two halves of the frontal bone in front and the two parietal bones behind. The fibrous membrane forming the floor of the anterior fontanelle is replaced by bone and is closed by 18 months of age. The **posterior fontanelle** is triangular and lies between the two parietal bones in front and the occipital bone behind. By the end of the first year, the fontanelle is usually closed and can no longer be palpated.

The **tympanic part of the temporal bone** is merely a C-shaped ring at birth, compared with a C-shaped curved plate in the adult. The **mastoid process** is not present at birth (Fig. 5-7) and develops later in response to the pull of the sternocleidomastoid muscle when the child moves his or her head.

The mandible has right and left halves at birth, united in the midline with fibrous tissue. The two halves fuse at the **symphysis menti** by the end of the first year.

CRANIAL CAVITY

The cranial cavity contains the brain and its surrounding meninges, portions of the CNs, arteries, veins, and venous sinuses.

Vault of the Skull

The internal surface of the vault shows the coronal, sagittal, and lambdoid sutures. In the midline is a shallow sagittal groove that lodges the **superior sagittal sinus**. Several narrow grooves are present for the anterior and posterior divisions of the **middle meningeal vessels** as they pass up the side of the skull to the vault.

Base of the Skull

The interior of the base of the skull (see Fig. 5-6) is divided into three cranial fossae: anterior, middle, and posterior. The anterior cranial fossa is separated from the middle cranial fossa by the lesser wing of the sphenoid, and the middle cranial fossa is separated from the posterior cranial fossa by the petrous part of the temporal bone.

Anterior Cranial Fossa

The anterior cranial fossa lodges the frontal lobes of the cerebral hemispheres. It is bounded anteriorly by

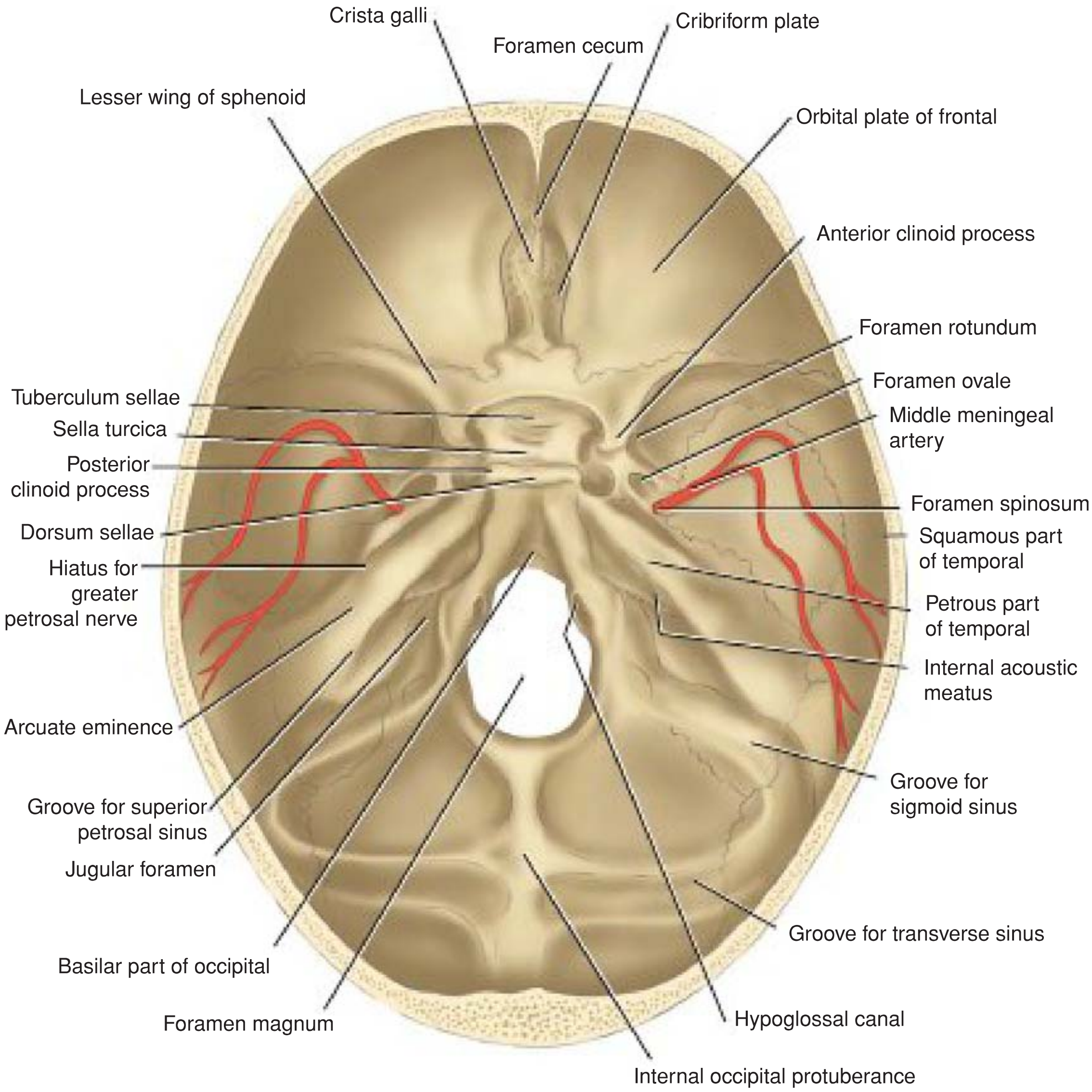

Figure 5-6 Internal surface of the base of the skull.

the inner surface of the frontal bone, and in the midline is a crest for the attachment of the **falx cerebri**. Its posterior boundary is the sharp lesser wing of the sphenoid, which articulates laterally with the frontal bone and meets the anteroinferior angle of the parietal bone, or the pterion. The medial end of the lesser wing of the sphenoid forms the **anterior clinoid process** on each side, which gives attachment to the **tentorium cerebelli**. The median part of the anterior cranial fossa is limited posteriorly by the groove for the optic chiasma.

The floor of the fossa is formed by the ridged orbital plates of the frontal bone laterally and by the **cribriform plate** of the ethmoid medially (see Fig. 5-6). The **crista galli** is a sharp upward projection of the ethmoid bone in the midline for the attachment of the falx cerebri. Between the crista galli and the crest of the frontal bone is a small aperture, the **foramen cecum**, for the transmission of a small vein from the nasal mucosa to the superior sagittal sinus. Alongside the crista galli is a narrow slit in the cribriform plate for the passage of the **anterior ethmoidal nerve** into the nasal cavity. The upper surface of the cribriform plate supports the **olfactory bulbs**, and the small perforations in the cribriform plate are for the **olfactory nerves**.

Middle Cranial Fossa

The middle cranial fossa consists of a small median part and expanded lateral parts (see Fig. 5-6). The median raised part is formed by the body of the sphenoid, and

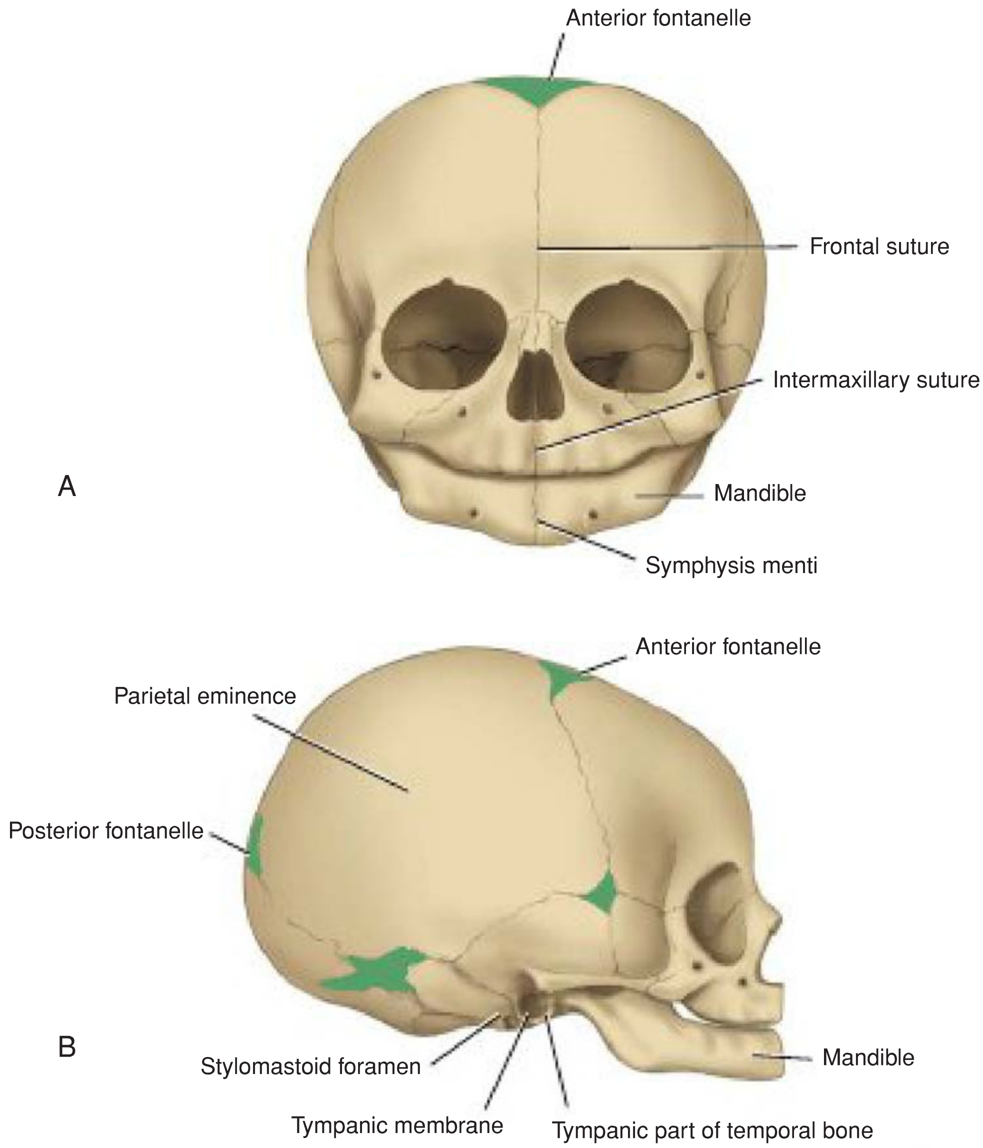

Figure 5-7 Neonatal skull as seen from the anterior (**A**) and lateral (**B**) aspects.

the expanded lateral parts form concavities on either side, which lodge the **temporal lobes** of the **cerebral hemispheres**.

It is bounded anteriorly by the sharp posterior edges of the lesser wings of the sphenoid and posteriorly by the superior borders of the petrous parts of the temporal bones. Laterally lie the squamous parts of the temporal bones, the greater wings of the sphenoid, and the parietal bones.

The floor of each lateral part of the middle cranial fossa is formed by the greater wing of the sphenoid and the squamous and petrous parts of the temporal bone.

The sphenoid bone resembles a bat having a centrally placed **body** with **greater** and **lesser wings** that are outstretched on each side. The body of the sphenoid contains the **sphenoid air sinuses**, which are lined with mucous membrane and communicate with the nasal cavity; they serve as voice resonators.

Anteriorly, the **optic** canal transmits the optic nerve and the ophthalmic artery, a branch of the internal carotid artery, to the orbit. The **superior** orbital fissure, which is a slitlike opening between the lesser and greater wings of the sphenoid, transmits the lacrimal, frontal, trochlear, oculomotor, nasociliary, and abducens nerves, together with the superior ophthalmic vein. The sphenoparietal venous sinus runs medially along the posterior border of the lesser wing of the sphenoid and drains into the cavernous sinus.

The **foramen** rotundum, which is situated behind the medial end of the superior orbital fissure, perforates the greater wing of the sphenoid and transmits the maxillary nerve from the trigeminal ganglion to the pterygopalatine fossa.

The **foramen ovale** lies posterolateral to the foramen rotundum. It perforates the greater wing of the sphenoid and transmits the large sensory root and small motor root of the mandibular nerve to the infratemporal fossa.

The small **foramen spinosum** lies posterolateral to the foramen ovale and also perforates the greater wing of the sphenoid. The foramen transmits the middle meningeal artery from the infratemporal fossa into the cranial cavity. The artery then runs forward and laterally in a groove on the upper surface of the squamous part of the temporal bone and the greater wing of the sphenoid. After a short distance, the artery divides into anterior and posterior branches. The anterior branch passes forward and upward to the anteroinferior angle of the parietal bone (see Fig. 15-5). Here, the bone is deeply grooved or tunneled by the artery for a short distance before it runs backward and upward on the parietal bone. At this site, the artery may be damaged after a blow to the side of the head. The posterior branch passes backward and upward across the squamous part of the temporal bone to reach the parietal bone.

The large and irregularly shaped **foramen lacerum** lies between the apex of the petrous part of the temporal bone and the sphenoid bone (see Fig. 5-6). The inferior opening of the foramen lacerum in life is filled by cartilage and fibrous tissue, and only small blood vessels pass through this tissue from the cranial cavity to the neck.

The **carotid** canal opens into the side of the foramen lacerum above the closed inferior opening. The internal carotid artery enters the foramen through the carotid canal and immediately turns upward to reach the side of the body of the sphenoid bone. Here, the artery turns forward in the cavernous sinus to reach the region of the anterior clinoid process. At this point, the internal carotid artery turns vertically upward, medial to the anterior clinoid process, and emerges from the cavernous sinus (see Fig. 5-6).

Lateral to the foramen lacerum is an impression on the apex of the petrous part of the temporal bone for the **trigeminal ganglion**. On the anterior surface of the petrous bone are two grooves for nerves; the largest medial groove is for the **greater petrosal nerve**, a branch of the facial nerve; the smaller lateral groove is for the **lesser petrosal nerve**, a branch of the tympanic plexus. The greater petrosal nerve enters the foramen lacerum deep to the trigeminal ganglion and joins the **deep petrosal nerve** (sympathetic fibers from around the internal carotid artery), to form the **nerve of the pterygoid canal**. The lesser petrosal nerve passes forward to the foramen ovale.

The abducens nerve bends sharply forward across the apex of the petrous bone, medial to the trigeminal ganglion. Here, it leaves the posterior cranial fossa and enters the cavernous sinus.

The **arcuate eminence** is a rounded eminence found on the anterior surface of the petrous bone and is caused by the underlying **superior semicircular canal**.

The **tegmen tympani**, a thin plate of bone, is a forward extension of the petrous part of the temporal bone and adjoins the squamous part of the bone. From behind forward, it forms the roof of the mastoid antrum, the tympanic cavity, and the auditory tube. This thin plate of bone is the only major barrier that separates infection in the tympanic cavity from the temporal lobe of the cerebral hemisphere.

The median part of the middle cranial fossa is formed by the body of the sphenoid bone. In front is the **sulcus chiasmatis**, which is related to the optic chiasma and leads laterally to the **optic canal** on each side. Posterior to the sulcus is an elevation, the **tuberculum sellae**. Behind the elevation is a deep depression, the **sella turcica**, which lodges the **hypophysis cerebri**. The sella turcica is bounded posteriorly by a square plate of bone called the **dorsum sellae**. The superior angles of the dorsum sellae have two tubercles, called the **posterior clinoid processes**, which give attachment to the fixed margin of the tentorium cerebelli.

The cavernous sinus is directly related to the side of the body of the sphenoid (see Fig. 5-6). It carries in its lateral wall the third and fourth CNs and the ophthalmic and maxillary divisions of the fifth CN (see Fig. 15-6). The internal carotid artery and the sixth CN pass forward through the sinus.

Posterior Cranial Fossa

The posterior cranial fossa is deep and lodges the parts of the hindbrain, namely, the **cerebellum**, **pons**, and **medulla oblongata**. Anteriorly, the fossa is bounded by the superior border of the petrous part of the temporal bone; posteriorly, it is bounded by the internal surface of the squamous part of the occipital bone (see Fig. 5-6). The floor of the posterior fossa is formed by the basilar, condylar, and squamous parts of the occipital bone and the mastoid part of the temporal bone.

The roof of the fossa is formed by a fold of dura, the **tentorium cerebelli**, which intervenes between the cerebellum below and the occipital lobes of the cerebral hemispheres above (see Fig. 15-3).

The **foramen magnum** occupies the central area of the floor and transmits the medulla oblongata and its surrounding meninges, the ascending spinal parts of the accessory nerves, and the two vertebral arteries.

The **hypoglossal canal** is situated above the anterolateral boundary of the foramen magnum (see Fig. 5-6) and transmits the **hypoglossal nerve**.

The **jugular foramen** lies between the lower border of the petrous part of the temporal bone and the condylar part of the occipital bone. It transmits the following structures from before backward: the **inferior petrosal sinus**; the **9th**, **10th**, and **11th CNs**; and the large **sigmoid sinus**. The inferior petrosal sinus descends in the groove on the lower border of the petrous part of the temporal bone to reach the foramen. The sigmoid

Table 5-1 Important Openings in the Base of the Skull and the Structures That Pass Through Them

Opening in Skull	Bone of Skull	Structures Transmitted
Anterior Cranial Fossa		
Perforations in cribriform plate	Ethmoid	Olfactory nerves
Middle Cranial Fossa		
Optic canal	Lesser wing of sphenoid	Optic nerve, ophthalmic artery
Superior orbital fissure	Between lesser and greater wings of sphenoid	Lacrimal, frontal, trochlear oculomotor, nasociliary, and abducens nerves; superior ophthalmic vein
Foramen rotundum	Greater wing of sphenoid	Maxillary division of the trigeminal nerve
Foramen ovale	Greater wing of sphenoid	Mandibular division of the trigeminal nerve, lesser petrosal nerve
Foramen spinosum	Greater wing of sphenoid	Middle meningeal artery
Foramen lacerum	Between petrous part of temporal and sphenoid	Internal carotid artery
Posterior Cranial Fossa		
Foramen magnum	Occipital	Medulla oblongata, spinal part of accessory nerve, and right and left vertebral arteries
Hypoglossal canal	Occipital	Hypoglossal nerve
Jugular foramen	Between petrous part of temporal and condylar part of occipital	Glossopharyngeal, vagus, and accessory nerves; sigmoid sinus becomes internal jugular vein
Internal acoustic meatus	Petrous part of temporal	Vestibulocochlear and facial nerves

sinus turns down through the foramen to become the **internal jugular vein**.

The **internal acoustic meatus** pierces the posterior surface of the petrous part of the temporal bone. It transmits the vestibulocochlear nerve and the motor and sensory roots of the facial nerve.

The **internal occipital crest** runs upward in the midline posteriorly from the foramen magnum to the **internal occipital protuberance;** it is attached the small **falx cerebelli** over the **occipital sinus**.

On each side of the internal occipital protuberance is a wide groove for the **transverse sinus**. This groove sweeps around on either side, on the internal surface of the occipital bone, to reach the posteroinferior angle or corner of the parietal bone. The groove now passes onto the mastoid part of the temporal bone; at this point, the transverse sinus becomes the **sigmoid sinus**. The **superior petrosal sinus** runs backward along the upper border of the petrous bone in a narrow groove and drains into the sigmoid sinus. As the sigmoid sinus descends to the jugular foramen, it deeply grooves the back of the petrous bone and the mastoid part of the temporal bone. Here, it lies directly posterior to the mastoid antrum.

Table 5-1 summarizes the important openings in the base of the skull and the structures that pass through them.

Mandible

The mandible, or lower jaw, is the largest and strongest bone of the face, and it articulates with the skull at the **temporomandibular joint** (see Fig. 5-3).

The mandible consists of a horseshoe-shaped **body** and a pair of **rami** (see Fig. 5-1). The body of the mandible meets the ramus on each side at the **angle of the mandible**.

INTRODUCTION TO THE BRAINSTEM

The brainstem is made up of the medulla oblongata, the pons, and the midbrain and occupies the posterior cranial fossa of the skull (Fig. 5-8). It is stalklike in shape and connects the narrow spinal cord with the expanded forebrain (see Atlas Plates 1–8).

The brainstem has three broad functions: (1) It serves as a conduit for the ascending tracts and descending tracts connecting the spinal cord to the different parts of the higher centers in the forebrain; (2) it contains important reflex centers associated with the control of respiration and the cardiovascular system and with the control of consciousness; and (3) it contains the important nuclei of CNs III through XII.

MEDULLA OBLONGATA

The medulla oblongata connects the pons superiorly with the spinal cord inferiorly (see Fig. 5-8). The junction of the medulla and spinal cord is at the origin of the anterior and posterior roots of the first cervical spinal nerve, which corresponds approximately to the level of the foramen magnum. The medulla oblongata is conical in shape, its broad extremity being directed superiorly (Fig. 5-9). The **central** canal of the spinal cord continues upward into the lower half of the medulla; in the upper half of the medulla, it expands as the **cavity** of the fourth ventricle.

On the anterior surface of the medulla is the anterior median fissure, which is continuous inferiorly with the **anterior median fissure** of the spinal cord (see Fig. 5-9A). Swellings on each side of the median fissure are called the **pyramids**. The pyramids are composed of bundles of nerve fibers, called corticospinal fibers, which originate in large nerve cells in the precentral gyrus of the cerebral cortex. The pyramids taper inferiorly, and here the majority of the descending fibers cross over to the opposite side, forming the **decussation of the pyramids**. The **anterior external arcuate fibers** emerge from the anterior median fissure above the decussation and pass laterally over the surface of the medulla oblongata to enter the cerebellum. Posterolateral to the pyramids are the **olives**, which are oval elevations produced by the underlying **inferior olivary nuclei**. In the groove between the pyramid and the olive emerge the rootlets of the hypoglossal nerve. Posterior to the olives are the **inferior cerebellar peduncles**, which connect the medulla to the cerebellum. In the groove between the olive and the inferior cerebellar peduncle emerge the roots of the glossopharyngeal and vagus nerves and the cranial roots of the accessory nerve.

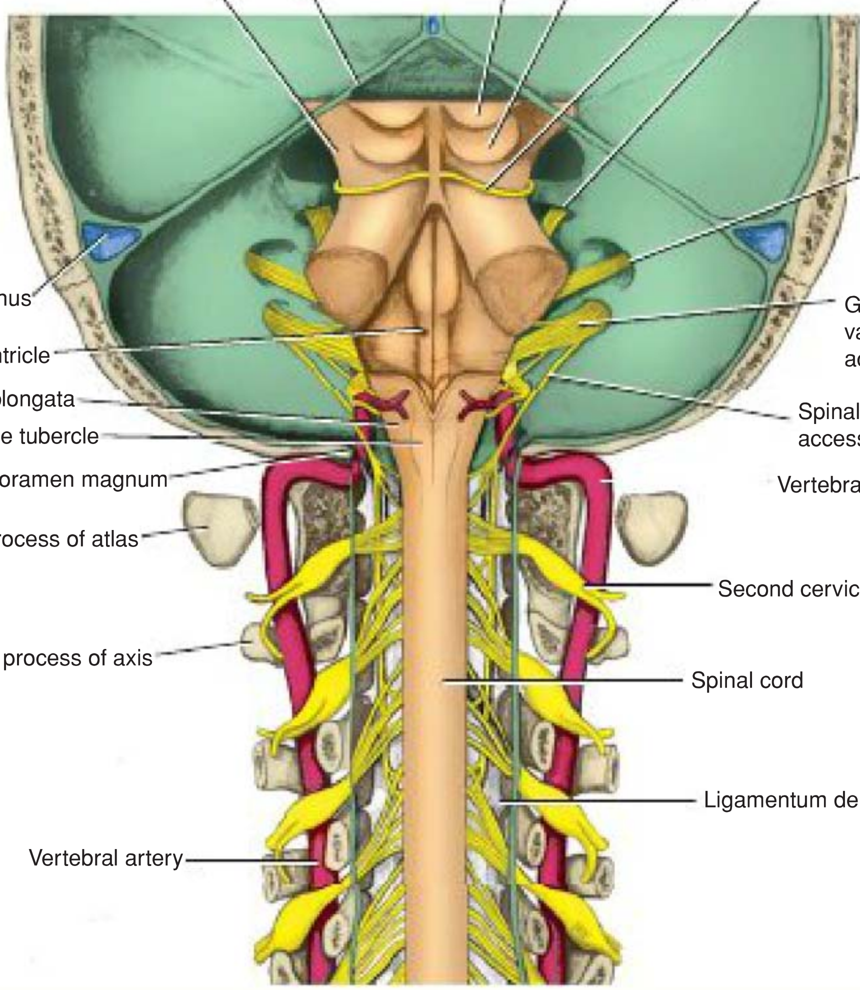

Figure 5-8 Posterior view of the brainstem after removal of the occipital and parietal bones and the cerebrum, the cerebellum, and the roof of the fourth ventricle. Laminae of the upper cervical vertebrae have also been removed.

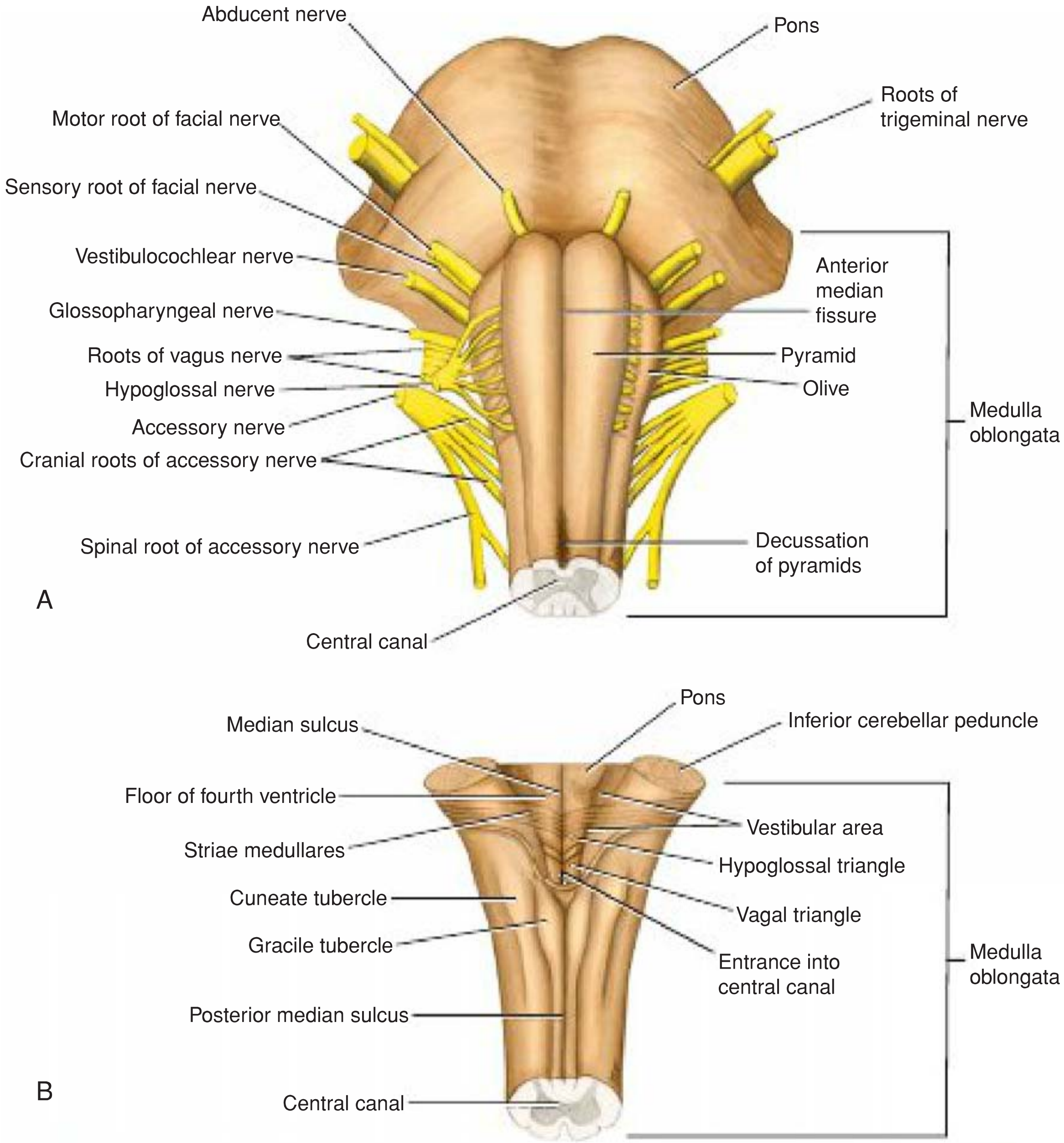

Figure 5-9 Medulla oblongata. **A:** Anterior view. **B:** Posterior view. Note that the roof of the fourth ventricle and the cerebellum have been removed.

The posterior surface of the superior half of the medulla oblongata forms the lower part of the **floor of the fourth ventricle** (see Fig. 5-9B). The posterior surface of the inferior half of the medulla is continuous with the posterior aspect of the spinal cord and possesses a **posterior median sulcus**. On each side of the median sulcus, an elongated swelling, the gracile tubercle, is produced by the underlying **gracile nucleus**. Lateral to the gracile tubercle is a similar swelling, the **cuneate tubercle**, produced by the underlying **cuneate nucleus**.

Internal Structure

As in the spinal cord, the medulla oblongata consists of white matter and gray matter, but a study of transverse sections of this region shows that they have been extensively rearranged. This rearrangement can be explained embryologically by the expansion of the **neural tube** to form the **hindbrain vesicle**, which becomes the fourth ventricle (Fig. 5-10). The extensive lateral spread of the **fourth ventricle** results in an alteration in the position of the derivatives of the **alar** and **basal plates** of the embryo. To assist in understanding this concept, remember that, in the spinal cord, the derivatives of the alar and basal plates are situated posterior and anterior to the **sulcus limitans**, respectively; in the case of the medulla oblongata, they are situated lateral and medial to the sulcus limitans, respectively.

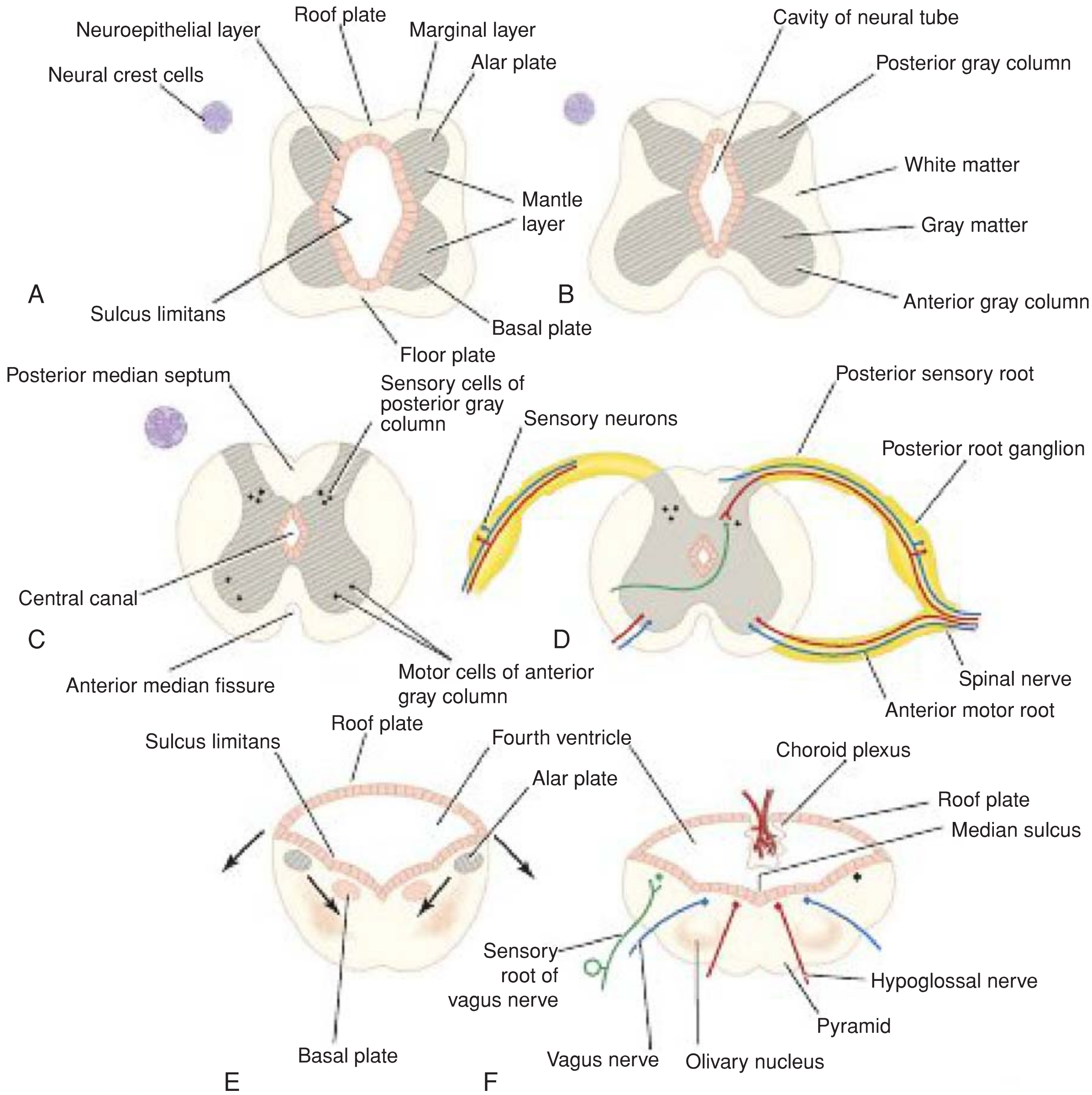

Figure 5-10 Stages in the development of the spinal cord (**A–D**) and the medulla oblongata (**E, F**). The neural crest cells will form the first afferent sensory neurons in the posterior root ganglia of the spinal nerves and the sensory ganglia of the cranial nerves.

The internal structure of the medulla oblongata is considered at four levels: (1) level of decussation of pyramids, (2) level of decussation of lemnisci, (3) level of the olives, and (4) level just inferior to the pons. Table 5-2 compares the different levels of the medulla oblongata and the major structures present at each level.

Level of Pyramid Decussation

A transverse section through the inferior half of the medulla oblongata (Figs. 5-11A and 5-12) passes through the **decussation** of the pyramids, the great motor decussation. In the superior part of the medulla, the corticospinal fibers occupy and form the pyramid, but inferiorly, about three-fourths of the fibers cross the median plane and continue down the spinal cord in the lateral white column as the **lateral** corticospinal tract. As these fibers cross the midline, they sever the continuity between the anterior column of the gray matter of the spinal cord and the gray matter that surrounds the central canal.

The **fasciculus gracilis** and the **fasciculus cuneatus** continue to ascend superiorly posterior to the central gray matter. The **nucleus gracilis** and the **nucleus cuneatus** appear as posterior extensions of the central gray matter.

Table 5-2 Levels of the Medulla Oblongata and Their Major Structures[a]

Level	Cavity	Nuclei	Motor Tracts	Sensory Tracts
Decussation of pyramids	Central canal	Nucleus gracilis, nucleus cuneatus, spinal nucleus of CN V, accessory nucleus	Decussation of corticospinal tracts, pyramids	Spinal tract of CN V, posterior spinocerebellar tract, lateral spinothalamic tract, anterior spinocerebellar tract
Decussation of medial lemnisci	Central canal	Nucleus gracilis, nucleus cuneatus, spinal nucleus of CN V, accessory nucleus, hypoglossal nucleus	Pyramids	Decussation of medial lemnisci, fasciculus gracilis, fasciculus cuneatus, spinal tract of CN V, posterior spinocerebellar tract, lateral spinothalamic tract, anterior spinocerebellar tract
Olives, inferior cerebellar peduncle	Fourth ventricle	Inferior olivary nucleus, spinal nucleus of CN V, vestibular nucleus, glossopharyngeal nucleus, vagal nucleus, hypoglossal nucleus, nucleus ambiguus, nucleus of tractus solitarius	Pyramids	Medial longitudinal fasciculus, tectospinal tract, medial lemniscus, spinal tract of CN V, lateral spinothalamic tract, anterior spinocerebellar tract
Just inferior to pons	Fourth ventricle	Lateral vestibular nucleus, cochlear nuclei		No major changes in distribution of gray and white matter

[a]Note that the reticular formation is present at all levels.
CN, cranial nerve.

The **substantia gelatinosa** in the posterior gray column of the spinal cord becomes continuous with the inferior end of the **nucleus of the spinal tract of the trigeminal nerve**. The fibers of the tract of the nucleus are situated between the nucleus and the surface of the medulla oblongata.

The lateral and anterior white columns of the spinal cord are easily identified in these sections, and their fiber arrangement is unchanged.

Level of Lemnisci Decussation

A transverse section through the inferior half of the medulla oblongata, a short distance above the level of the decussation of the pyramids, passes through the **decussation of lemnisci**, the great sensory decussation (Fig. 5-13; also see Fig. 5-11B). The decussation of the lemnisci takes place anterior to the central gray matter and posterior to the pyramids. It should be understood that the lemnisci have been formed from the **internal arcuate fibers**, which have emerged from the anterior aspects of the **nucleus gracilis** and **nucleus cuneatus**. The internal arcuate fibers first travel anteriorly and laterally around the central gray matter. They then curve medially toward the midline, where they decussate with the corresponding fibers of the opposite side.

The **nucleus of the spinal tract of the trigeminal nerve** lies lateral to the internal arcuate fibers. The **spinal tract of the trigeminal nerve** lies lateral to the nucleus.

The **lateral** and **anterior spinothalamic tracts** and the **spinotectal tracts** occupy an area lateral to the decussation of the lemnisci. They are very close to one another and collectively are known as the **spinal lemniscus**. The **spinocerebellar**, **vestibulospinal**, and the **rubrospinal tracts** are situated in the anterolateral region of the medulla oblongata.

Level of the Olives

A transverse section through the olives passes across the inferior part of the fourth ventricle (Figs. 5-14 and 5-15). The amount of gray matter has increased at this level owing to the presence of the olivary nuclear complex; the nuclei of the vestibulocochlear, glossopharyngeal, vagus, accessory, and hypoglossal nerves; and the arcuate nuclei.

Olivary Nuclear Complex

The largest nucleus of this complex is the **inferior olivary nucleus**. The gray matter is shaped like a crumpled bag with its mouth directed medially; it is responsible for the elevation on the surface of the medulla called the **olive**. Smaller **dorsal** and **medial accessory olivary nuclei** also are present. The cells of the inferior olivary nucleus send fibers medially across the midline to enter the cerebellum through the inferior cerebellar peduncle. Afferent fibers reach the inferior olivary nuclei from the spinal cord (the **spino-olivary tracts**) and from the cerebellum and cerebral cortex. The function of the olivary nuclei is associated with voluntary muscle movement.

Vestibulocochlear Nuclei

The **vestibular nuclear complex** is made up of the following nuclei: (1) **medial vestibular nucleus**, (2) **inferior vestibular nucleus**, (3) **lateral vestibular nucleus**, and (4) **superior vestibular nucleus**. The details of these nuclei and their connections are discussed later.

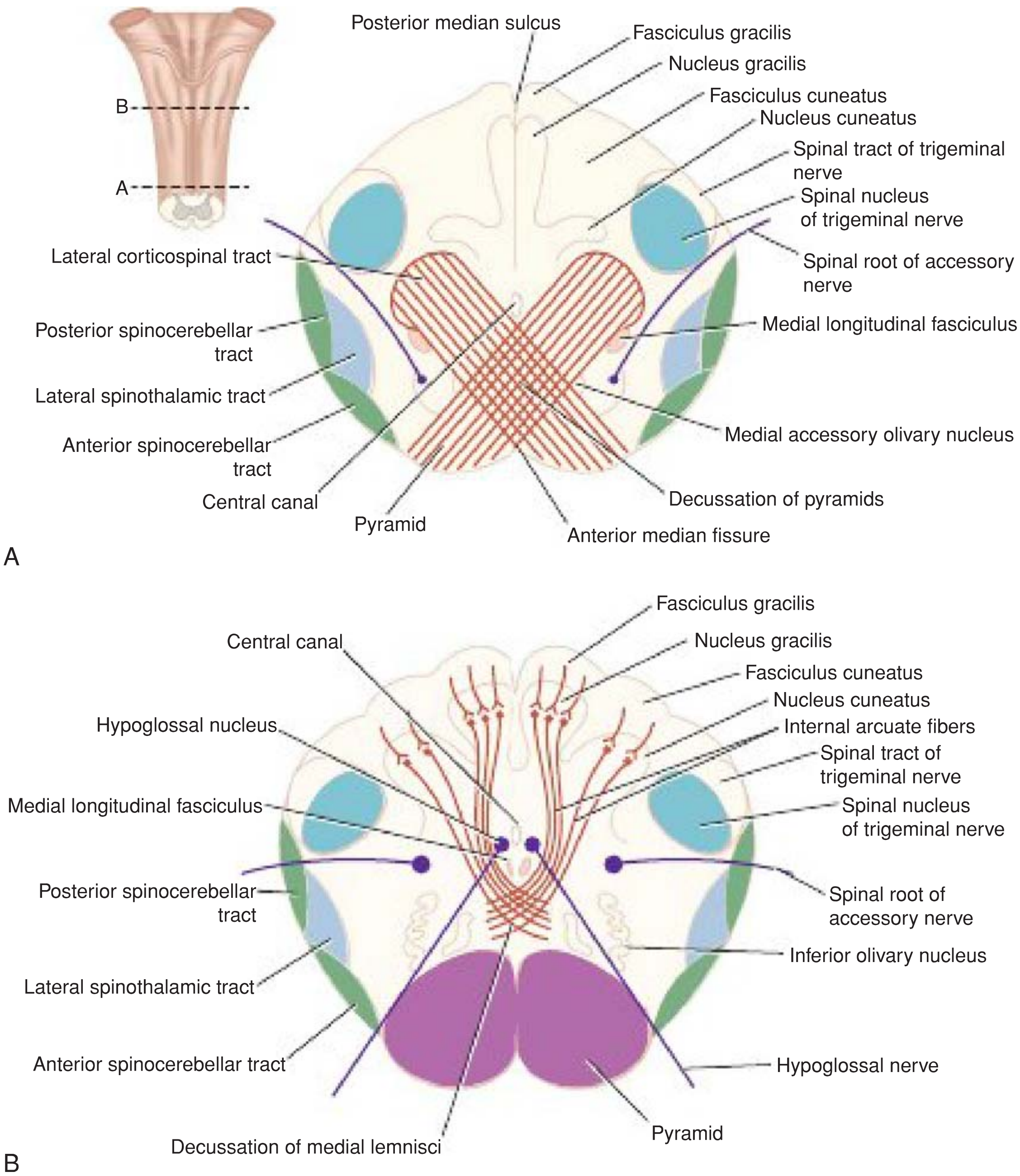

Figure 5-11 Transverse sections of the medulla oblongata. **A:** Level of decussation of the pyramids. **B:** Level of decussation of the medial lemnisci.

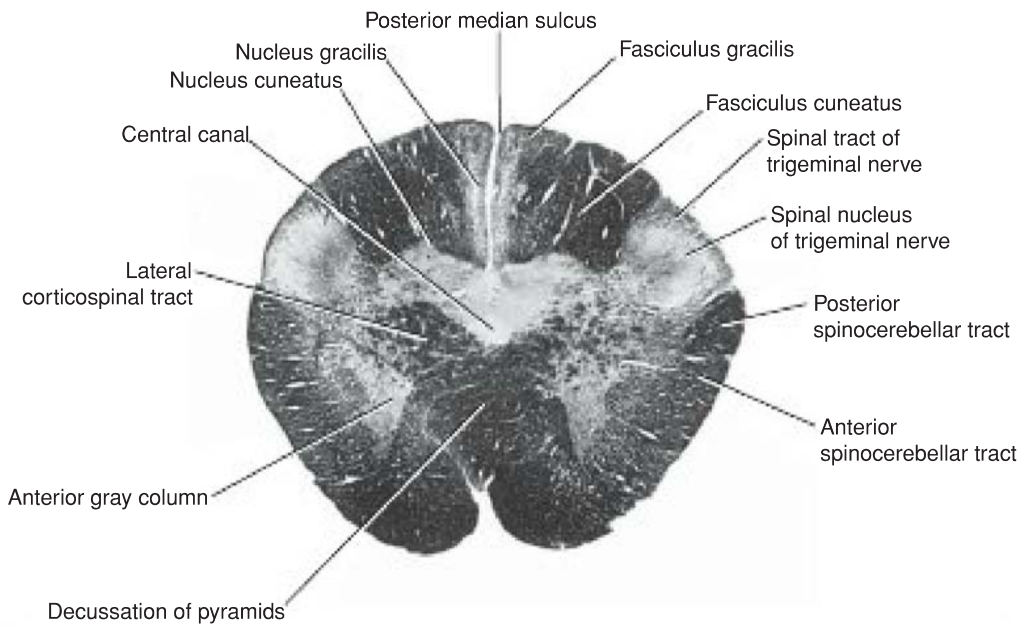

Figure 5-12 Transverse section of the medulla oblongata at the level of decussation of the pyramids. (Weigert stain.)

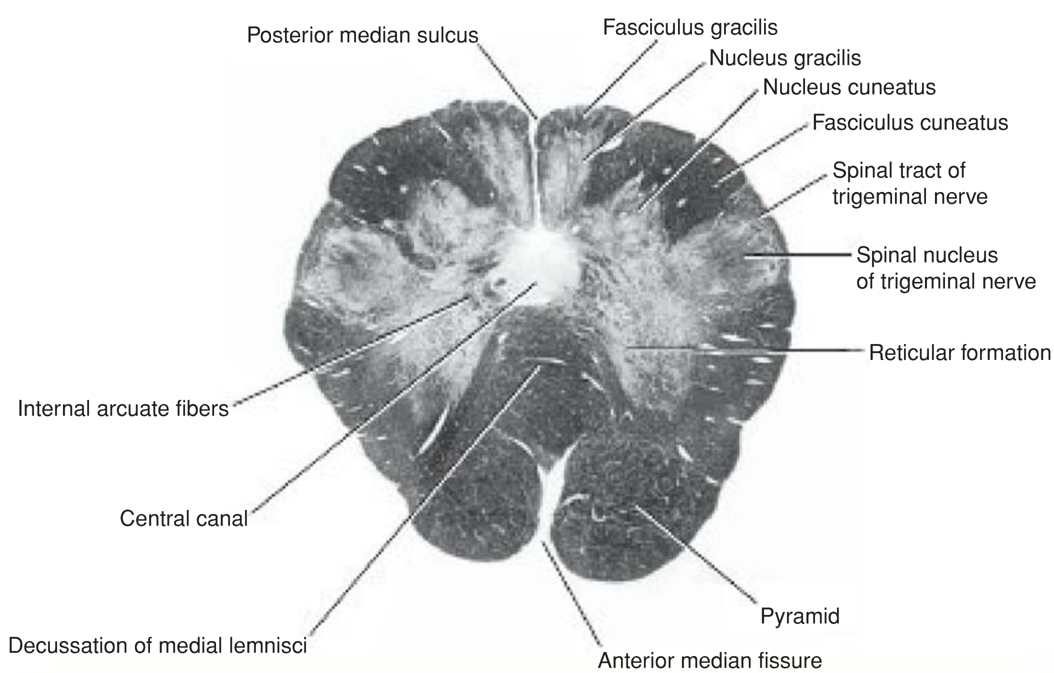

Figure 5-13 Transverse section of the medulla oblongata at the level of decussation of the medial lemnisci. (Weigert stain.)

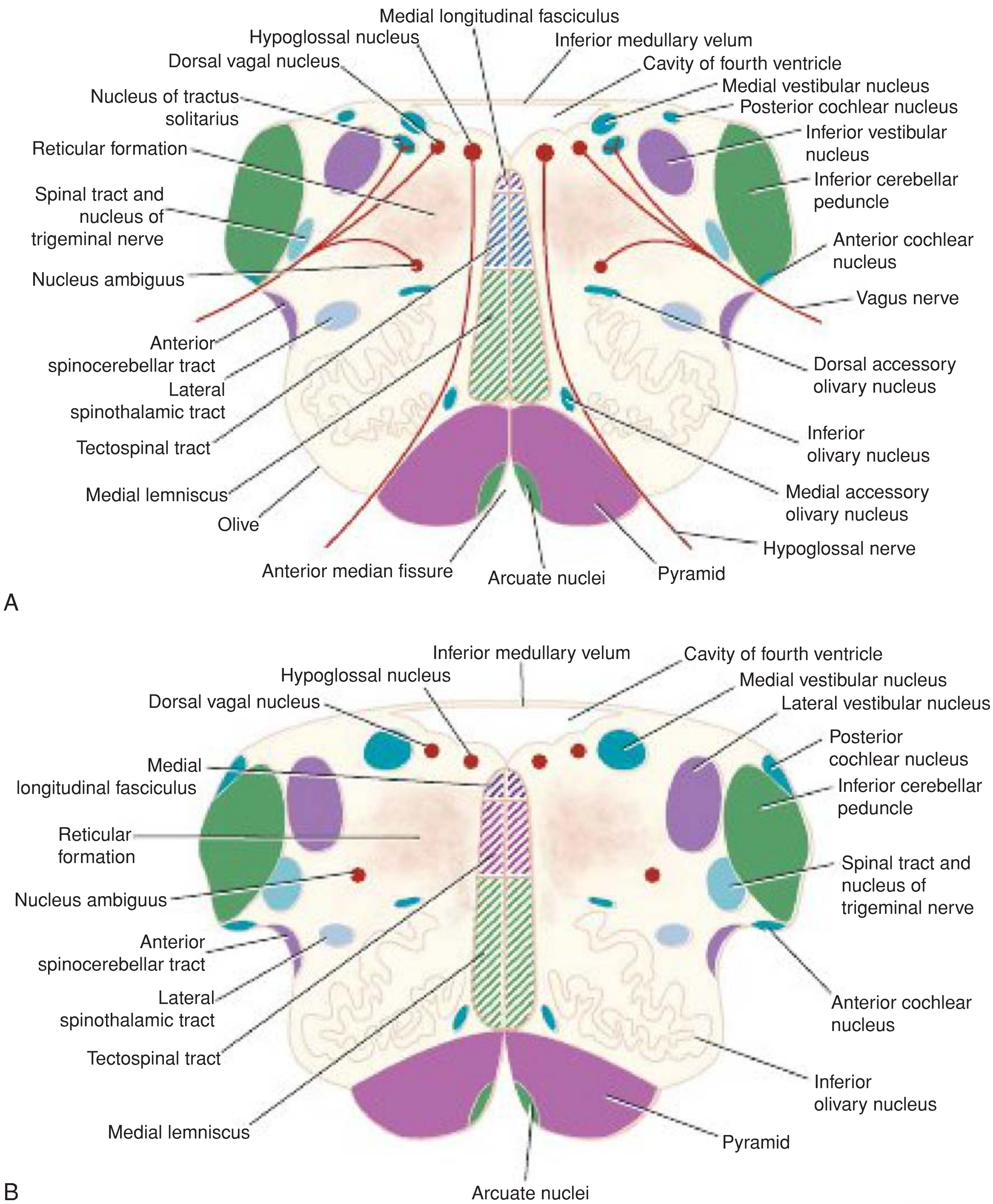

Figure 5-14 Transverse sections of the medulla oblongata at the level of the middle of the olivary nuclei (**A**) and the superior part of the olivary nuclei just inferior to the pons (**B**).

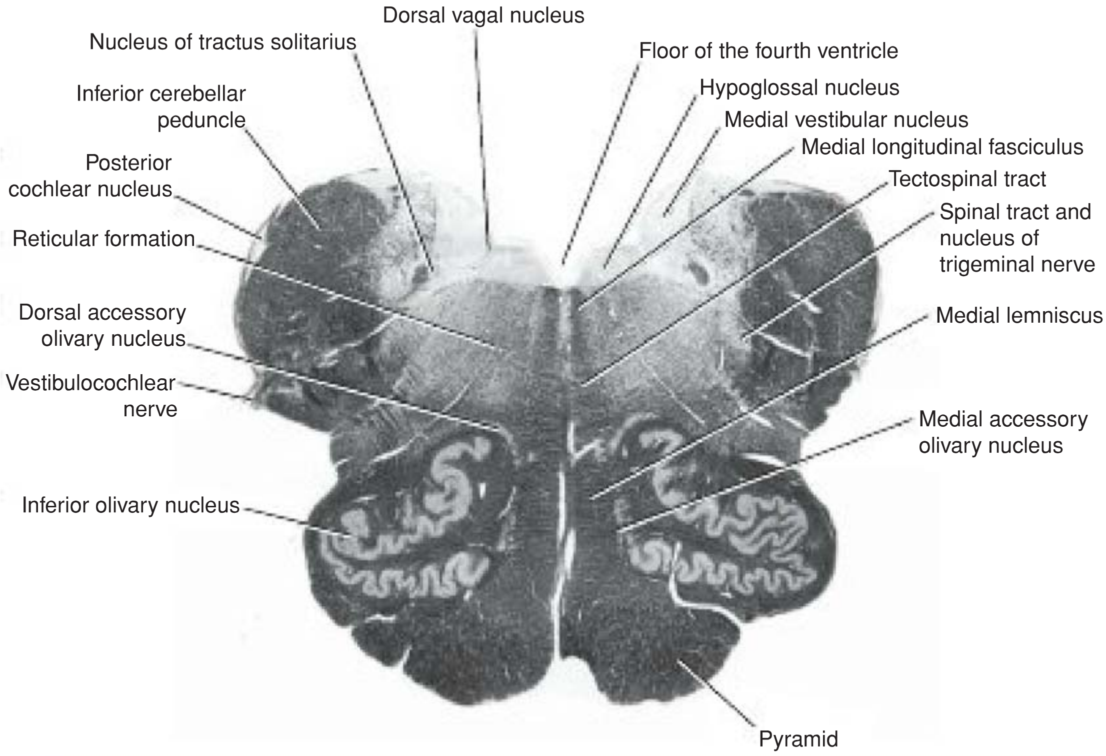

Figure 5-15 Transverse section of the medulla oblongata at the level of the middle of the olivary nuclei. (Weigert stain.)

The medial and inferior vestibular nuclei can be seen on section at this level.

The two **cochlear nuclei** are the **anterior cochlear nucleus**, situated on the anterolateral aspect of the inferior cerebellar peduncle, and the **posterior cochlear nucleus**, situated on the posterior aspect of the peduncle lateral to the floor of the fourth ventricle. The connections of these nuclei are described later (see pp. 204-207).

Nucleus Ambiguus

The nucleus ambiguus consists of large motor neurons and is situated deep within the reticular formation (Fig. 5-16; also see Fig. 5-14). The emerging nerve fibers join the glossopharyngeal, vagus, and cranial part of the accessory nerve and are distributed to voluntary skeletal muscle.

Central Gray Matter

The central gray matter lies beneath the floor of the fourth ventricle at this level (see Figs. 5-14 and 5-15). Passing from medial to lateral (see Fig. 5-16), the following important structures may be recognized: (1) the **hypoglossal nucleus**, (2) the **dorsal nucleus of the vagus**, (3) the **nucleus of the tractus solitarius**, and (4) the **medial** and **inferior vestibular nuclei**. The nucleus ambiguus has become deeply placed within the reticular formation (see Fig. 5-14). The connections and functional significance of these nuclei are described in Chapter 11.

The arcuate nuclei are thought to be inferiorly displaced **pontine nuclei** (see pp. 206-207) and are situated on the anterior surface of the pyramids. They receive nerve fibers from the cerebral cortex and send efferent fibers to the cerebellum through the **anterior external arcuate fibers**.

The **pyramids** containing the corticospinal and some corticonuclear fibers are situated in the anterior part of the medulla separated by the anterior median fissure (see Figs. 5-14 and 5-15); the corticospinal fibers descend to the spinal cord, and the corticonuclear fibers are distributed to the motor nuclei of the CNs situated within the medulla.

The **medial lemniscus** forms a flattened tract on each side of the midline posterior to the pyramid (see Figs. 5-7 and 5-15). These fibers emerge from the decussation of the lemnisci and convey sensory information to the thalamus.

The **medial longitudinal fasciculus** forms a small tract of nerve fibers situated on each side of the midline posterior to the medial lemniscus and anterior to the hypoglossal nucleus (see Figs. 5-14 and 5-15). It consists of ascending and descending fibers, the connections of which are described on page 205.

The **inferior cerebellar peduncle** is situated in the posterolateral corner of the section on the lateral side of the fourth ventricle.

The **spinal tract of the trigeminal nerve** and **its nucleus** are situated on the anteromedial aspect of the inferior cerebellar peduncle.

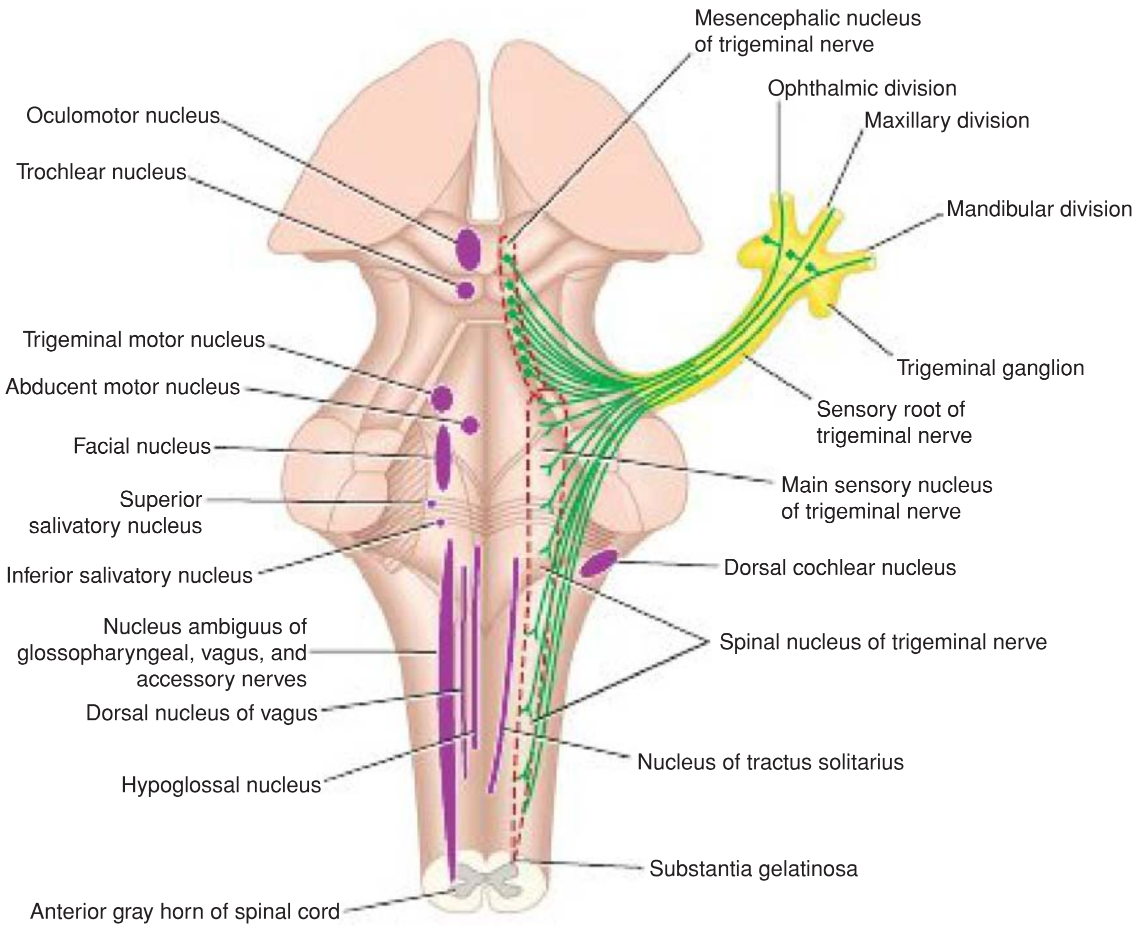

Figure 5-16 Position of the cranial nerve nuclei within the brainstem. The hatched area indicates the position of the vestibular nuclei.

The **anterior spinocerebellar tract** is situated near the surface in the interval between the inferior olivary nucleus and the nucleus of the spinal tract of the trigeminal nerve. The **spinal lemniscus**, consisting of the **anterior spinothalamic**, the **lateral spinothalamic**, and **spinotectal tracts**, is deeply placed.

The **reticular formation**, consisting of a diffuse mixture of nerve fibers and small groups of nerve cells, is deeply placed posterior to the olivary nucleus. The reticular formation represents, at this level, only a small part of this system, which is also present in the pons and midbrain.

The **glossopharyngeal**, **vagus**, and **cranial part of the accessory nerves** can be seen running forward and laterally through the reticular formation (see Fig. 5-14). The nerve fibers emerge between the olives and the inferior cerebellar peduncles. The **hypoglossal nerves** also run anteriorly and laterally through the reticular formation and emerge between the pyramids and the olives.

Level Just Inferior to the Pons

In comparison to the previous level, little changes in the distribution of the gray and white matter (see Figs. 5-14 and 5-16). The lateral vestibular nucleus has replaced the inferior vestibular nucleus, and the cochlear nuclei now are visible on the anterior and posterior surfaces of the inferior cerebellar peduncle.

PONS

The pons is anterior to the cerebellum (Fig. 5-17; see also Fig. 6-1) and connects the medulla oblongata to the midbrain. It is about 1 inch (2.5 cm) long and owes its name to the appearance presented on the anterior surface, which is that of a bridge connecting the right and left cerebellar hemispheres.

The anterior surface is convex from side to side and shows many transverse fibers that converge on each side to form the **middle cerebellar peduncle**. A shallow groove in the midline, the **basilar groove**, lodges the basilar artery. On the anterolateral surface of the pons, the **trigeminal nerve** emerges on each side. Each nerve consists of a smaller, medial part, known as the **motor root**, and a larger, lateral part, known as the **sensory root**. In the groove between the pons and the medulla oblongata, from medial to lateral, the **abducens**, **facial**, and **vestibulocochlear nerves** emerge.

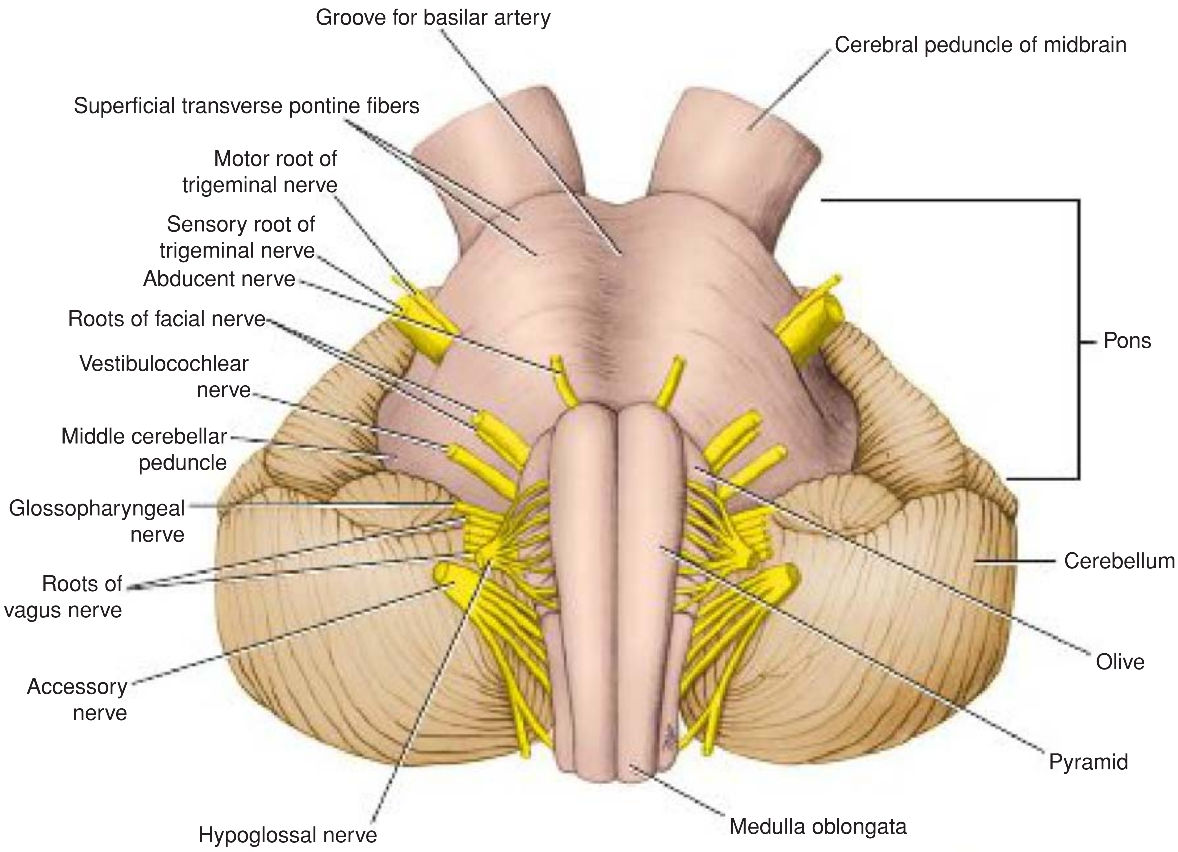

Figure 5-17 Anterior surface of the brainstem showing the pons.

The posterior surface of the pons is hidden from view by the cerebellum (Fig. 5-18). It forms the upper half of the floor of the fourth ventricle and is triangular in shape. The posterior surface is limited laterally by the **superior cerebellar peduncles** and is divided into symmetrical halves by a **median sulcus**. Lateral to this sulcus is an elongated elevation, the **medial eminence**, which is bounded laterally by a sulcus, the **sulcus limitans**. The inferior end of the medial eminence is slightly expanded to form the **facial colliculus**, which is produced by the root of the facial nerve winding around the nucleus of the abducens nerve (Fig. 5-19). The floor of the superior part of the **sulcus limitans** is bluish-gray in color and is called the **substantia ferruginea**; it owes its color to a group of deeply pigmented nerve cells. Lateral to the sulcus limitans is the **area vestibuli** produced by the underlying vestibular nuclei (see Fig. 5-18).

Internal Structure

For purposes of description, the pons is commonly divided into a posterior part, the **tegmentum**, and an anterior **basal part** by the transversely running fibers of the **trapezoid body** (see Fig. 5-19).

The structure of the pons may be studied at two levels: (1) transverse section through the caudal part, passing through the facial colliculus, and (2) transverse section through the cranial part, passing through the trigeminal nuclei. Table 5-3 compares the two levels of the pons and the major structures present at each level.

Transverse Section Through the Caudal Part

The **medial lemniscus** rotates as it passes from the medulla into the pons. It is situated in the most anterior part of the tegmentum, with its long axis running transversely. The medial lemniscus is accompanied by the spinal and lateral lemnisci.

The **facial nucleus** lies posterior to the lateral part of the medial lemniscus. The fibers of the facial nerve wind around the **nucleus of the abducens nerve**, producing the **facial colliculus**. The fibers of the facial nerve then pass anteriorly between the facial nucleus and the superior end of the nucleus of the spinal tract of the trigeminal nerve.

The **medial longitudinal fasciculus** is situated beneath the floor of the fourth ventricle on either side of the midline. The medial longitudinal fasciculus is the main pathway that connects the vestibular and cochlear nuclei with the nuclei controlling the extraocular muscles (oculomotor, trochlear, and abducens nuclei).

The **medial vestibular nucleus** is situated lateral to the abducens nucleus and is in close relationship to the inferior cerebellar peduncle. The superior part of the

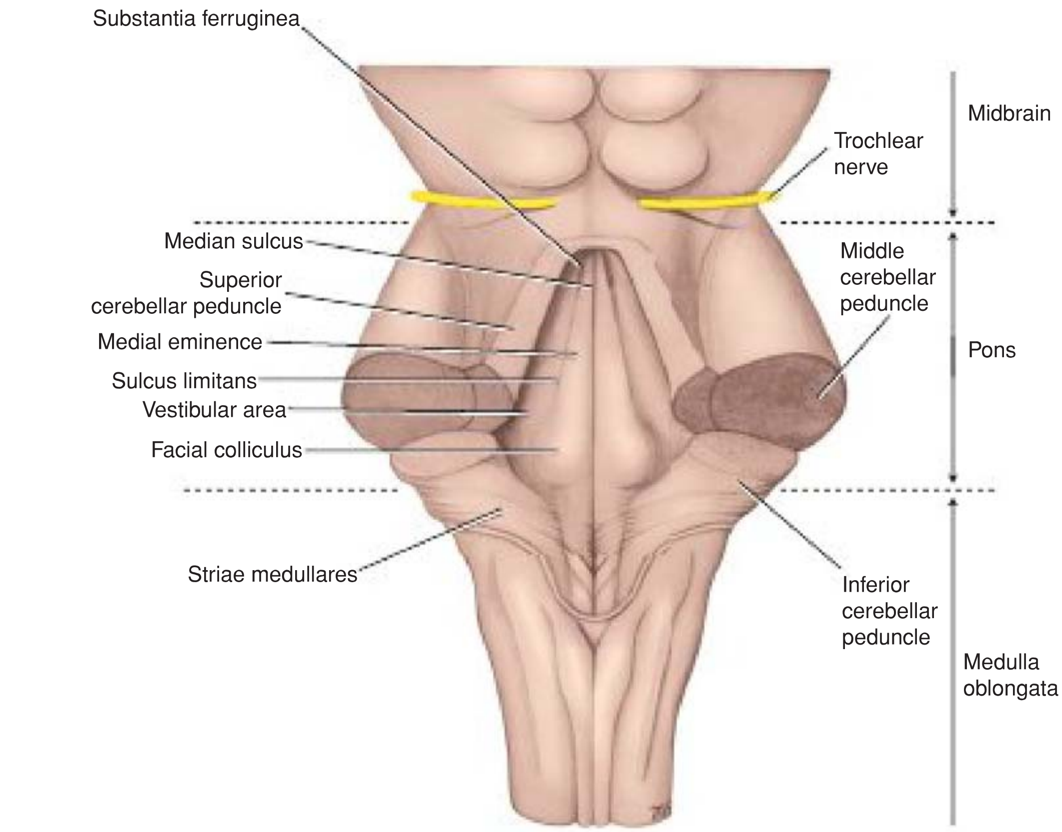

Figure 5-18 Posterior surface of the brainstem showing the pons. The cerebellum has been removed.

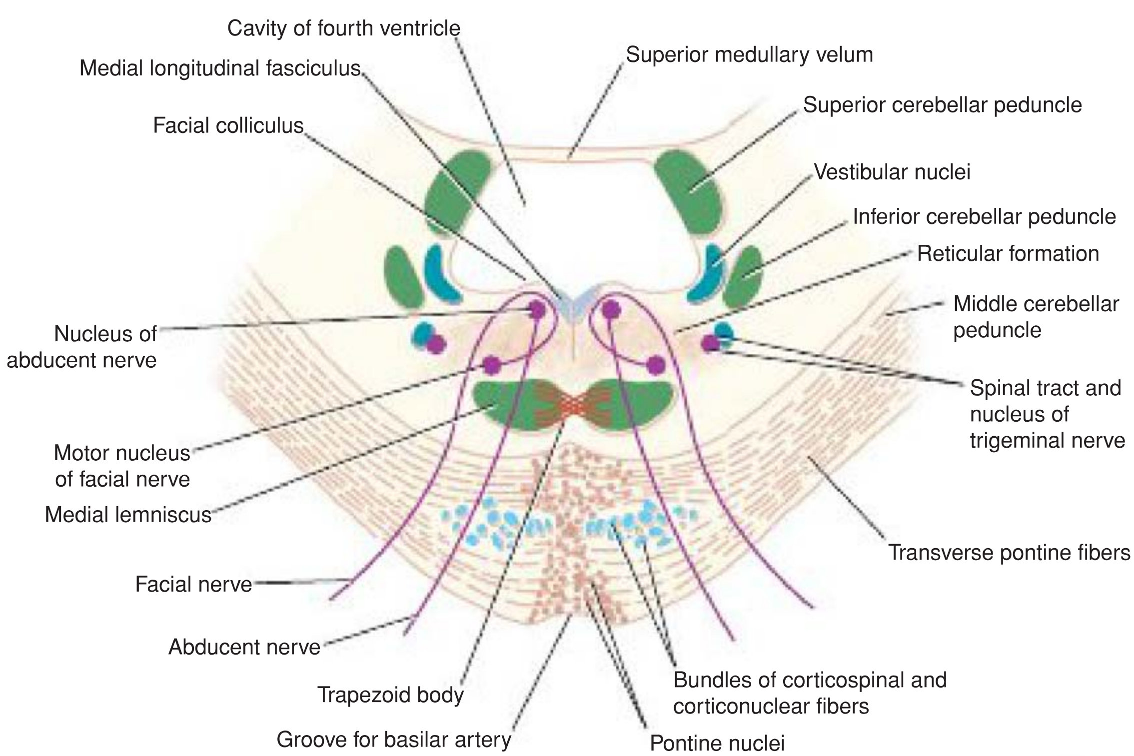

Figure 5-19 Transverse section through the caudal part of the pons at the level of the facial colliculus.

Table 5-3 Levels of the Pons and Their Major Structures[a]

Level	Cavity	Nuclei	Motor Tracts	Sensory Tracts
Facial colliculus	Fourth ventricle	Facial nucleus, abducens nucleus, medial vestibular nucleus, spinal nucleus of CN V, pontine nuclei, trapezoid nuclei	Corticospinal and corticonuclear tracts, transverse pontine fibers, medial longitudinal fasciculus	Spinal tract of CN V; lateral, spinal, and medial lemnisci
Trigeminal nuclei	Fourth ventricle	Main sensory and motor nucleus of CN V, pontine nuclei, trapezoid nuclei	Corticospinal and corticonuclear tracts, transverse pontine fibers, medial longitudinal fasciculus	Lateral, spinal, and medial lemnisci

[a]Note that the reticular formation is present at all levels.
CN, cranial nerve.

lateral and the inferior part of the superior vestibular nucleus are found at this level. The **posterior** and **anterior cochlear nuclei** are also found at this level.

The **spinal nucleus of the trigeminal nerve** and its tract lie on the anteromedial aspect of the inferior cerebellar peduncle.

The **trapezoid body** is made up of fibers derived from the cochlear nuclei and the nuclei of the trapezoid body. They run transversely in the anterior part of the tegmentum (see p. 210).

The basilar part of the pons, at this level, contains small masses of nerve cells called **pontine nuclei**. The **corticopontine fibers** of the crus cerebri of the midbrain terminate in the pontine nuclei. The axons of these cells give origin to the **transverse fibers** of the pons, which cross the midline and intersect the corticospinal and corticonuclear tracts, breaking them up into small bundles. The transverse fibers of the pons enter the middle cerebellar peduncle and are distributed to the cerebellar hemisphere. This connection forms the main pathway linking the cerebral cortex to the cerebellum.

Transverse Section Through the Cranial Part

The internal structure of the cranial part of the pons is similar to that seen at the caudal level (Figs. 5-20 to 5-22), but it now contains the motor and principal sensory nuclei of the trigeminal nerve.

The **motor nucleus of the trigeminal nerve** is situated beneath the lateral part of the fourth ventricle within the reticular formation (see Figs. 5-20 and 5-21). The emerging motor fibers travel anteriorly through

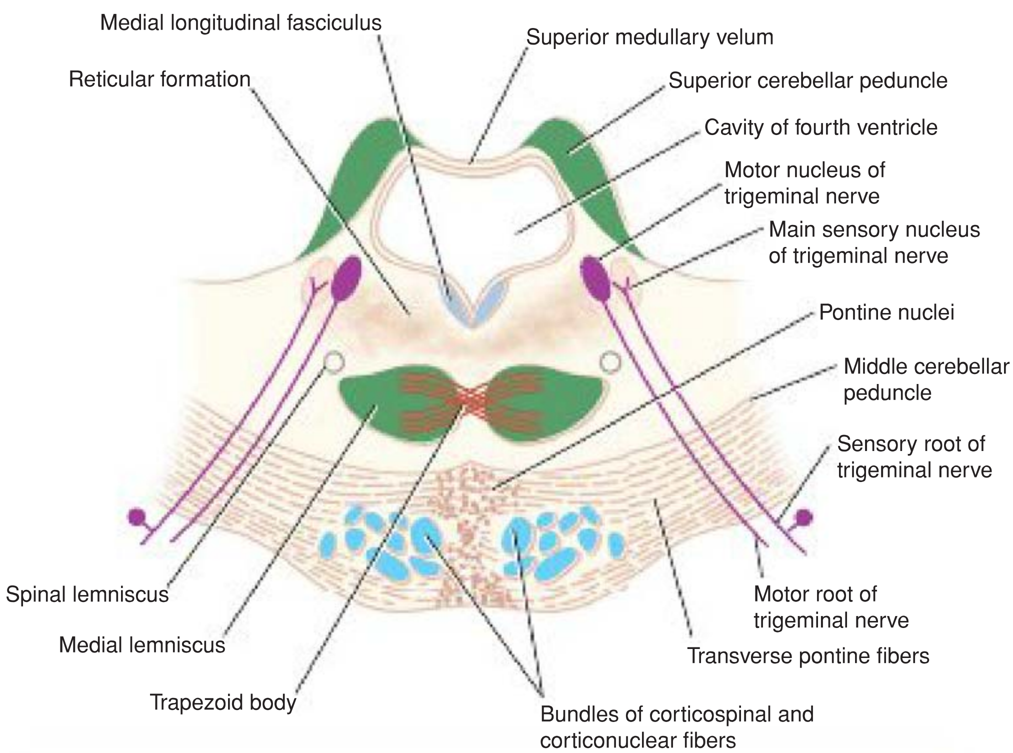

Figure 5-20 Transverse section through the pons at the level of the trigeminal nuclei.

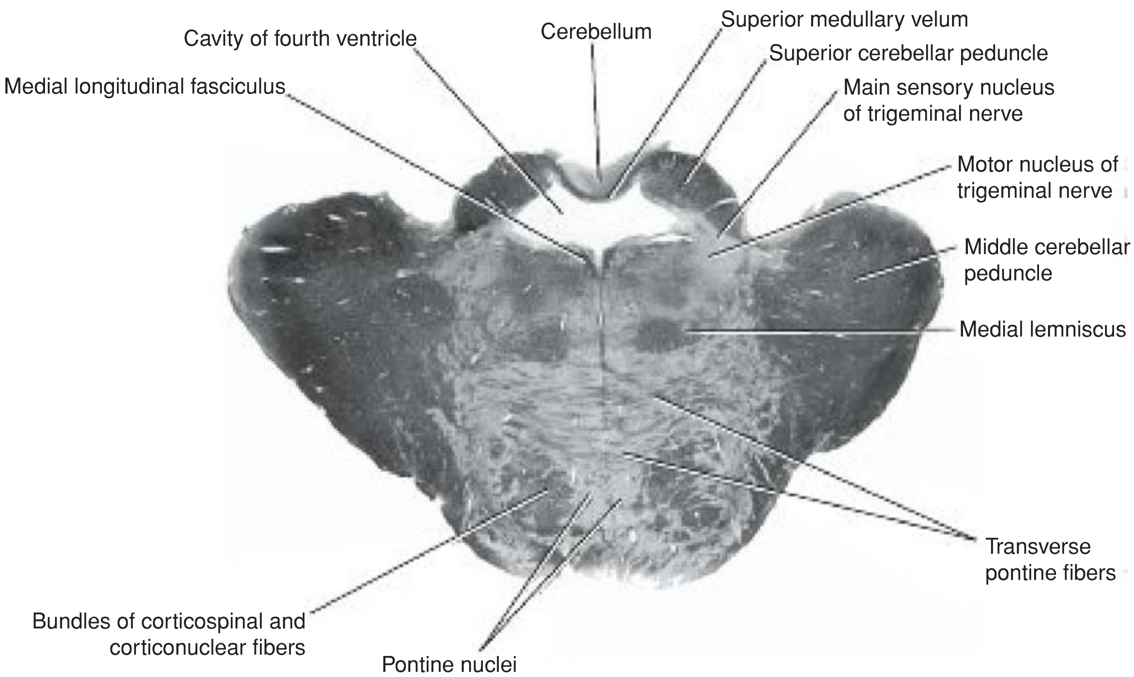

Figure 5-21 Photomicrograph of a transverse section of the pons at the level of the trigeminal nuclei.

the substance of the pons and exit on its anterior surface.

The **principal** sensory nucleus of the trigeminal nerve is situated on the lateral side of the motor nucleus; it is continuous inferiorly with the nucleus of the spinal tract. The entering sensory fibers travel through the substance of the pons and lie lateral to the motor fibers (see Fig. 5-20).

The **superior cerebellar peduncle** is situated posterolateral to the motor nucleus of the trigeminal nerve (see Figs. 5-20 and 5-21). It is joined by the **anterior spinocerebellar tract**.

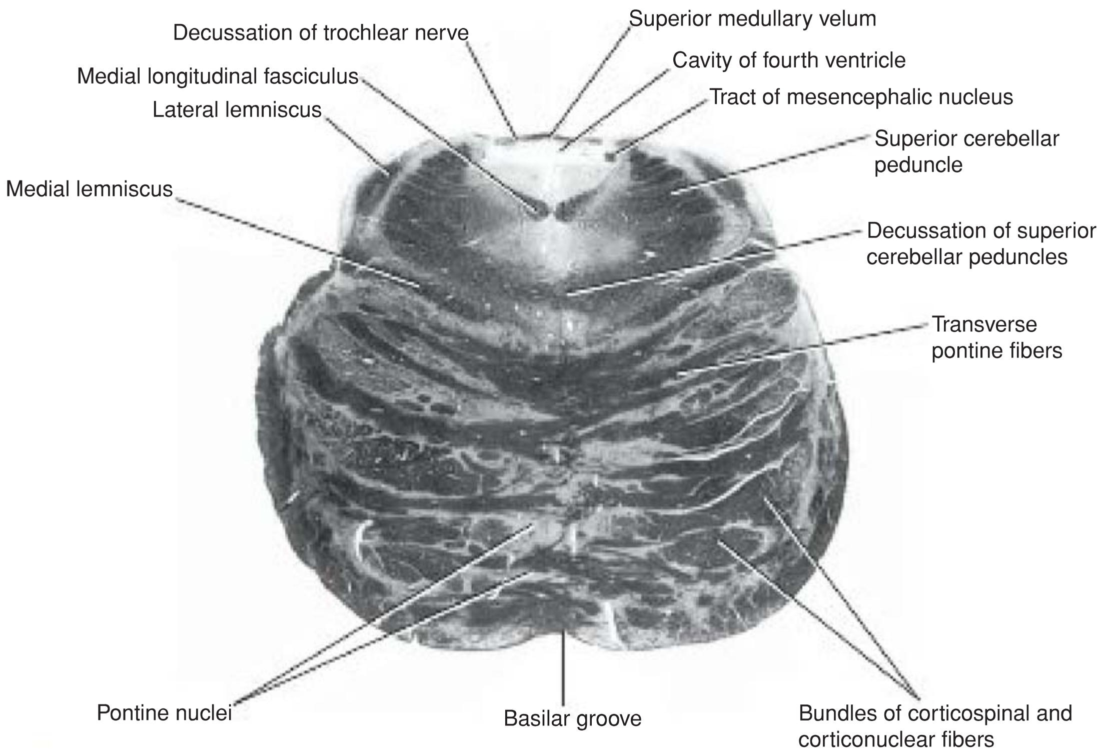

Figure 5-22 Photomicrograph of a transverse section of the most rostral part of the pons.

The **trapezoid body** and the **medial lemniscus** are situated in the same position as they were in the previous section (see Fig. 5-20). The **lateral** and **spinal lemnisci** lie at the lateral extremity of the medial lemniscus (see Figs. 5-20 and 5-22).

MIDBRAIN

The midbrain measures about 0.8 in (2 cm) in length and connects the pons and cerebellum with the forebrain (Fig. 5-23). Its long axis inclines anteriorly as it ascends through the opening in the tentorium cerebelli. The midbrain is traversed by a narrow channel, the **cerebral aqueduct**, which is filled with cerebrospinal fluid (Figs. 5-24 to 5-28).

On the posterior surface are four **colliculi** (corpora quadrigemina). These are rounded eminences that are divided into superior and inferior pairs by a vertical and a transverse groove (see Fig. 5-26). The superior colliculi are centers for visual reflexes (see p. 213), and the inferior colliculi are lower auditory centers. In the midline below the inferior colliculi, the **trochlear** nerves emerge. These are small-diameter nerves that wind around the lateral aspect of the midbrain to enter the lateral wall of the cavernous sinus.

On the lateral aspect of the midbrain, the superior and inferior brachia ascend in an anterolateral direction (see Fig. 5-23B). The **superior brachium** passes from the superior colliculus to the lateral geniculate body and the optic tract. The **inferior brachium** connects the inferior colliculus to the **medial geniculate body**.

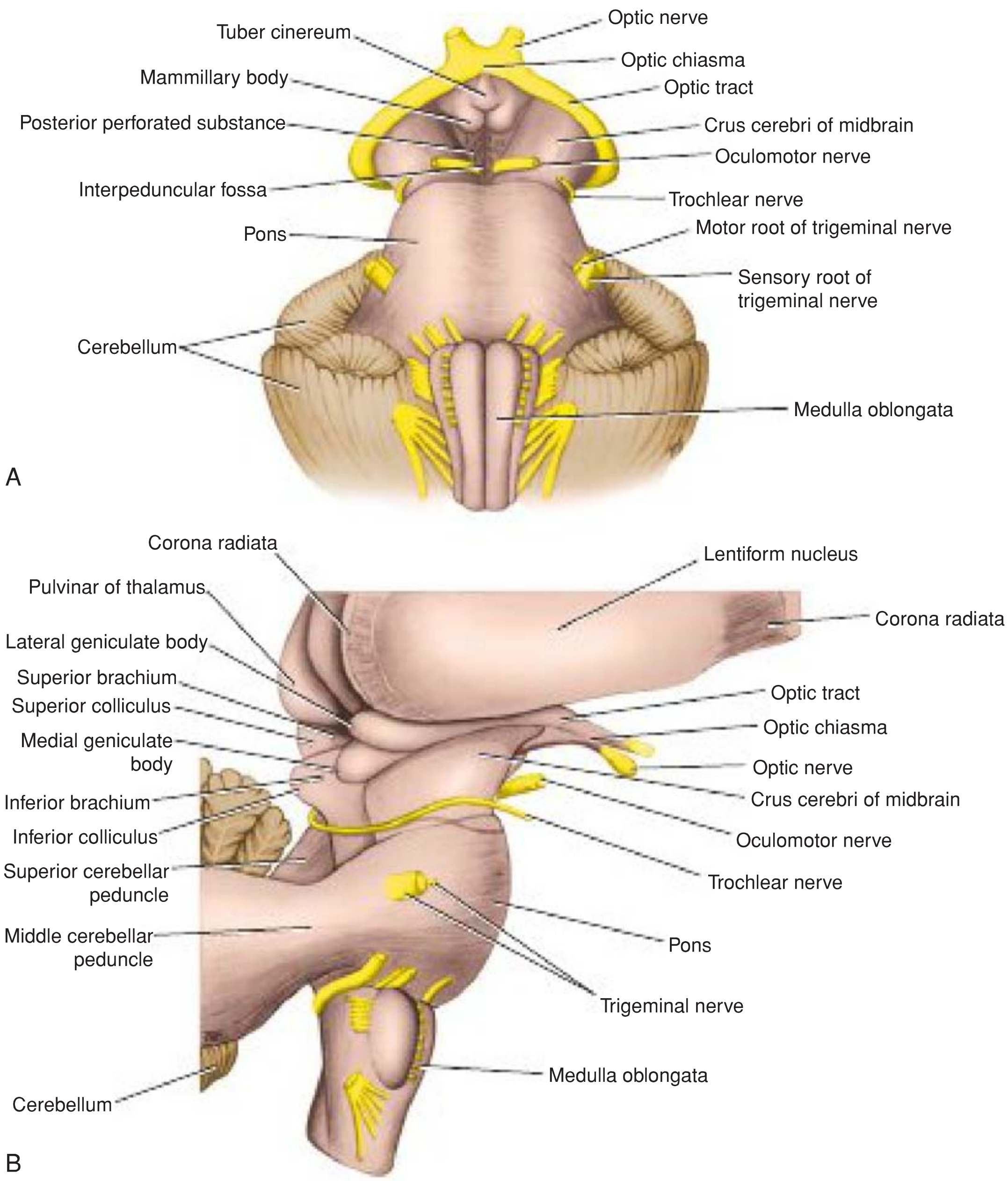

Figure 5-23 The midbrain. **A:** Anterior view. **B:** Lateral view.

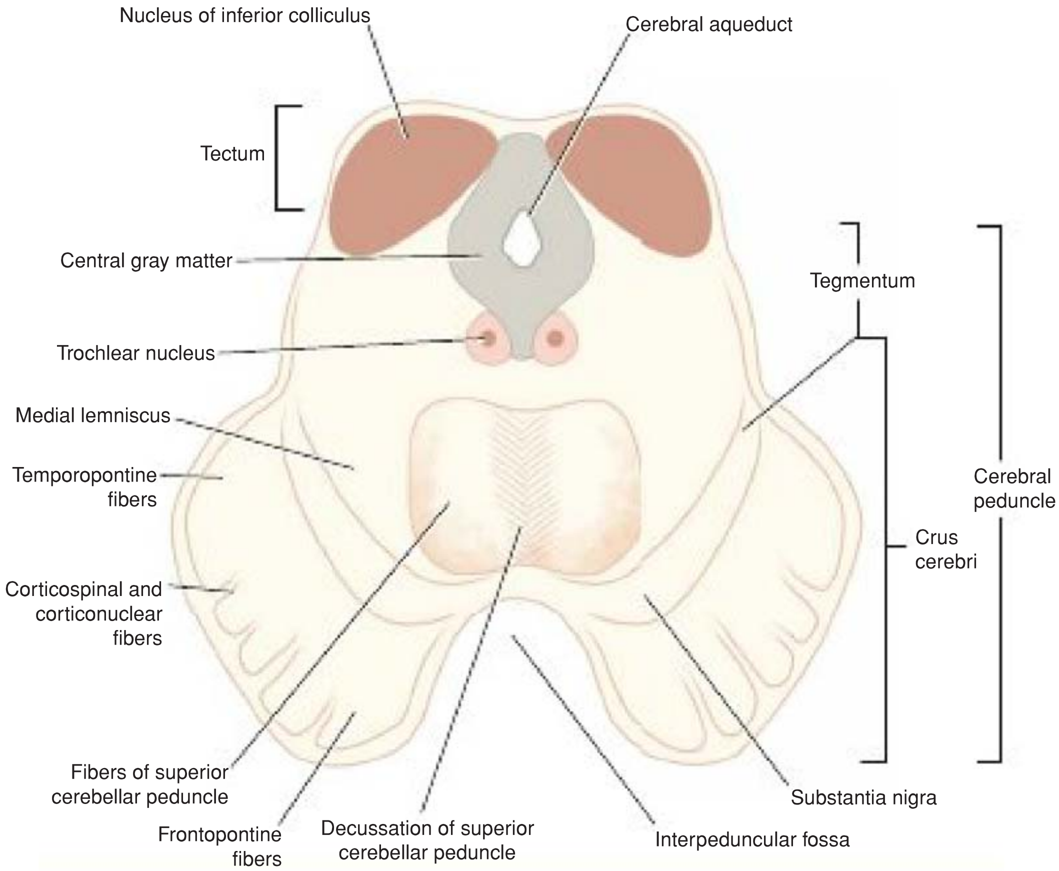

Figure 5-24 Transverse section of the midbrain through the inferior colliculi shows the division of the midbrain into the tectum and the cerebral peduncles. Note that the cerebral peduncles are subdivided by the substantia nigra into the tegmentum and the crus cerebri.

On the anterior aspect of the midbrain, a deep depression in the midline, the **interpeduncular fossa**, is bounded on either side by the **crus cerebri**. Many small blood vessels perforate the floor of the interpeduncular fossa, and this region is termed the **posterior perforated substance** (see Fig. 5-23A). The oculomotor nerve emerges from a groove on the medial side of the crus cerebri and passes forward in the lateral wall of the cavernous sinus.

Internal Structure

The midbrain comprises two lateral halves, called the **cerebral peduncles**; each of these is divided into an anterior part, the **crus cerebri**, and a posterior part, the **tegmentum**, by a pigmented band of gray matter, the **substantia nigra** (see Figs. 5-24 and 5-25). The narrow cavity of the midbrain is the **cerebral aqueduct**, which connects the third and fourth ventricles. The **tectum** is the part of the midbrain posterior to the cerebral aqueduct; it has four small surface swellings referred to previously; these are the **two superior** and **two inferior colliculi**. The cerebral aqueduct is lined by ependyma and is surrounded by the **central gray matter**. On transverse sections of the midbrain, the interpeduncular fossa can be seen to separate the crura cerebri, whereas the tegmentum is continuous across the median plane (see Fig. 5-24).

Transverse Section of the Midbrain at the Level of the Inferior Colliculi

The **inferior** colliculus, consisting of a large nucleus of gray matter, lies beneath the corresponding surface elevation and forms part of the auditory pathway (see Figs. 5-25A and 5-27). It receives many of the terminal fibers of the lateral lemniscus. The pathway then continues through the inferior brachium to the medial geniculate body.

The **trochlear nucleus** is situated in the central gray matter close to the median plane just posterior to the **medial longitudinal fasciculus**. The emerging fibers of the trochlear nucleus pass laterally and posteriorly around the central gray matter and leave the midbrain just below the inferior colliculi. The fibers of the trochlear nerve now **decussate completely** in the superior medullary velum. The **mesencephalic nuclei of the trigeminal nerve** are lateral to the cerebral aqueduct. The **decussation of the superior cerebellar peduncles** occupies the central part of the tegmentum anterior to the cerebral aqueduct. The **reticular formation** is smaller than that of the pons and is situated lateral to the decussation.

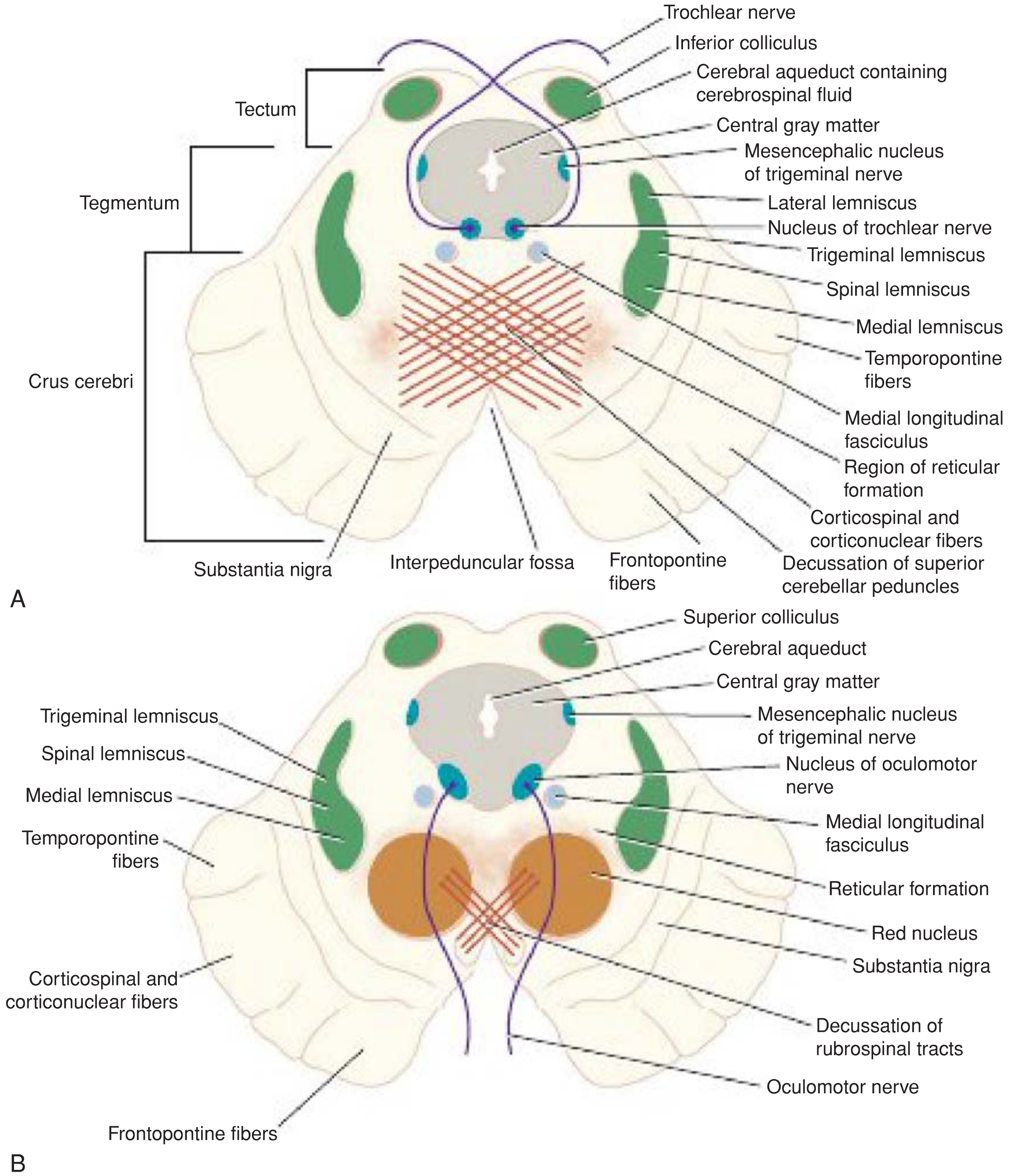

Figure 5-25 Transverse sections of the midbrain. **A:** At the level of the inferior colliculus. **B:** At the level of the superior colliculus. Note that trochlear nerves completely decussate within the superior medullary velum.

The **medial lemniscus** ascends posterior to the substantia nigra; the **spinal** and **trigeminal lemnisci** are situated lateral to the medial lemniscus (see Figs. 5-25 and 5-27). The **lateral lemniscus** is located posterior to the trigeminal lemniscus.

The **substantia nigra** is a large motor nucleus situated between the tegmentum, and the crus cerebri and is found throughout the midbrain. The nucleus is composed of medium-size multipolar neurons that possess inclusion granules of melanin pigment within their cytoplasm. The substantia nigra is concerned with muscle tone and is connected to the cerebral cortex, spinal cord, hypothalamus, and basal nuclei.

The **crus cerebri** contains important descending tracts and is separated from the tegmentum by the substantia nigra. The corticospinal and corticonuclear fibers occupy the middle two thirds of the crus. The frontopontine fibers occupy the medial part of the crus, and

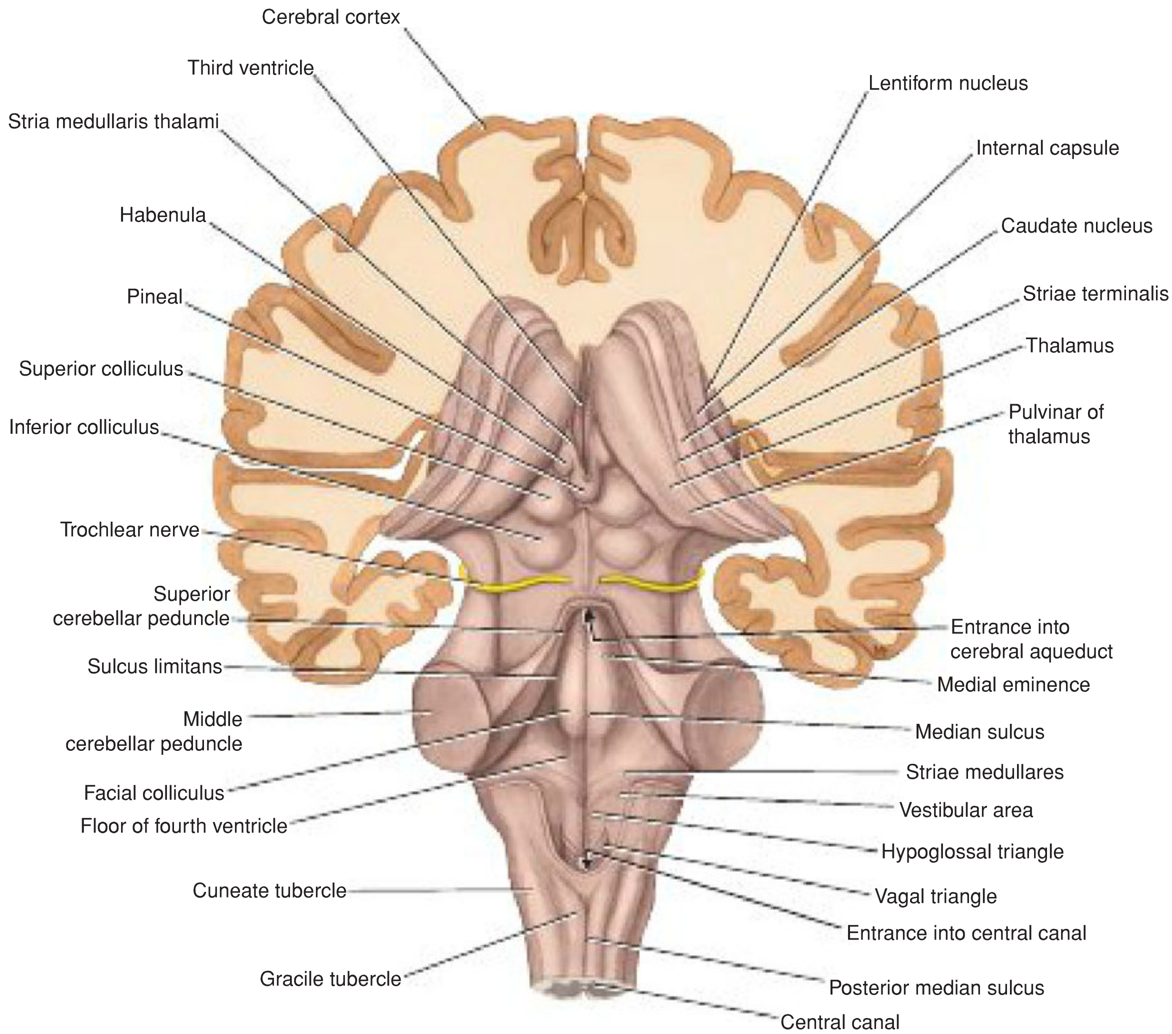

Figure 5-26 Posterior view of the brainstem showing the two superior and the two inferior colliculi of the tectum.

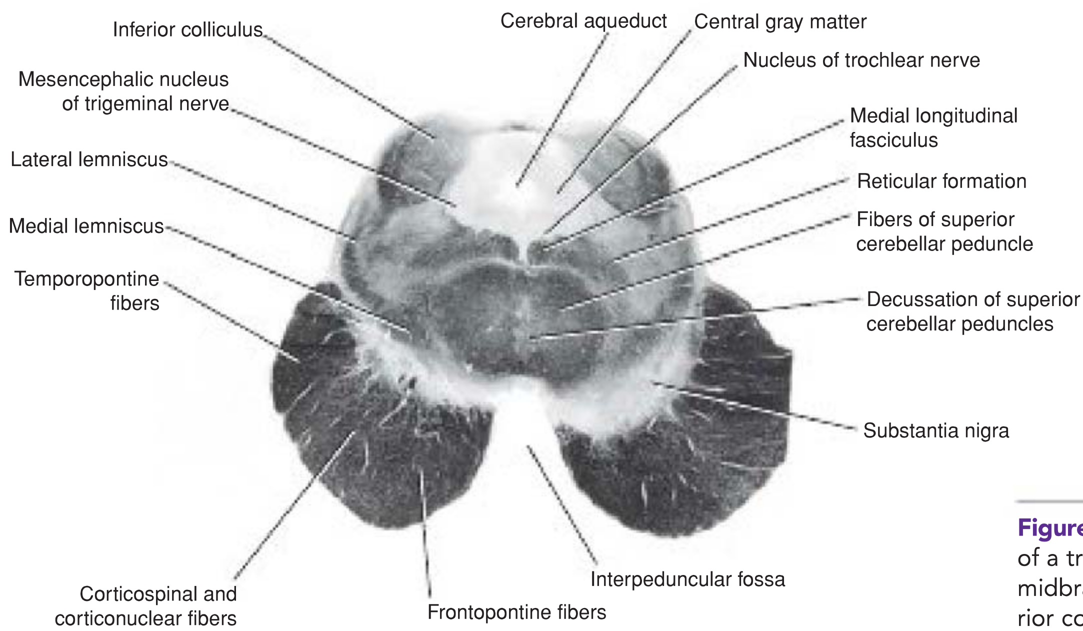

Figure 5-27 Photomicrograph of a transverse section of the midbrain at the level of the inferior colliculus. (Weigert stain.)

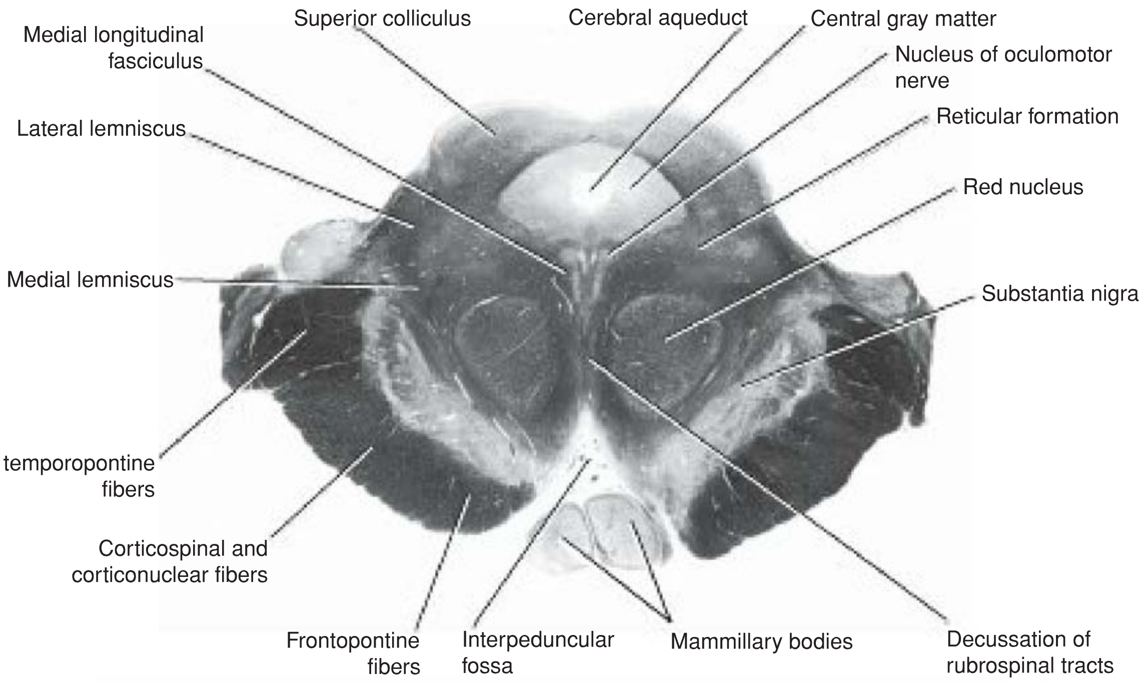

Figure 5-28 Photomicrograph of a transverse section of the midbrain at the level of the superior colliculus. (Weigert stain.)

the temporopontine fibers occupy the lateral part of the crus. These descending tracts connect the cerebral cortex to the anterior gray column cells of the spinal cord, the CN nuclei, the pons, and the cerebellum (Table 5-4).

Transverse Section of the Midbrain at the Level of the Superior Colliculi

The **superior colliculus** (see Figs. 5-25B and 5-28), a large nucleus of gray matter that lies beneath the corresponding surface elevation, forms part of the visual reflexes. It is connected to the lateral geniculate body by the superior brachium. It receives afferent fibers from the optic nerve, the visual cortex, and the spinotectal tract. The efferent fibers form the tectospinal and tectobulbar tracts, which are probably responsible for the reflex movements of the eyes, head, and neck in response to visual stimuli. The afferent pathway for the **light reflex** ends in the **pretectal nucleus**. This is a small group of neurons situated close to the lateral part of the superior colliculus. After relaying in the pretectal nucleus, the fibers pass to the parasympathetic nucleus of the oculomotor nerve (Edinger–Westphal nucleus). The emerging fibers then pass to the oculomotor nerve. The **oculomotor nucleus** is situated in the central gray matter close to the median plane, just posterior to the **medial longitudinal fasciculus**. The fibers of the oculomotor nucleus pass anteriorly through the red nucleus

Table 5-4 Two Levels of the Midbrain and Their Major Structures[a]

Level	Cavity	Nuclei	Motor Tract	Sensory Tracts
Inferior colliculi	Cerebral aqueduct	Inferior colliculus, substantia nigra, trochlear nucleus, mesencephalic nuclei of CN V	Corticospinal and corticonuclear tracts, temporopontine, frontopontine, medial longitudinal fasciculus	Lateral, trigeminal, spinal, and medial lemnisci; decussation of superior cerebellar peduncles
Superior colliculi	Cerebral aqueduct	Superior colliculus, substantia nigra, oculomotor nucleus, Edinger–Westphal nucleus, red nucleus, mesencephalic nucleus of CN V	Corticospinal and corticonuclear tracts, temporopontine, frontopontine, medial longitudinal fasciculus, decussation of rubrospinal tract	Trigeminal, spinal, and medial lemnisci

[a]Note that the reticular formation is present at all levels.
CN, cranial nerve.

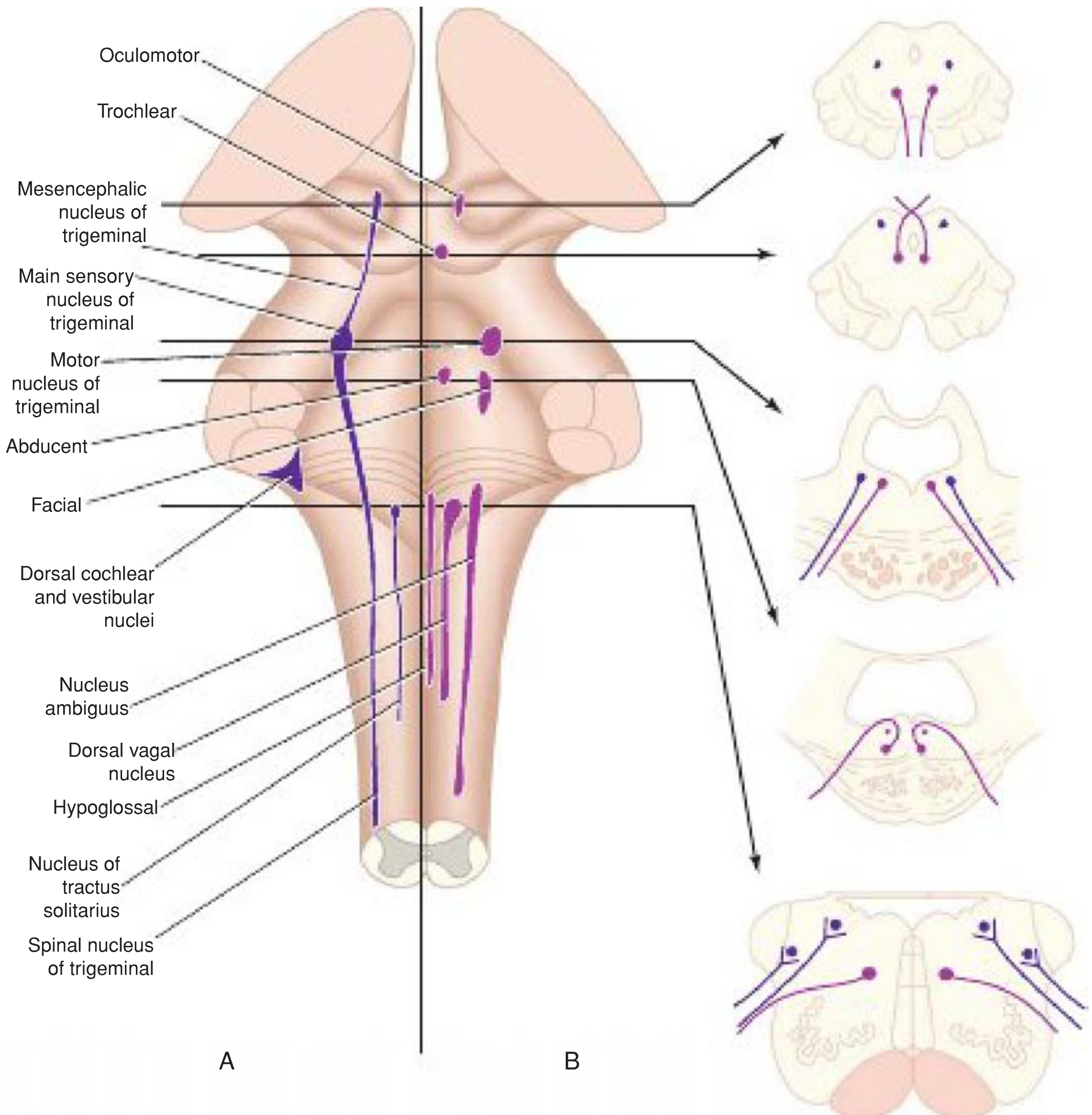

Figure 5-29 Position of some of the cranial nerve nuclei in the brainstem. **A:** Surface projection on the posterior aspect of the brainstem. **B:** Cross sections. The motor nuclei are in red and the sensory nuclei in blue.

to emerge on the medial side of the crus cerebri in the interpeduncular fossa. The nucleus of the oculomotor nerve is divisible into a number of cell groups.

The **medial**, **spinal**, and **trigeminal lemnisci** form a curved band posterior to the substantia nigra, but the **lateral lemniscus** does not extend superiorly to this level.

The **red nucleus** is a rounded mass of gray matter situated between the cerebral aqueduct and the substantia nigra. Its reddish hue, seen in fresh specimens, is due to its vascularity and the presence of an iron-containing pigment in the cytoplasm of many of its neurons. Afferent fibers reach the red nucleus from (1) the cerebral cortex through the corticospinal fibers, (2) the cerebellum through the superior cerebellar peduncle, and (3) the lentiform nucleus, subthalamic and hypothalamic nuclei, substantia nigra, and spinal cord. Efferent fibers leave the red nucleus and pass to (1) the spinal cord through the rubrospinal tract (as this tract descends, it decussates), (2) the reticular formation through the rubroreticular tract, (3) the thalamus, and (4) the substantia nigra.

The **reticular formation** is situated in the tegmentum lateral and posterior to the red nucleus.

The **crus cerebri** contains the identical important descending tracts—the **corticospinal**, **corticonuclear**, and **corticopontine fibers**—that are present at the level of the inferior colliculus (see Table 5-4).

The continuity of the various CN nuclei through the different regions of the brainstem is shown diagrammatically in Figure 5-29.

Clinical Notes

Clinical Significance of the Medulla Oblongata

The medulla oblongata not only contains many cranial nerve (CN) nuclei that are concerned with vital functions (e.g., regulation of heart rate and respiration), but it also serves as a conduit for the passage of ascending and descending tracts connecting the spinal cord to the higher centers of the nervous system. These tracts may become involved in demyelinating diseases, neoplasms, and vascular disorders.

Raised Pressure in the Posterior Cranial Fossa

The medulla oblongata is situated in the posterior cranial fossa, lying beneath the tentorium cerebelli and above the foramen magnum. It is related anteriorly to the basal portion of the occipital bone and the upper part of the odontoid process of the axis and posteriorly to the cerebellum.

In patients with tumors of the posterior cranial fossa, the intracranial pressure is raised, and the brain—that is, the cerebellum and the medulla oblongata—tends to be pushed toward the area of least resistance; the medulla and cerebellar tonsils herniate downward through the foramen magnum. This causes headache, neck stiffness, and paralysis of the glossopharyngeal, vagus, accessory, and hypoglossal nerves owing to traction. In these circumstances, **performing a lumbar puncture is extremely dangerous** because the sudden withdrawal of cerebrospinal fluid (CSF) may precipitate further herniation of the brain through the foramen magnum and a sudden failure of vital functions, resulting from pressure and ischemia of the CN nuclei present in the medulla oblongata.

Arnold–Chiari Phenomenon

The **Arnold–Chiari malformation** is a congenital anomaly in which there is a herniation of the tonsils of the cerebellum and the medulla oblongata through the foramen magnum into the vertebral canal (Fig. 5-30). This results in the blockage of the exits in the roof of the fourth ventricle to the CSF, causing internal hydrocephalus. It is commonly associated with craniovertebral anomalies or various forms of spina bifida. Signs and symptoms related to pressure on the cerebellum and medulla oblongata and involvement of the last four CNs are associated with this condition.

Figure 5-30 Arnold–Chiari phenomenon. This coronal section of the skull shows the herniation of the cerebellar tonsil and the medulla oblongata through the foramen magnum into the vertebral canal. (From Dudek, R. W., & Louis, T. M. [2015]. *High-yield gross anatomy* (5th ed.). Baltimore, MD: Wolters Kluwer.)

Vascular Disorders

The medulla oblongata is a heterogeneous collection of nuclei and tracts, and damage to different regions will elicit the following syndromes.

LATERAL MEDULLARY SYNDROME OF WALLENBERG

The lateral part of the medulla oblongata is supplied by the posterior inferior cerebellar artery, which is usually a branch of the vertebral artery. Thrombosis of either of these arteries (Fig. 5-31) produces the following signs and symptoms: dysphagia and dysarthria due to paralysis of the ipsilateral palatal and laryngeal muscles (innervated by the nucleus ambiguus); analgesia and thermoanesthesia on the ipsilateral side of the face (nucleus and spinal tract of the trigeminal nerve); vertigo, nausea, vomiting, and nystagmus (vestibular nuclei); ipsilateral Horner syndrome (descending sympathetic fibers); ipsilateral cerebellar signs—gait and limb ataxia (cerebellum or inferior cerebellar peduncle); and contralateral loss of sensations of pain and temperature (spinal lemniscus—spinothalamic tract).

MEDIAL MEDULLARY SYNDROME

The medial part of the medulla oblongata is supplied by the vertebral artery. Thrombosis of the medullary branch (Fig. 5-32) produces the following signs and symptoms: contralateral hemiparesis (pyramidal tract), contralateral impaired sensations of position and movement and tactile discrimination (medial lemniscus), and ipsilateral paralysis of tongue muscles with deviation to the paralyzed side when the tongue is protruded (hypoglossal nerve).

Clinical Significance of the Pons

The pons, like the medulla oblongata and the cerebellum, is situated in the posterior cranial fossa lying beneath the tentorium cerebelli. It is related anteriorly to the basilar artery, the dorsum sellae of the sphenoid bone, and the basilar part of the occipital bone. In addition to forming the upper half of the floor of the fourth ventricle, it possesses several important CN nuclei (trigeminal, abducens, facial, and vestibulocochlear) and serves as a conduit for important ascending and descending tracts (corticonuclear, corticopontine, corticospinal, medial longitudinal fasciculus and medial, spinal, and lateral lemnisci). Not surprisingly, therefore, tumors, hemorrhage, or infarcts in this area of the brain produce a variety of symptoms and signs. For example, involvement of

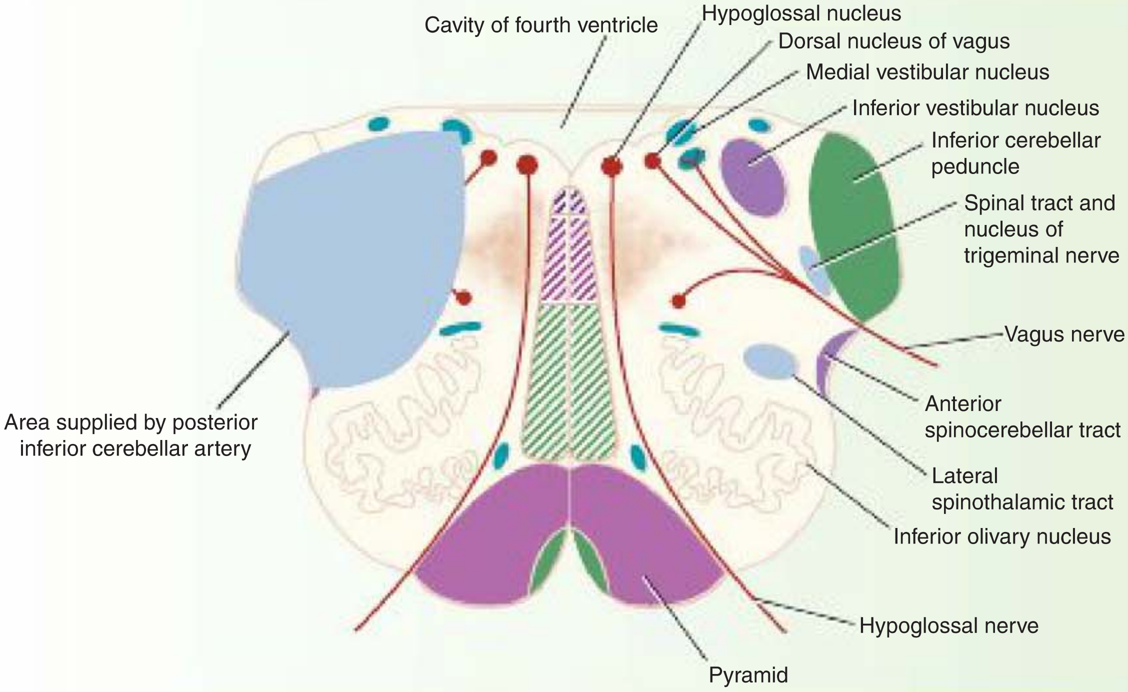

Figure 5-31 Transverse section of the medulla oblongata at the level of the inferior olivary nuclei showing the extent of the lesion producing the lateral medullary syndrome.

the corticopontocerebellar tracts will produce marked cerebellar ataxia, and voluntary movements are accompanied by a rhythmic tremor that develops and becomes further accentuated as the movements proceed (intention tumor).

Tumors

Astrocytoma of the pons occurring in childhood is the most common tumor of the brainstem. The symptoms and signs are those of ipsilateral CN paralysis and contralateral

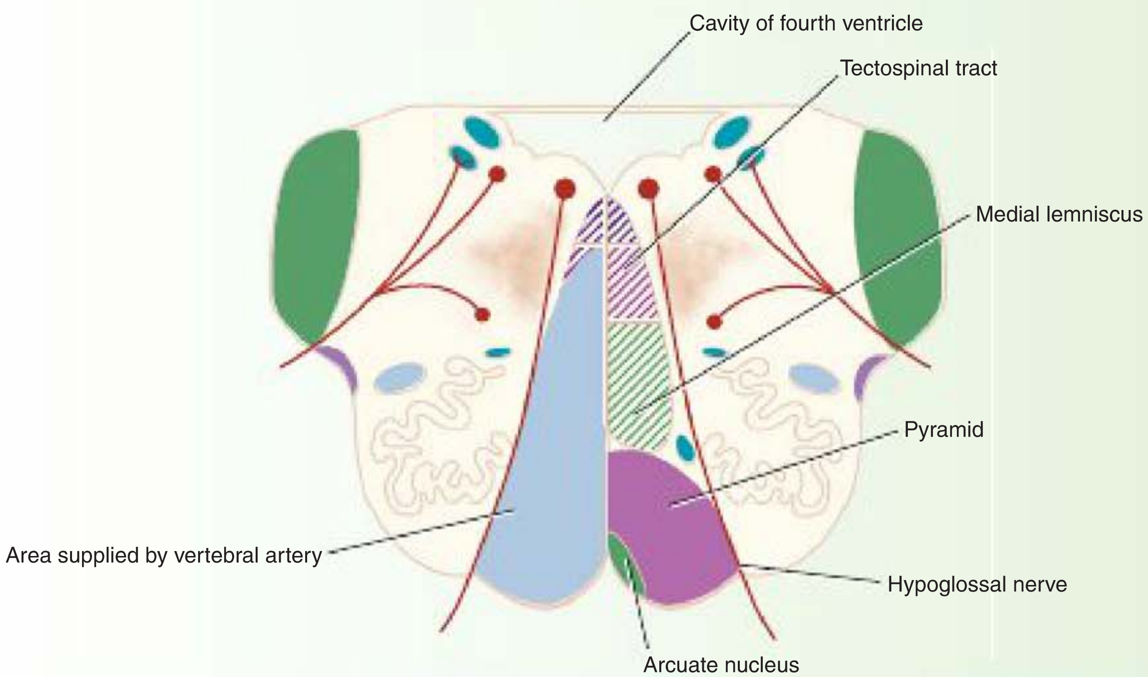

Figure 5-32 Transverse section of the medulla oblongata at the level of the inferior olivary nuclei showing the extent of the lesion producing the medial medullary syndrome.

hemiparesis: weakness of the facial muscles on the same side (facial nerve nucleus), weakness of the lateral rectus muscle on one or both sides (abducens nerve nucleus), nystagmus (vestibular nucleus), weakness of the jaw muscles (trigeminal nerve nucleus), impairment of hearing (cochlear nuclei), contralateral hemiparesis, quadriparesis (corticospinal fibers), anesthesia to light touch with the preservation of appreciation of pain over the skin of the face (principal sensory nucleus of trigeminal nerve involved, leaving spinal nucleus and tract of trigeminal intact), and contralateral sensory defects of the trunk and limbs (medial and spinal lemnisci). Involvement of the corticopontocerebellar tracts may cause ipsilateral cerebellar signs and symptoms. There may be impairment of conjugate deviation of the eyeballs due to involvement of the medial longitudinal fasciculus, which connects the oculomotor, trochlear, and abducens nerve nuclei.

Hemorrhage

The pons is supplied by the basilar artery and the anterior, inferior, and superior cerebellar arteries. If the hemorrhage occurs from one of those arteries and is unilateral, facial paralysis on the side of the lesion (involvement of the facial nerve nucleus and, therefore, a lower motor neuron palsy) and paralysis of the limbs on the opposite side (involvement of the corticospinal fibers as they pass through the pons) will result. Paralysis of conjugate ocular deviation (involvement of the abducens nerve nucleus and the medial longitudinal fasciculus) is common.

When the hemorrhage is extensive and bilateral, the pupils may be "pinpoint" (involvement of the ocular sympathetic fibers); bilateral paralysis of the face and the limbs is common. The patient may become poikilothermic because severe damage to the pons has cut off the body from the heat-regulating centers in the hypothalamus.

Infarctions

Usually, infarction of the pons is due to thrombosis or embolism of the basilar artery or its branches. If it involves the paramedian area of the pons, the corticospinal tracts, the pontine nuclei, and the fibers passing to the cerebellum through the middle cerebellar peduncle may be damaged. A laterally situated infarct will involve the trigeminal nerve, the medial lemniscus, and the middle cerebellar peduncle; the corticospinal fibers to the lower limbs also may be affected.

The clinical conditions mentioned above will be understood more clearly if the ascending and descending tracts of the brain and spinal cord are reviewed (see Chapter 4).

Clinical Significance of the Midbrain

The midbrain forms the upper end of the narrow stalk of the brain or brainstem. As it ascends out of the posterior cranial fossa through the relatively small rigid opening in the tentorium cerebelli, it is vulnerable to traumatic injury. It possesses two important CN nuclei (oculomotor and trochlear), reflex centers (the colliculi), and the red nucleus and substantia nigra, which greatly influence motor function, and the midbrain serves as a conduit for many important ascending and descending tracts. As in other parts of the brainstem, it is a site for tumors, hemorrhage, or infarcts that will produce a wide variety of symptoms and signs.

Trauma

Among the mechanisms of injuries to the midbrain, a sudden lateral movement of the head could result in the cerebral peduncles impinging against the sharp rigid free edge of the tentorium cerebelli. Sudden movements of the head resulting from trauma cause different regions of the brain to move at different velocities relative to one another. For example, the large anatomical unit, the forebrain, may move at a different velocity from the remainder of the brain, such as the cerebellum. This will result in the midbrain being bent, stretched, twisted, or torn.

Involvement of the oculomotor nucleus will produce ipsilateral paralysis of the levator palpebrae superioris; the superior, inferior, and medial rectus muscles; and the inferior oblique muscle. Malfunction of the parasympathetic nucleus of the oculomotor nerve produces a dilated pupil that is insensitive to light and does not constrict on accommodation.

Involvement of the trochlear nucleus will produce contralateral paralysis of the superior oblique muscle of the eyeball. Thus, involvement of one or both of these nuclei, or the corticonuclear fibers that converge on them, will cause impairment of ocular movements.

Cerebral Aqueduct Blockage

The cavity of the midbrain, the cerebral aqueduct, is one of the narrower parts of the ventricular system. Normally, CSF that has been produced in the lateral and third ventricles passes through this channel to enter the fourth ventricle and so escapes through the foramina in its roof to enter the subarachnoid space. In congenital hydrocephalus, the cerebral aqueduct may be blocked or replaced by numerous small tubular passages that are insufficient for normal CSF flow. A tumor of the midbrain (Fig. 5-33A) or pressure on the midbrain from a tumor arising outside the midbrain may compress the aqueduct and produce hydrocephalus. When the cerebral aqueduct is blocked, the accumulating CSF within the third and lateral ventricles produces lesions in the midbrain. The presence of the oculomotor and trochlear nerve nuclei, together with the important descending corticospinal and corticonuclear tracts, will provide symptoms and signs that are helpful in accurately localizing a lesion in the brainstem.

Vascular Lesions

The midbrain houses CN III nuclei and serves as a conduit for all ascending and descending fibers between the cerebrum and brainstem; lesions of each will result in the following syndromes.

WEBER SYNDROME

Weber syndrome (see Fig. 5-33B), which is commonly produced by occlusion of a branch of the posterior cerebral artery that supplies the midbrain, results in the necrosis of brain tissue involving the oculomotor nerve and the crus cerebri. Ipsilateral ophthalmoplegia and contralateral paralysis of the lower part of the face, the tongue, and the arm and leg also result. The eyeball is deviated laterally because of the paralysis of the medial rectus muscle; the upper lid droops (ptosis), and the pupil is dilated and fixed to light and accommodation.

BENEDIKT SYNDROME

Benedikt syndrome (see Fig. 5-33C) is similar to Weber syndrome, but the necrosis involves the medial lemniscus and red nucleus, producing contralateral hemianesthesia and involuntary movements of the limbs of the opposite side.

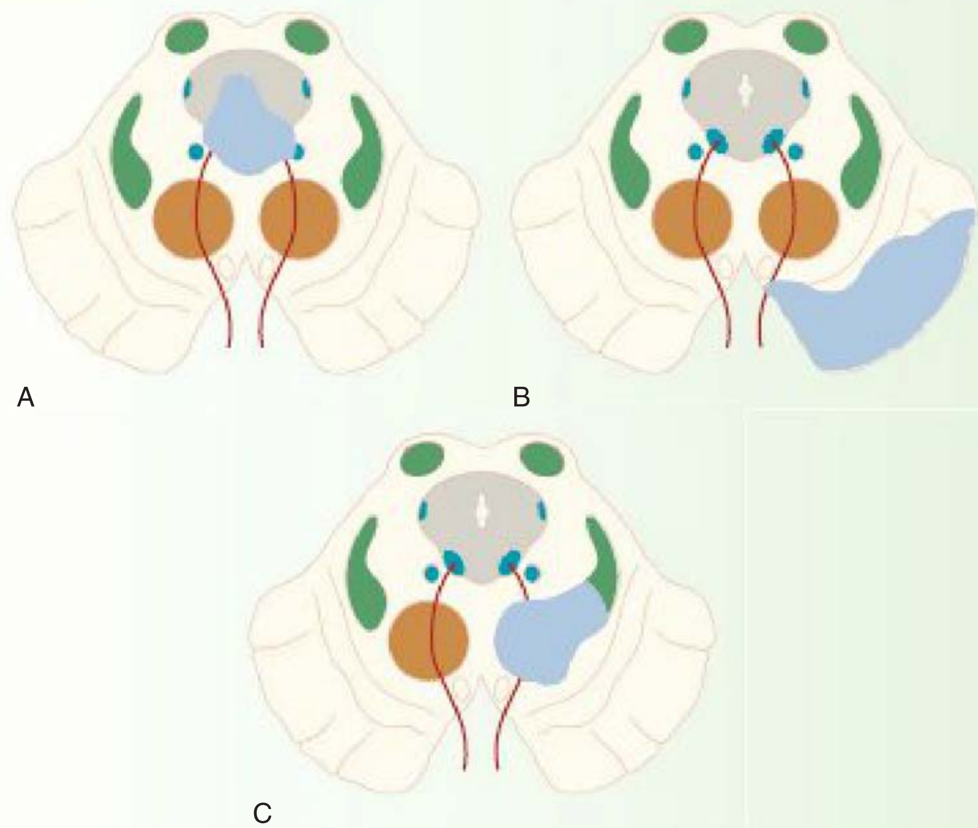

Figure 5-33 Pathology of the midbrain. **A:** Tumor of the midbrain blocking the cerebral aqueduct. **B:** Weber syndrome involving the oculomotor nerve and the crus cerebri following occlusion of the blood supply to the midbrain. **C:** Benedikt syndrome involving the red nucleus and the medial lemniscus following occlusion of the blood supply to the midbrain.

Key Concepts

Medulla Oblongata

- The medulla oblongata connects the pons superiorly and spinal cord inferiorly. On either side of the anterior median sulcus are the two pyramids that taper inferiorly, whereas most fibers cross at the decussation of the pyramids.
- Posterolateral to the pyramids are the olives, which are elevations produced by the underlying inferior olivary nuclei.
- The medulla oblongata contains multiple CN and cerebellar nuclei, the olivary nuclear complex, nucleus ambiguous, hypoglossal nucleus, vestibulocochlear nucleus, dorsal nucleus of the vagus, and nucleus of the tractus solitarius, and spinal nucleus of the trigeminal nerve.

Pons

- The pons is anterior to the cerebellum and connects the medulla oblongata to the midbrain. The anterior surface is convex, and the trigeminal nerve emerges anterolaterally.
- The anterior or basal part of the pons consists of transversely running fibers, called the trapezoid body, and descending bundles of the corticospinal tract.
- The posterior part, or tegmentum, contains multiple nuclei, including facial, abducens, vestibular,

pontine, trapezoid, and trigeminal (main sensory, spinal, and motor).

Midbrain

- The midbrain connects the pons and the cerebellum with the forebrain.
- The lateral halves, called the cerebral peduncles, are comprised of the crus cerebri, which contain corticospinal fibers, and the substantia nigra, a pigmented band of gray matter.
- The cerebral aqueduct, which connects the third and fourth ventricles, passes through the midbrain and divides the anterior (tegmentum) from the posterior (tectum).
- The tectum consists of four swellings, two superior and two inferior colliculi, that are associated with vision and hearing, respectively.
- The midbrain contains multiple nuclei including, inferior and superior colliculi, substantia nigra, trochlear, mesencephalic (trigeminal), oculomotor, Edinger–Westphal, and the red nucleus.

Clinical Problem Solving

1. While carrying out a physical examination of a patient with an intracranial tumor, the neurologist turns to a medical student and asks, “What signs or symptoms would you look for that would enable you to localize the tumor to the region of the medulla oblongata?” How would you have answered that question?
2. A 6-month-old boy dies with hydrocephalus and a myelocele in the lower thoracic region. At autopsy, the hindbrain is found to be deformed. The lower part of the medulla oblongata extends inferiorly through the foramen magnum into the vertebral canal as far as the third cervical vertebra. The lower four cranial nerves are longer than normal, and the upper cervical nerve roots ascend to reach their exit from the vertebral canal. The cerebellum on the left side extends inferiorly through the foramen magnum to the third cervical vertebra, where it adheres to the spinal cord. The roof of the fourth ventricle is abnormally low. (a) What is the name of this malformation? (b) Is hydrocephalus common in this condition? (c) Is an association possible between the thoracic myelocele and the presence of part of the hindbrain in the vertebral canal?
3. A 68-year-old man is admitted to the hospital with the sudden onset of severe dizziness (vertigo), hiccups, and vomiting. He also complains of a hot, painful sensation in the skin of the right side of the face. On physical examination, the soft palate is drawn up to the left side when the patient was asked to say “ah,” and the right vocal cord lacked mobility as seen on laryngoscopic examination. The patient also shows drooping of the right upper eyelid (ptosis), sunken right eye (enophthalmos), and a constricted right pupil (myosis). When asked to protrude his tongue straight out of his mouth, the patient tries to do so, but the tip of the tongue pointed to the right side. Impaired pain and temperature sensation is evident in the trunk and extremities on the left side. Using your knowledge of anatomy, make the diagnosis.
4. A pathologist, while exploring the posterior cranial fossa during an autopsy, is endeavoring to determine where the 9th, the 10th, and the cranial part of the 11th cranial nerves emerge from the hindbrain. Describe where these nerves emerge from the hindbrain.
5. A 10-year-old girl is taken to a physician because her mother has noticed that the right half of her face was weak and does not appear to react to emotional changes. Her mouth is pulled over slightly to the left, especially when she is tired. On questioning, the patient admits that food tends to stick inside her right cheek and that the right side of her face “felt funny.” The mother had first noticed the facial changes 3 months previously, and the condition has progressively worsened. On examination, definite weakness of the facial muscles on the right side is noted; the facial muscles on the left side are normal. Skin sensation on stimulation of the face is normal. On testing of the ocular movements, slight weakness of the lateral rectus muscle is evident on the right side. Examination of the movements of the arm and leg shows slight weakness on the left side. Using your knowledge of neuroanatomy, relate these symptoms and signs to a lesion in the pons.
6. A 65-year-old man is admitted to the emergency department with a diagnosis of a severe pontine hemorrhage. On examination, he is found to have bilateral “pinpoint” pupils and quadriplegia. How can you explain the presence of the “pinpoint” pupils?
7. A 46-year-old man with symptoms of deafness, vertigo, and double vision (diplopia) visits his physician. On questioning, he says that he also suffers from severe headaches, which are increasing in frequency and severity. The week before, he vomited several times during one of the headache attacks.