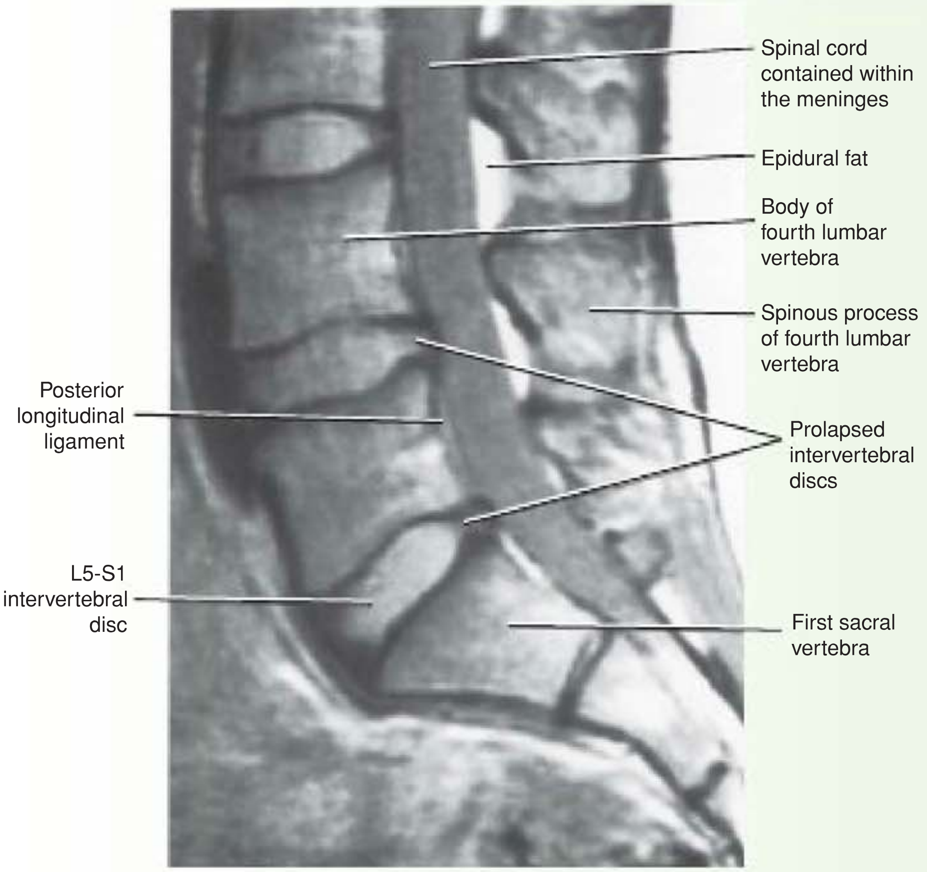


Figure 4-35 Sagittal MRI of the lumbosacral part of the vertebral column showing several prolapsed intervertebral discs. (*Courtesy Dr. Pait.*)

Figure 4-36 Posteroanterior myelogram of the cervical region of a 22-year-old woman.

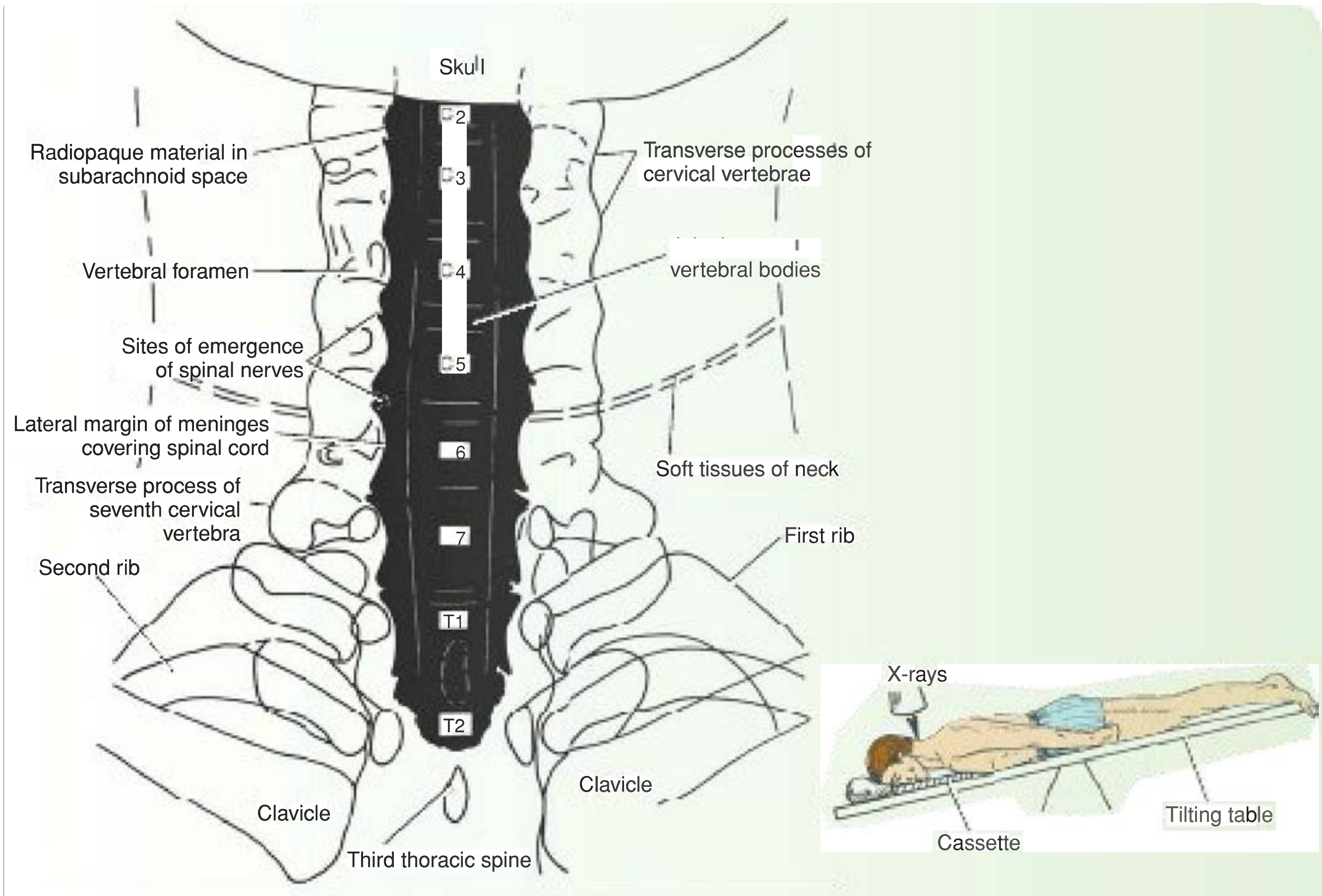


Figure 4-37 Diagrammatic explanation of the myelogram shown in Figure 4-36.

Key Concepts

Vertebral Column

- The vertebral column is composed of 33 vertebrae—7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused), and 4 coccygeal (fused).
- Because it is segmented and made up of vertebrae, joints, and intervertebral discs, it is a flexible structure.
- The vertebral arch encloses a space called the vertebral foramen. The collective vertebral foramina form the vertebral canal—the housing of the spinal cord.

Spinal Cord

- Roughly cylindrical, the spinal cord extends from the rostral end of the medulla oblongata to the eventual tapering of the cord, called the conus medullaris.
- Within the vertebral canal, the spinal cord is covered by three layers of meninges, the dura mater, arachnoid mater, and pia mater. Between the latter two, is the subarachnoid space, which is filled with CSF.
- The spinal cord is composed of an inner core of gray matter surrounded by an outer covering of white matter.
- On cross section, the gray matter is seen as an H-shaped pillar with anterior and posterior columns or horns. A lateral gray column is present in thoracic and upper lumbar segments.
- Most nerve cells in the anterior columns are large, alpha and multipolar, and their axons pass out in the anterior roots of the spinal nerves.
- The substantia gelatinosa of the posterior gray column is largely composed of neurons receiving

afferent fibers concerned with pain, temperature, and touch from the posterior root.

- The nucleus proprius is situated anterior to the substantia gelatinosa throughout the spinal cord and communicates information regarding the senses of proprioception, two-point discrimination, and vibration with the posterior white columns.
- The lateral gray column extends from T1 to L2(3) segments and contains cells that give rise to preganglionic sympathetic fibers.
- The white matter of the spinal cord can be described as anterior, lateral, and posterior columns formed from multiple myelinated nerve bundles, or tracts.

Ascending Tracts

- Pain and temperature sensations ascend in the lateral spinothalamic tract; light touch and pressure ascend in the anterior spinothalamic tract. Together, these are also referred to as the anterolateral system.
- First-order axons entering the spinal cord with pain and temperature information, synapse on second-order neurons of the substantia gelatinosa, cross obliquely to the opposite side through the anterior gray and white commissure, and ascend in the contralateral white column as the lateral spinothalamic tract. The anterior spinothalamic ascends in the contralateral anterior white column.
- As the anterolateral system tracts ascend through the medulla oblongata and pons, they form the spinal lemniscus and eventually synapse on third-order neurons in the ventral posterolateral nucleus of the thalamus.
- First-order axons carrying discriminative touch and vibration sensations enter the dorsal horn and continue traveling upward in the posterior white column as the fasciculus gracilis (sacral, lumbar, and lower thoracic spinal nerves) and fasciculus cuneatus (thoracic and cervical spinal nerves). Fibers of these fasciculi synapse on the second-order neurons of the ipsilateral nuclei gracilis and cuneatus in the medulla oblongata, respectively.
- The axons of the second-order neurons cross anteromedially as the internal arcuate fibers and ascend a compact bundle, called the medial lemniscus, until synapsing with third-order neurons in the ventral posterolateral nucleus of the thalamus.

Descending Tracts

- Motor neurons situated in the anterior gray columns of the spinal cord send axons through the anterior roots to the spinal nerves and are often referred to as lower motor neurons. This is the final pathway to the muscles.
- Corticospinal tracts are pathways concerned with voluntary movement of muscles. Axons of pyramidal cells in the motor cortex descend through the internal capsule, form the cerebral peduncles of the midbrain, then separates into smaller bundles throughout the pons. As the axons approach the medulla, they coalesce, forming the pyramid of the rostral medulla oblongata and cross caudal medulla as the decussation of the pyramids. The axons continue as the lateral corticospinal tract of the spinal cord until they synapse on the lower motor neurons of the anterior horns.
- Reticulospinal tracts may facilitate or inhibit voluntary movements or reflex activity.
- Tectospinal tracts are concerned with reflex postural movements in response to visual stimuli while vestibulospinal tracts are concerned with postural activity associated with balance.
- The rubrospinal tract facilitates the activity of flexor muscles and inhibits the activity of extensor muscles.

Clinical Problem Solving

1. A 53-year-old widower is admitted to the hospital complaining of a burning pain over his right shoulder region and the upper part of his right arm. The pain started 3 weeks previously and, since that time, has progressively worsened. The pain is accentuated when the patient moves his neck or coughs. Two years previously, he had been treated for osteoarthritis of his vertebral column. The patient states that he had been a football player at college and continued to take an active part in the game until he was 42 years old. Physical examination reveals weakness, wasting, and fasciculation of the right deltoid and biceps brachii muscles. The right biceps tendon reflex is absent. Radiologic examination reveals extensive spur formation on the bodies of the fourth, fifth,

and sixth cervical vertebrae. The patient demonstrates hyperesthesia and partial analgesia in the skin over the lower part of the right deltoid and down the lateral side of the arm. Using your knowledge of neuroanatomy, make the diagnosis. How is the pain produced? Why is the pain made worse by coughing?

2. A 66-year-old woman is admitted to the hospital because of her increasing difficulty with walking. Two weeks before admission, she had been able to walk with the help of a stick. Since that time, walking has become increasingly difficult, and for the past 2 days, she cannot walk at all. She has complete control of micturition and defecation. On examination, the handgrip is weak on both sides, but power is normal in the proximal segments of the upper extremities. The tendon reflexes of the upper limbs and the sensory functions are normal. Both lower limbs show muscular weakness with increased muscle tone, especially on the left side. The knee jerks and ankle jerks (tendon reflexes) in both lower limbs are grossly exaggerated, and extensor plantar responses are seen bilaterally. The patient has a loss of sensation of pain below the fifth thoracic dermatome on both sides of the body. Postural sense is impaired in both great toes, and vibration sense is absent below the fifth thoracic segmental level. Radiologic examination, including an MRI, of the vertebral column shows nothing abnormal. A myelogram in the lumbar region reveals a complete block at the lower border of the fourth thoracic vertebra. Using your knowledge of neuroanatomy, suggest a possible diagnosis. How would you treat this patient? Name the tracts in the spinal cord that are responsible for pain sensation conduction. What is the position of these tracts in the spinal cord? Name the tracts responsible for the conduction of postural sense and vibration sense from the spinal cord to the brain. Why did the patient have increasing difficulty in walking? Why were the tendon reflexes in the lower limbs exaggerated, and why did the patient exhibit bilateral extensor plantar responses?
3. A 20-year-old male student celebrates the passing of an examination by drinking several beers at a party. On the way home, he drives his car head-on into a bridge abutment. On examination in the emergency department, he is found to have a fracture dislocation of the ninth thoracic vertebra with signs and symptoms of severe damage to the spinal cord. On physical examination, he has an upper motor neuron paralysis of the left leg. He also has loss of muscle joint sense of the left leg. On testing of cutaneous sensibility, he has a band of cutaneous hyperesthesia extending around the abdominal wall on the left side at the level of the umbilicus. Just below this, he has a narrow band of anesthesia and analgesia. On the right side, total analgesia, thermoanesthesia, and partial loss of tactile sense of the skin of the abdominal wall below the level of the umbilicus and involving the whole of the right leg are present. Using your knowledge of neuroanatomy, state the level at which the spinal cord was damaged. Was the spinal cord completely sectioned? If not, on which side did the hemisection occur? Explain the sensory losses found on examination in this patient.
4. A 35-year-old woman is admitted to the hospital for investigation. She has symptoms of analgesia and thermoanesthesia on the medial side of the left hand that persist for 6 months. Three weeks prior to her admittance, she had severely burned the little finger of her left hand on a hot stove and was unaware that the burn had occurred until she smelled the burning skin. On physical examination, she is found to have considerably reduced pain and temperature sense involving the eighth cervical and first thoracic dermatomes of the left hand. However, her sense of tactile discrimination is perfectly normal in these areas. Examination of the right arm shows a similar but much less severe dissociated sensory loss involving the same areas. No further abnormal signs are discovered. Using your knowledge of neuroanatomy, state which tract or tracts were involved in this pathologic process. Name this disease.
5. A 60-year-old man walks into the neurology clinic, and the clinician pays particular attention to his gait. The patient raises his feet unnecessarily high and brings them to the ground in a stamping manner. While he is waiting for the clinician, he is seen to stand with his feet wide apart. On questioning, the patient says that he is finding it increasingly difficult to walk and is starting to use a stick, especially when he goes out for walks in the dark. The clinician asks the patient to stand with his toes and heels together and to close his eyes. The patient immediately starts to sway, and the nurse has to steady him to prevent him from falling. On further examination, the patient is found to have loss of muscle joint sense of both legs and is unable to detect any feeling of vibration when a vibrating tuning fork was placed on the medial malleolus of either leg. No other sensory losses are noted. Using your knowledge of neuroanatomy, name the ascending pathways that are involved, by disease, in this patient. Name a disease that could be responsible for these findings.
6. A 68-year-old man has an advanced inoperable carcinoma of the prostate with multiple metastases in the lumbar vertebrae and hip bones. Apart from the severe intractable pain, the patient is still able to enjoy life among his family. After a full discussion of the prognosis with the patient and his wife, the wife turned to the clinician and says, “Can’t you do something to stop this terrible pain so that my husband can die happy?” What can a

clinician do to help a patient under these circumstances?

7. A third-year medical student attends a lecture on the effects of vertebral column trauma. The orthopedic surgeon describes very superficially the different neurologic deficits that may follow injury to the spinal cord. At the end of the lecture, the student says he does not understand what was meant by the term *spinal shock*. He cannot understand what the underlying mechanism for this condition is. He also asks the surgeon to explain what was meant by paraplegia in extension and paraplegia in flexion. Can the surgeon explain why one condition sometimes passes into the other? These are good questions. Can you answer them?
8. While examining a patient with right-sided hemiplegia caused by a cerebrovascular accident, the neurologist asks the student which clinical signs can be attributed to an interruption of the corticospinal tracts and which signs can be attributed to damage to other descending tracts. Using your knowledge of neuroanatomy, answer this question.
9. A large civilian aircraft is forced to abort its takeoff because three tires have burst as the plane speeds along the runway. The pilot miraculously manages to halt the plane as it veers off the runway and comes to an abrupt halt in a ditch. All the passengers escape injury, but one of the flight attendants is admitted to the emergency department with suspected spinal cord injury. On questioning, the 25-year-old patient says that although she had her seatbelt fastened, she was thrown violently forward on impact. She says she cannot feel anything in either leg and cannot move her legs. On examination, complete motor and sensory loss is noted in both legs below the inguinal ligament as well as absence of all deep tendon reflexes of both legs. Twelve hours later, she is able to move the toes and ankle of her left lower limb, and she has a return of sensations to her right leg except for loss of tactile discrimination, vibratory sense, and proprioceptive sense. She has a band of complete anesthesia over her right inguinal ligament. Her left leg shows total analgesia, thermoanesthesia, and partial loss of tactile sense. Her right leg is totally paralyzed, and the muscles are spastic. A right-sided Babinski response is seen as well as right-sided ankle clonus. The right knee jerk is exaggerated. Using your knowledge of neuroanatomy, explain the symptoms and signs found in this patient. Which vertebra was damaged?
10. Why is moving a patient with suspected vertebral column fracture or dislocation so dangerous?
11. An 18-year-old man is admitted to the hospital following a severe automobile accident. After a complete neurologic investigation, his family is told that he will be paralyzed from the waist down for the rest of his life. The neurologist outlines to the medical personnel the importance of preventing complications in these cases. The common complications are the following: (a) urinary infection, (b) bedsores, (c) nutritional deficiency, (d) muscular spasms, and (e) pain. Using your knowledge of neuroanatomy, explain the underlying reasons for these complications. How long after the accident would giving an accurate prognosis in this patient be possible?
12. A 67-year-old man is brought to the neurology clinic by his daughter because she notices that his right arm has a tremor. Apparently, this had started about 6 months previously and is becoming steadily worse. When questioned, the patient says he notices that the muscles of his limbs sometimes felt stiff, but he has attributed this to old age. While talking, the patient rarely smiles and then only with difficulty. He infrequently blinks his eyes. The patient tends to speak in a low, faint voice. When asked to walk, the patient has normal posture and gait, although he tends to hold his right arm flexed at the elbow joint. When he is sitting, the fingers of the right hand are alternately contracting and relaxing, and a fine tremor involving the wrist and elbow on the right side is seen. The tremor is worse when the arm is at rest. When he is asked to hold a book in his right hand, the tremor stops momentarily, but it starts again immediately after the book is placed on the table. The daughter says that when her father falls asleep, the tremor stops immediately. On examination, passive movements of the right elbow and wrist show increased tone, and cogwheel rigidity is noted. The patient has neither cutaneous or deep sensibility sensory loss, and the reflexes are normal. Using your knowledge of neuroanatomy, make a diagnosis. Which regions of the brain are diseased?
13. Name a center in the central nervous system that may be responsible for the following clinical signs: (a) intention tremor, (b) athetosis, (c) chorea, (d) dystonia, and (e) hemiballismus.

Answers and Explanations to Clinical Problem Solving

1. This patient was suffering from spondylosis, which is a general term used for degenerative changes in the vertebral column caused by osteoarthritis. In the cervical region, the growth of osteophytes was exerting pressure on the anterior and posterior roots of the fifth and sixth spinal nerves. As the result of repeated trauma and aging, degenerative changes occurred at the articulating

surfaces of the fourth, fifth, and sixth cervical vertebrae. Extensive spur formation resulted in narrowing of the intervertebral foramina with pressure on the nerve roots. The burning pain, hyperesthesia, and partial analgesia were due to pressure on the posterior roots, and weakness, wasting, and fasciculation of the deltoid and biceps brachii muscles were due to pressure on the anterior roots. Movements of the neck presumably intensified the symptoms by exerting further traction or pressure on the nerve roots. Coughing or sneezing raised the pressure within the vertebral canal and resulted in further pressure on the nerve roots.

2. The patient was operated on and laminectomy of the third, fourth, and fifth thoracic vertebrae was carried out. At the level of the fourth thoracic vertebra, a small swelling was seen on the posterior surface of the spinal cord; it was attached to the dura mater. Histologic examination showed that it was a meningioma. The tumor was easily removed, and the patient successfully recovered from the operation. Power of the lower limbs progressively returned, with the patient walking without a stick. This patient emphasizes the importance of making an early, accurate diagnosis because benign extramedullary spinal tumors are readily treatable. The lateral spinal thalamic tracts are responsible for the conduction of pain impulses up the spinal cord. These tracts are situated in the lateral white columns of the spinal cord (see p. 141). Postural sense and vibration sense are conducted up the spinal cord in the posterior white column through the fasciculus cuneatus from the upper limbs and the upper part of the thorax and in the fasciculus gracilis from the lower part of the trunk and the leg. The difficulty in walking was due to pressure on the corticospinal tracts in the lateral white column. The exaggeration in the tendon reflexes of the lower limbs and the bilateral extensor plantar responses were due to the pressure on the descending tracts in the spinal cord at the level of the tumor. This also resulted in spastic paralysis of the muscles of the lower limbs.
3. A fracture dislocation of the 9th thoracic vertebra would result in severe damage to the 10th thoracic segment of the spinal cord. The unequal sensory and motor losses on the two sides indicate a left hemisection of the cord. The narrow band of hyperesthesia on the left side was due to the irritation of the cord immediately above the site of the lesion. The band of anesthesia and analgesia was due to the destruction of the cord on the left side at the level of the 10th thoracic segment; that is, all afferent fibers entering the cord at that point were interrupted. The loss of pain and thermal sensibilities and the loss of light touch below the level of the umbilicus on the right side were caused by the interruption of the lateral and anterior spinothalamic tracts on the left side of the cord.
4. This patient has the early signs and symptoms of syringomyelia. The gliosis and cavitation had resulted in interruption of the lateral and anterior spinothalamic tracts as they decussated in the anterior gray and white commissures of the spinal cord at the level of the eighth cervical and first thoracic segments of the spinal cord. Because of uneven growth of the cavitation, the condition was worse on the left side than the right. Because tactile discrimination was normal in both upper limbs, the fasciculus cuneatus in both posterior white columns was unaffected. This dissociated sensory loss is characteristic of this disease.
5. The peculiar stamping gait and the swaying posture on closing the eyes are the characteristic signs of loss of appreciation of proprioceptive sensation from the lower limbs. These, together with the inability to detect the vibrations of a tuning fork placed on the medial malleoli of both legs, indicated that the patient had a lesion involving the fasciculus gracilis in both posterior white columns. Further questioning of this patient indicated that he had been treated for syphilis. The diagnosis was tabes dorsalis.
6. The treatment of intractable pain in terminal cancer is a difficult problem. Narcotic drugs with their strong analgesic action are generally used. The likelihood that these drugs will be habit-forming is accepted in a dying patient. Alternative treatments include the continuous infusion of morphine directly into the spinal cord (see p. 164) or the surgical section of the nerve fibers carrying the sensations of pain into the nervous system. The techniques of posterior rhizotomy and cordotomy are described on page 164.
7. Spinal shock is a temporary interruption of physiologic function of the spinal cord following injury. It may in part be a vascular phenomenon involving the gray matter of the spinal cord; on the other hand, some authorities believe it is due to the sudden interruption of the influence of the higher centers on the local segmental reflexes. Whatever the cause, it usually disappears after 1 to 4 weeks. The condition is characterized by flaccid paralysis and loss of sensation and reflex activity below the level of the lesion; this includes paralysis of the bladder and rectum.

   Paraplegia in extension and paraplegia in flexion follow severe injury to the spinal cord. Paraplegia in extension indicates an increase in the extensor muscle tone owing to the overactivity of the γ efferent nerve fibers to the muscle spindles as the result of the release of these neurons from the higher centers. However, some neurologists believe that the vestibulospinal tracts are intact in these cases. Should all the descending tracts be severed, the condition of paraplegia in flexion occurs where the reflex responses are flexor in nature when a noxious stimulus is applied. Recall that paraplegia in extension and paraplegia in flexion occur only after spinal shock has ceased. Paraplegia in extension may change to paraplegia in flexion if the damage to the spinal cord becomes more extensive and the vestibulospinal tracts are destroyed.

8. If this patient is assumed to have a lesion in the left internal capsule following a cerebral hemorrhage, the corticospinal fibers would have been interrupted as they descended through the posterior limb of the internal capsule. Because most of these fibers crossed to the right side at the decussation of the pyramids or lower down at the segmental level of the spinal cord, the muscles of the opposite side would have been affected. Interruption of these corticospinal fibers would have produced the following clinical signs: (a) a positive Babinski sign; (b) loss of superficial abdominal and cremasteric reflexes; and (c) loss of performance of fine, skilled voluntary movements, especially at the distal ends of the limbs.

   In patients with severe hemorrhage into the internal capsule, subcortical connections between the cerebral cortex and the caudate nucleus and the globus pallidus and other subcortical nuclei may be damaged. Moreover, some of the nuclei themselves may be destroyed. The interruption of other descending tracts from these subcortical centers would produce the following clinical signs: (a) severe paralysis on the opposite side of the body; (b) spasticity of the paralyzed muscles; (c) exaggerated deep muscle reflexes on the opposite side of the body to the lesion (clonus may be demonstrated); and (d) clasp-knife reaction, which may be felt in the paralyzed muscles.

9. A lateral radiograph of the thoracic part of the vertebral column showed a fracture dislocation involving the 10th vertebra. The first lumbar segment of the spinal cord is related to this vertebra. The first lumbar dermatome overlies the inguinal ligament, and total anesthesia over the right ligament would suggest a partial lesion of the spinal cord involving the total sensory input at that level. Loss of tactile discrimination and vibratory and proprioceptive senses in the right leg was caused by interruption of the ascending tracts in the posterior white column on the right side of the spinal cord. Loss of pain and temperature senses in the skin of the left leg was due to destruction of the crossed lateral spinothalamic tracts on the right side at the level of the lesion. Loss of tactile sense in the skin of the left leg was caused by the destruction of the crossed anterior spinothalamic tracts on the right side. Spastic paralysis of the right leg and the right-sided ankle clonus were due to the interruption of the right-sided descending tracts other than the corticospinal tracts. The right-sided Babinski response was brought about by the interruption of the corticospinal fibers on the right side.

   The complete motor and sensory loss of both legs and the absence of all deep tendon reflexes of both legs during the first 12 hours were due to spinal shock.

10. The spinal cord occupies the vertebral canal of the vertebral column, and therefore, under normal circumstances, it is well protected. Unfortunately, once the integrity of the bony protection is destroyed by a fracture dislocation, especially in the thoracic region, where the canal is of small diameter, the bone can damage the cord and sever it just as a knife cuts through butter. All patients suspected of having an injury to the spine must be handled with great care to prevent the bones undergoing further dislocation and causing further injury to the cord. The patient should be carefully lifted by multiple supports under the feet, knees, pelvis, back, shoulders, and head and placed on a rigid stretcher or board for transportation to the nearest medical center.

11. Urinary infection secondary to bladder dysfunction is extremely common in paraplegic patients. The patient has not only lost control of the bladder but also does not know when it is full. An indwelling Foley catheter is placed in the bladder immediately for continuous drainage, and antibiotic therapy is instituted.

    Bedsores are very common in patients who have lost all sensory perception over their bony points, such as the ischial tuberosities and the sacrum. Bedsores are best prevented by (a) keeping the skin scrupulously clean, (b) frequently changing the position of the patient, and (c) keeping soft padding beneath the bony points.

    Nutritional deficiency is common in active individuals who are suddenly confined to their beds and who are paralyzed. Loss of appetite must be combated by giving the patients a high-calorie diet that has all the required ingredients, especially vitamins.

    Muscle spasms occur in paraplegia in extension or paraplegia in flexion and may follow only minor stimuli. The cause is unknown, but neuronal irritation at the site of injury may be responsible. Warm baths are helpful, but, occasionally, in extreme cases, nerve section may be necessary.

    Pain occurs in the anesthetic areas in about 25% of patients who have a complete section of the spinal cord. The pain may be burning or shooting and superficial, or deep visceral. Here again, neuronal irritation at the site of injury may be responsible. Analgesics should be tried, but in some individuals, rhizotomy or even chordotomy may be necessary.

    An accurate prognosis is not possible until the stage of spinal shock has ended, and this may last as long as 4 weeks.

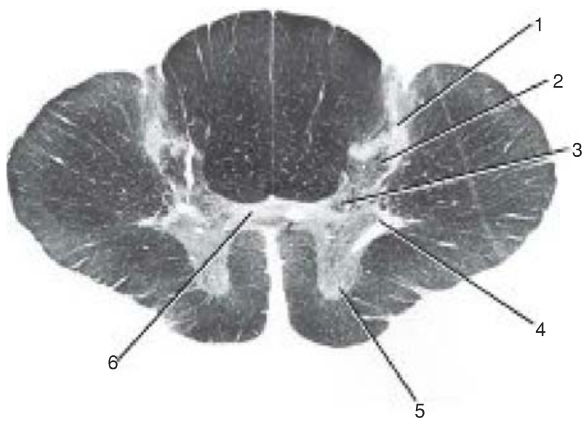
12. The characteristic coarse tremor of the right hand (pill rolling) and right arm, the unsmiling masklike face with unblinking eyes, and the cogwheel rigidity of the involved muscles make the diagnosis of early Parkinson disease (paralysis agitans) certain. Degenerative lesions occur in the substantia nigra and other subcortical nuclei, including the lentiform nucleus. The loss of normal function of these subcortical areas and the absence of their influence on the lower motor neurons are responsible for the increased tone and tremor.
13. (a) Intention tremor occurs in cerebellar disease. (b) Athetosis occurs in lesions of the corpus striatum. (c) Chorea occurs in lesions of the corpus striatum. (d) Dystonia occurs in disease of the lentiform nucleus. (e) Hemiballismus occurs in disease of the opposite subthalamic nucleus.

Review Questions

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

1. The following statements concern the spinal cord:
   (a) The anterior and posterior gray columns on the two sides are united by a white commissure.
   (b) The terminal ventricle is the expanded lower end of the fourth ventricle.
   (c) The larger nerve cell bodies in the anterior gray horns give rise to α efferent nerve fibers in the anterior roots.
   (d) The substantia gelatinosa groups of cells are located at the base of each posterior gray column.
   (e) The nucleus dorsalis (Clarke column) is a group of nerve cells found in the posterior gray column and restricted to the lumbar segments of the cord.
2. The following statements concern the white columns of the spinal cord:
   (a) The posterior spinocerebellar tract is situated in the posterior white column.
   (b) The anterior spinothalamic tract is found in the anterior white column.
   (c) The lateral spinothalamic tract is found in the anterior white column.
   (d) The fasciculus gracilis is found in the lateral white column.
   (e) The rubrospinal tract is found in the anterior white column.
3. The following statements concern the spinal cord:
   (a) The spinal cord has a cervical enlargement for the brachial plexus.
   (b) The spinal cord possesses spinal nerves that are attached to the cord by anterior and posterior rami.
   (c) In the adult, the spinal cord usually ends inferiorly at the lower border of the fourth lumbar vertebra.
   (d) The ligamentum denticulatum anchors the spinal cord to the pedicles of the vertebra along each side.
   (e) The central canal does not communicate with the fourth ventricle of the brain.

Directions: Matching Questions. Questions 4 through 9 apply to the following figure. Match the numbers listed on the left with the appropriate lettered structure listed on the right. Each lettered option may be selected once, more than once, or not at all.



4. Number 1 (a) Nucleus proprius
5. Number 2 (b) Preganglionic sympathetic outflow
6. Number 3 (c) Nucleus dorsalis
7. Number 4 (d) Substantia gelatinosa
8. Number 5 (e) None of the above
9. Number 6

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

10. The following statements concern the cell of origin of the tracts listed below:
    (a) The fasciculus cuneatus arises from cells in the substantia gelatinosa.
    (b) The anterior spinothalamic arises from cells in the posterior root ganglion.
    (c) The fasciculus gracilis arises from cells in the nucleus dorsalis (Clarke column).
    (d) The anterior spinocerebellar arises from cells in the posterior root ganglion.
    (e) The lateral spinothalamic arises from cells in the substantia gelatinosa.

11. The following statements concern the courses taken by the tracts listed below:
    (a) The fasciculus gracilis does not cross to the opposite side of the neural axis.
    (b) The spinotectal tract does not cross to the opposite side of the spinal cord.
    (c) The lateral spinothalamic tract does not cross to the opposite side of the spinal cord.
    (d) The posterior spinocerebellar tract crosses to the opposite side of the neural axis.
    (e) The anterior spinothalamic tract immediately crosses to the opposite side of the spinal cord.
12. The following statements concern the nucleus of termination of the tracts listed below:
    (a) The posterior white column tracts terminate in the inferior colliculus.
    (b) The spinoreticular tract terminates on the neurons of the hippocampus.
    (c) The spinotectal tract terminates in the inferior colliculus.
    (d) The anterior spinothalamic tract terminates in the ventral posterolateral nucleus of the thalamus.
    (e) The anterior spinocerebellar tract terminates in the dentate nucleus of the cerebellum.
13. The following statements relate sensations with the appropriate nervous pathways:
    (a) Two-point tactile discrimination travels in the lateral spinothalamic tract.
    (b) Pain travels in the anterior spinothalamic tract.
    (c) Unconscious muscle joint sense travels in the anterior spinocerebellar tract.
    (d) Pressure travels in the posterior spinothalamic tract.
    (e) Vibration travels in the posterior spinocerebellar tract.
14. The following statements concern the gating theory of pain:
    (a) Stimulation of small non–pain-conducting fibers in a peripheral nerve may reduce pain sensitivity.
    (b) Massage applied to the skin over a painful joint may reduce pain sensitivity.
    (c) Stimulation of δ A- and C-type fibers in a spinal nerve posterior root may decrease pain sensitivity.
    (d) Degeneration of large non–pain-conducting fibers in a peripheral nerve decreases pain sensitivity.
    (e) Inhibition of pain conduction in the spinal cord does not involve connector neurons.
15. The following statements concern the reception of pain:
    (a) Serotonin is not a transmitter substance in the analgesic system.
    (b) Substance P is thought to be the neurotransmitter at the synapses where the first-order neuron terminates on the cells in the posterior gray column of the spinal cord.
    (c) Enkephalins and endorphins may stimulate substance P release in the posterior gray column of the spinal cord.
    (d) Many of the tracts conducting the initial, sharp, pricking pain terminate in the dorsal anterolateral nucleus of the thalamus.
    (e) The slow-conducting C-type fibers are responsible for prolonged, burning pain.
16. The following statements concern the corticospinal tracts:
    (a) They occupy the posterior limb of the internal capsule.
    (b) They are mainly responsible for controlling the voluntary movements in proximal limb muscles.
    (c) They arise as axons of the pyramidal cells in the fourth layer of the cerebral cortex.
    (d) Those that control the movements of the upper limb originate in the precentral gyrus on the medial side of the cerebral hemisphere.
    (e) Those that are concerned with the movements of the lower limb are located in the medial area of the middle three fifths of the basis pedunculi.
17. The following statements concern the course taken by the tracts listed below:
    (a) The rubrospinal tract crosses the midline of the neuroaxis in the medulla oblongata.
    (b) The tectospinal tract (most of the nerve fibers) crosses the midline in the posterior commissure.
    (c) The vestibulospinal tract crosses the midline in the midbrain.
    (d) The lateral corticospinal tract crosses the midline in the medulla oblongata.
    (e) The anterior corticospinal tract crosses the midline in the midbrain.
18. The following statements concern the nerve cells of origin for the tracts listed below:
    (a) The vestibulospinal tract originates from cells of the medial vestibular nucleus situated in the pons.
    (b) The tectospinal tract originates from cells in the inferior colliculus.
    (c) The lateral corticospinal tract originates from cells in area 4 of the cerebral cortex.
    (d) The rubrospinal tract originates from cells in the reticular nucleus.
    (e) The reticulospinal tract originates from cells in the reticular formation that is confined to the midbrain.
19. The following statements concern muscle movement:
    (a) Muscular fasciculation is seen only with rapid destruction of lower motor neurons.
    (b) Muscle spindle afferent nerve fibers send information only to the spinal cord.
    (c) In Parkinson disease, dopamine-secreting neurons that originate in the vestibular nucleus degenerate.
    (d) Brain neuronal activity preceding a voluntary movement is limited to the precentral gyrus (area 4).
    (e) Hyperactive ankle-jerk reflexes and ankle clonus indicate release of lower motor neuron supraspinal inhibition.

20. After a hemorrhage into the left internal capsule in a right-handed person, the following sign or symptom might be present:
    (a) Left homonymous hemianopia
    (b) Right astereognosis
    (c) Left hemiplegia
    (d) Normal speech
    (e) Left-sided positive Babinski response
21. A patient with a traumatic lesion of the left half of the spinal cord at the level of the eighth cervical segment might present the following sign(s) and symptom(s):
    (a) Loss of pain and temperature sensations on the left side below the level of the lesion
    (b) Loss of position sense of the right leg
    (c) Right hemiplegia
    (d) Left positive Babinski sign
    (e) Right-sided lower motor paralysis in the segment of the lesion and muscular atrophy

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is BEST in each case.

22. Which of the signs and symptoms listed below indicate a cerebellar lesion?
    (a) Cogwheel rigidity
    (b) Hemiballismus
    (c) Chorea
    (d) Intention tremor
    (e) Athetosis
23. Which of the following regions of white matter would not contain corticospinal fibers?
    (a) Pyramid of medulla oblongata
    (b) Lateral white column of the spinal cord
    (c) Cerebral peduncle of the midbrain
    (d) Anterior limb of the internal capsule
    (e) Corona radiata

Directions: Each case history is followed by questions. Read the case history, then select the ONE BEST lettered answer.

A 59-year-old woman was experiencing pain in the back and showed evidence of loss of pain and temperature sensations down the back of her left leg. Three years previously, she underwent a radical mastectomy followed by radiation and chemotherapy for advanced carcinoma of her right breast.

Examination showed that she was experiencing pain over the lower part of the back, with loss of the skin sensations of pain and temperature down the back of her left leg in the area of the S1–S3 dermatomes. No other neurologic deficits were identified. Radiographic examination of the vertebral column showed evidence of metastases in the bodies of the 9th and 10th thoracic vertebrae. An MRI revealed an extension of one of the metastases into the vertebral canal, with slight indentation of the spinal cord on the right side.

24. The pain in the back could be explained in this patient by the following facts **except**:
    (a) Osteoarthritis of the joints of the vertebral column
    (b) Metastases in the bodies of the 9th and 10th thoracic vertebrae
    (c) Tumor pressure on the spinal nerve posterior roots
    (d) A prolapsed intervertebral disc pressing on the spinal nerves
    (e) Spasm of the postvertebral muscles following tumor pressure on the posterior white columns of the spinal cord
25. Loss of pain and temperature sensations down the back of the patient's left leg in the area of the S1–S3 dermatomes could be explained by the following factual statements **except**:
    (a) Lateral spinothalamic tracts in the spinal cord conduct the sensations of pain.
    (b) Lateral spinothalamic tracts are laminated, with the sacral segments of the body located most laterally.
    (c) The sacral segments of the tracts are the most exposed to external cord pressure from a metastasizing tumor.
    (d) Loss of temperature sensations in the leg could be explained by tumor pressure on the anterior spinothalamic tract.
26. The severe intractable pain in the back in this patient could be treated by the following methods **except**:
    (a) Prescription of salicylates in large doses
    (b) Intramuscular injection of morphine or even the direct injection of the opiate into the spinal cord
    (c) Posterior rhizotomy
    (d) Cordotomy
    (e) Injection of opiates into the subarachnoid space

Answers and Explanations to Review Questions

1. C is correct. The larger nerve cell bodies in the anterior gray horns give rise to α efferent nerve fibers in the anterior roots. A. The anterior and posterior gray columns on the two sides of the spinal cord are united by a gray commissure formed of gray matter. B. The terminal ventricle is the expanded lower end of the central canal. D. The substantia gelatinosa group of cells is located at the apex of each posterior gray column throughout the length of the spinal cord. E. The nucleus dorsalis (Clarke column) is a group of nerve cells found in the posterior gray column and extending from the eighth cervical segment of the cord to the third or fourth lumbar segment.
2. B is correct. In the spinal cord, the anterior spinothalamic tract is found in the anterior white column. A. The posterior spinocerebellar tract is situated in the lateral white column. C. The lateral spinothalamic tract is found in the lateral white

column. D. The fasciculus gracilis is found in the posterior white column. E. The rubrospinal tract is found in the lateral white column.

3. A is correct. The spinal cord has a cervical enlargement for the brachial plexus (Fig. 4-5). B. The spinal cord possesses spinal nerves that are attached to the cord by anterior and posterior nerve roots. C. In the adult, the spinal cord usually ends inferiorly at the lower border of the first lumbar vertebra. D. The ligamentum denticulatum anchors the spinal cord to the dura mater along each side. E. The central canal, which contains cerebrospinal fluid, communicates with the fourth ventricle of the brain.
4. D is correct.
5. A is correct.
6. C is correct.
7. B is correct.
8. E is correct. The structure is the anterior gray horn.
9. E is correct. The structure is the gray commissure.
10. E is correct. In the spinal cord, the lateral spinothalamic tract arises from cells in the substantia gelatinosa. A. The fasciculus cuneatus arises from cells in the posterior root ganglion. B. The anterior spinal thalamic arises from cells in the substantia gelatinosa. C. The fasciculus gracilis arises from cells in the posterior root ganglion. D. The anterior spinocerebellar arises from cells in Clarke column.
11. A is correct. The fasciculus gracilis does not cross to the opposite side of the neural axis. B. The spinotectal tract crosses to the opposite side of the spinal cord. C. The lateral spinothalamic tract crosses to the opposite side of the spinal cord. D. The posterior spinocerebellar tract does not cross to the opposite side of the spinal cord. E. The anterior spinothalamic tract crosses very obliquely to the opposite side of the spinal cord.
12. D is correct. The anterior spinothalamic tract terminates in the ventral posterolateral nucleus of the thalamus. A. The posterior white column tracts terminate in the nucleus gracilis and cuneatus. B. The spinoreticular tract terminates on the neurons of the reticular formation in the medulla, pons, and midbrain. C. The spinotectal tract terminates in the superior colliculus. E. The anterior spinocerebellar tract terminates in the cerebellar cortex.
13. C is correct. Unconscious muscle joint sense travels in the anterior spinocerebellar tract. A. Two-point tactile discrimination travels in the fasciculus cuneatus. B. Pain travels in the lateral spinothalamic tract. D. Pressure travels in the anterior spinothalamic tract. E. Vibration travels in the fasciculus gracilis.
14. B is correct concerning the gating theory of pain. Massage applied to the skin over a painful joint may reduce pain sensitivity. A. Stimulation of large non–pain-conducting fibers in a peripheral nerve may reduce pain sensitivity. C. Stimulation of δ A- and C-type fibers in a spinal nerve posterior root may increase pain sensitivity. D. Degeneration of large non–pain-conducting fibers in a peripheral nerve increases pain sensitivity. E. Inhibition of pain conduction in the spinal cord could be brought about by means of connector neurons.
15. E is correct. The slow-conducting C-type fibers are responsible for prolonged, burning pain. A. Serotonin is a transmitter substance in the analgesic system. B. Substance P is a peptide and is thought to be the neurotransmitter at the synapses where the first-order neuron terminates on the cells in the posterior gray column of the spinal cord. C. Enkephalins and endorphins may inhibit the release of substance P in the posterior gray column of the spinal cord. D. Many of the tracts conducting the initial, sharp, pricking pain terminate in the ventral posterolateral nucleus of the thalamus.
16. A is correct. The corticospinal tracts occupy the posterior limb of the internal capsule (Fig. 4-11). B. The corticospinal tracts are mainly responsible for controlling the voluntary movements in the distal muscles of the limbs. C. They arise as axons of the pyramidal cells in the fifth layer of the cerebral cortex. D. Those that control the movements of the upper limb originate in the precentral gyrus on the lateral side of the cerebral hemisphere. E. Those that are concerned with the movements of the lower limb are located in the lateral area of the middle three fifths of the basis pedunculi.
17. D is correct. The lateral corticospinal tract crosses the midline in the medulla oblongata (Fig. 4-21). A. The rubrospinal tract crosses the midline of the neuroaxis in the midbrain. B. The tectospinal tract (most of the nerve fibers) crosses the midline in the midbrain. C. The vestibulospinal tract does not cross the midline and descends through the medulla oblongata and spinal cord in the anterior white column (Figs. 4-20 and 4-25). E. The anterior corticospinal tract crosses the midline in the spinal cord.
18. C is correct. The lateral corticospinal tract originates from cells in area 4 of the cerebral cortex. A. The vestibulospinal tract originates from cells of the lateral vestibular nucleus situated in the pons. B. The tectospinal tract originates from cells in the superior colliculus. D. The rubrospinal tract originates from cells in the red nucleus. E. The reticulospinal tract originates from cells in the reticular formation in the midbrain, pons, and medulla oblongata.
19. E is correct. Hyperactive ankle-jerk reflexes and ankle clonus indicate lower motor neuron release from supraspinal inhibition. A. Muscular fasciculation is seen only with slow destruction of the lower motor neurons. B. Muscle spindle afferent nerve fibers send information to the brain as well as to the spinal cord. C. In Parkinson disease, dopamine-secreting neurons decrease in the substantia nigra. D. Brain neuronal activity preceding a voluntary movement is not limited to the precentral gyrus (area 4).
20. B is correct. Right astereognosis. A. Right homonymous hemianopia is seen. C. Right hemiplegia is present. D. Aphasia is present. E. A right-sided positive Babinski response is seen.

21. D is correct. Left positive Babinski sign is present. A. Pain and temperature sensations are lost on the right side below the level of the lesion. B. Position sense of the left leg is lost. C. Left hemiplegia is present. E. Left-sided lower motor paralysis is seen in the segment of the lesion and muscular atrophy.
22. D is correct. Intention tremor is present. A. Cogwheel rigidity occurs in Parkinson disease when the muscle resistance is overcome as a series of jerks. B. Hemiballismus is a rare form of involuntary movement confined to one side of the body; it occurs in disease of the subthalamic nuclei. C. Chorea consists of a series of continuous, rapid, involuntary, jerky, coarse, purposeless movements, which may take place during sleep; it occurs with lesions of the corpus striatum. E. Athetosis consists of continuous, slow, involuntary, dysrhythmic movements that are always the same in the same individual, and they disappear during sleep; it occurs with lesions of the corpus striatum.
23. D is correct. The anterior limb of the internal capsule does not contain corticospinal fibers.
24. E is correct. Spasm of the postvertebral muscles would not be produced by pressure on the posterior white columns of the spinal cord.
25. D is correct. The sensation of temperature travels in the lateral spinothalamic tract along with the pain impulses.
26. A is correct. Salicylates, such as aspirin, sodium salicylate, and diflunisal, are used clinically only for the relief of mild to moderate pain, as found in patients suffering from headache and dysmenorrhea.

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

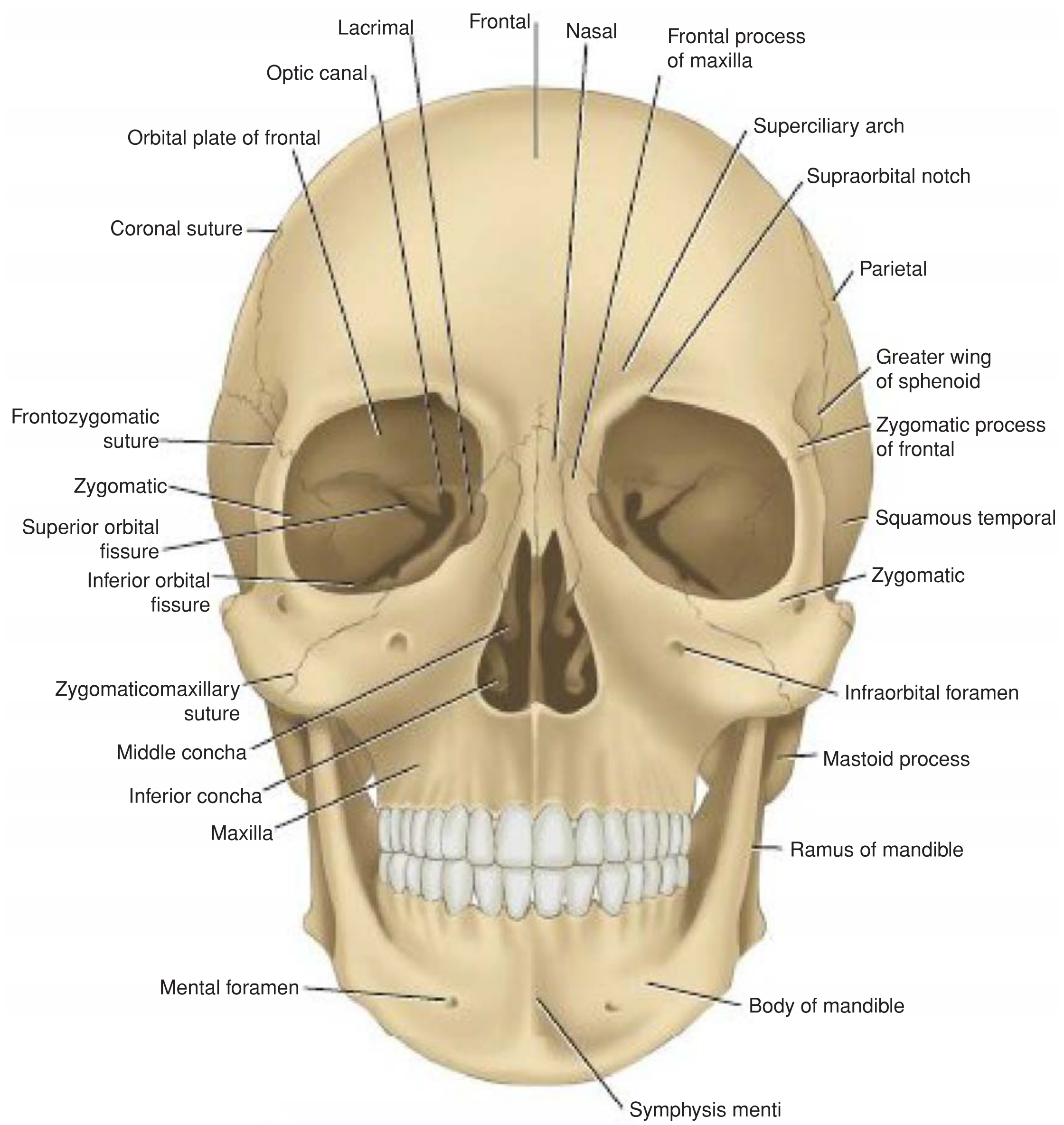


Figure 5-1 Bones of the anterior aspect of the skull.

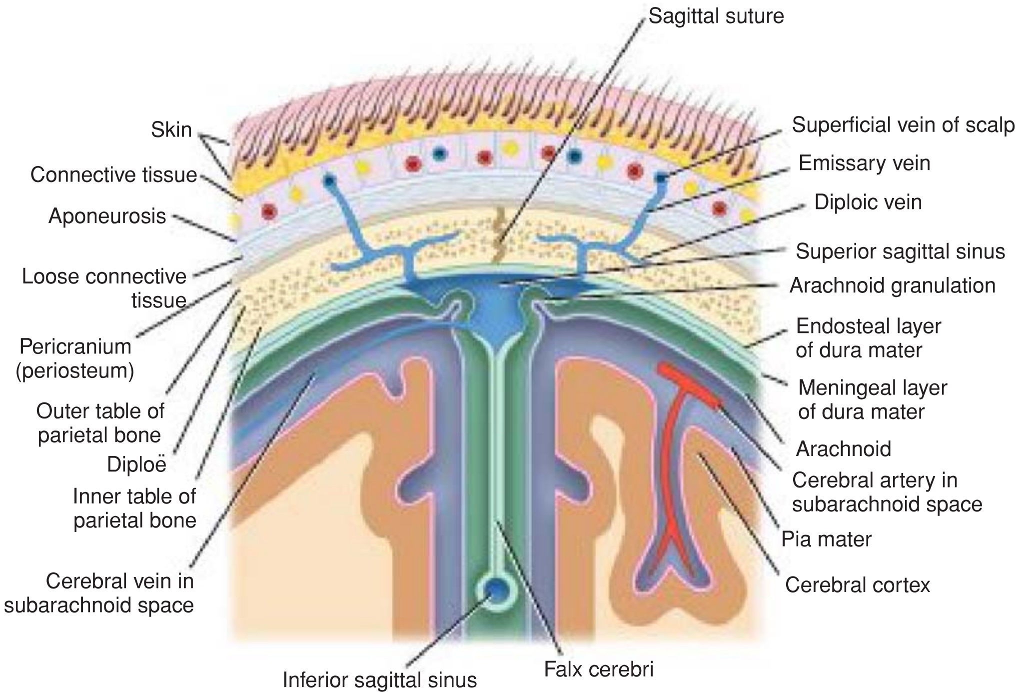


Figure 5-2 Coronal section of the upper part of the head showing the layers of the scalp, the sagittal suture of the skull, the falx cerebri, the superior and inferior sagittal venous sinuses, the arachnoid granulations, the emissary veins, and the relation of cerebral blood vessels to the subarachnoid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

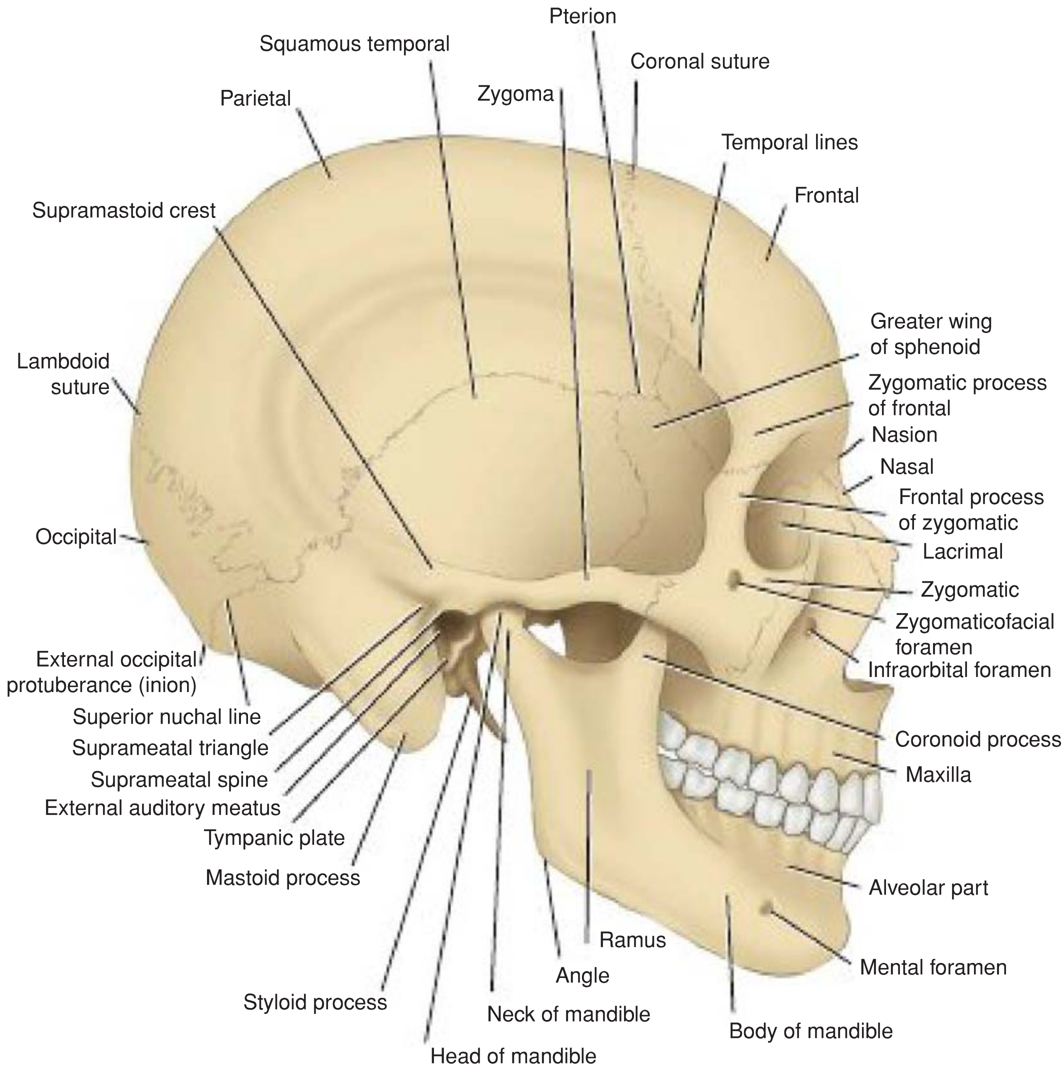


Figure 5-3 Bones of the lateral aspect of the skull.

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

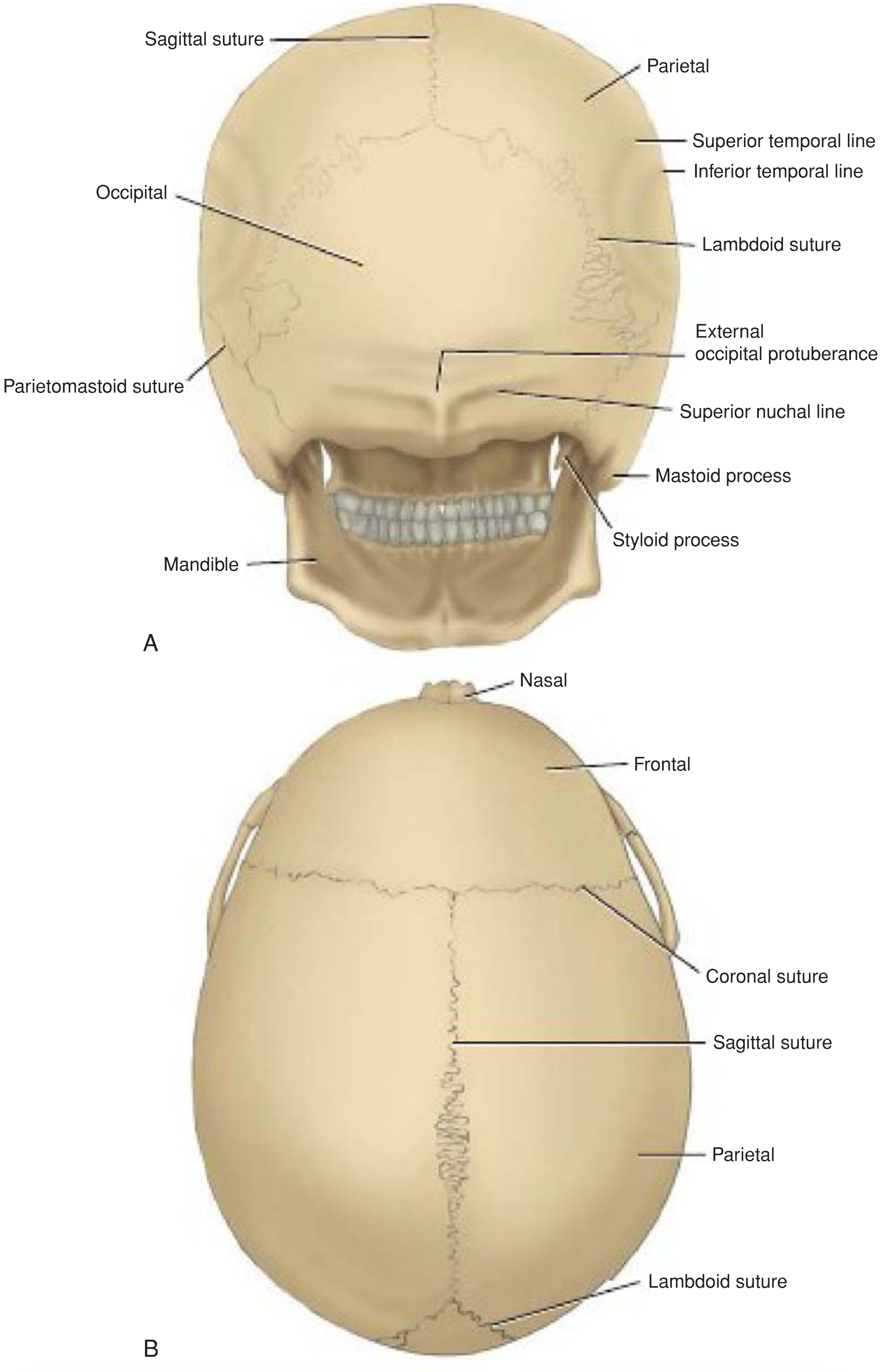


Figure 5-4 Bones of the skull viewed from the posterior (**A**) and superior (**B**) aspects.

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

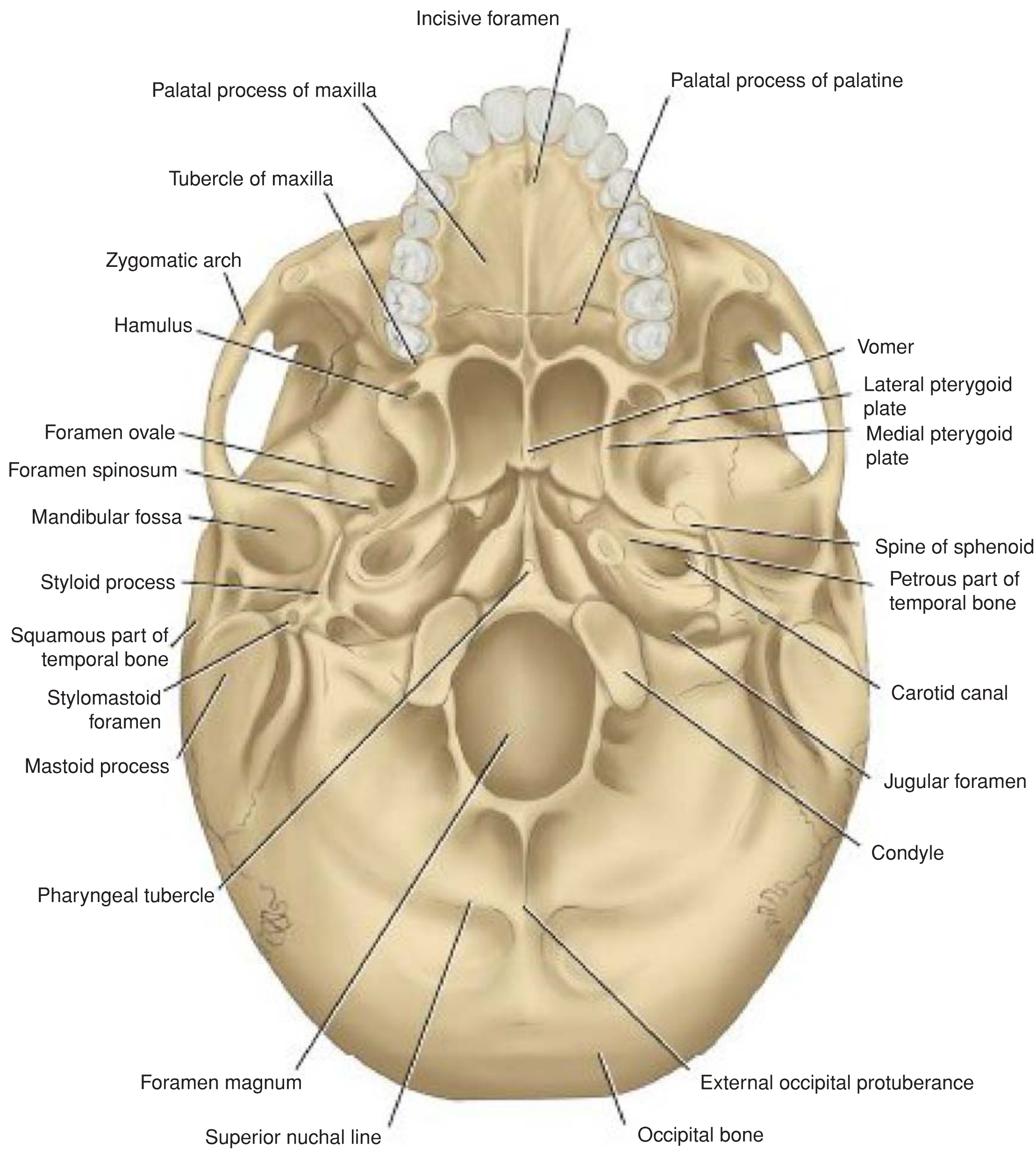


Figure 5-5 Inferior surface of the base of the skull.

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

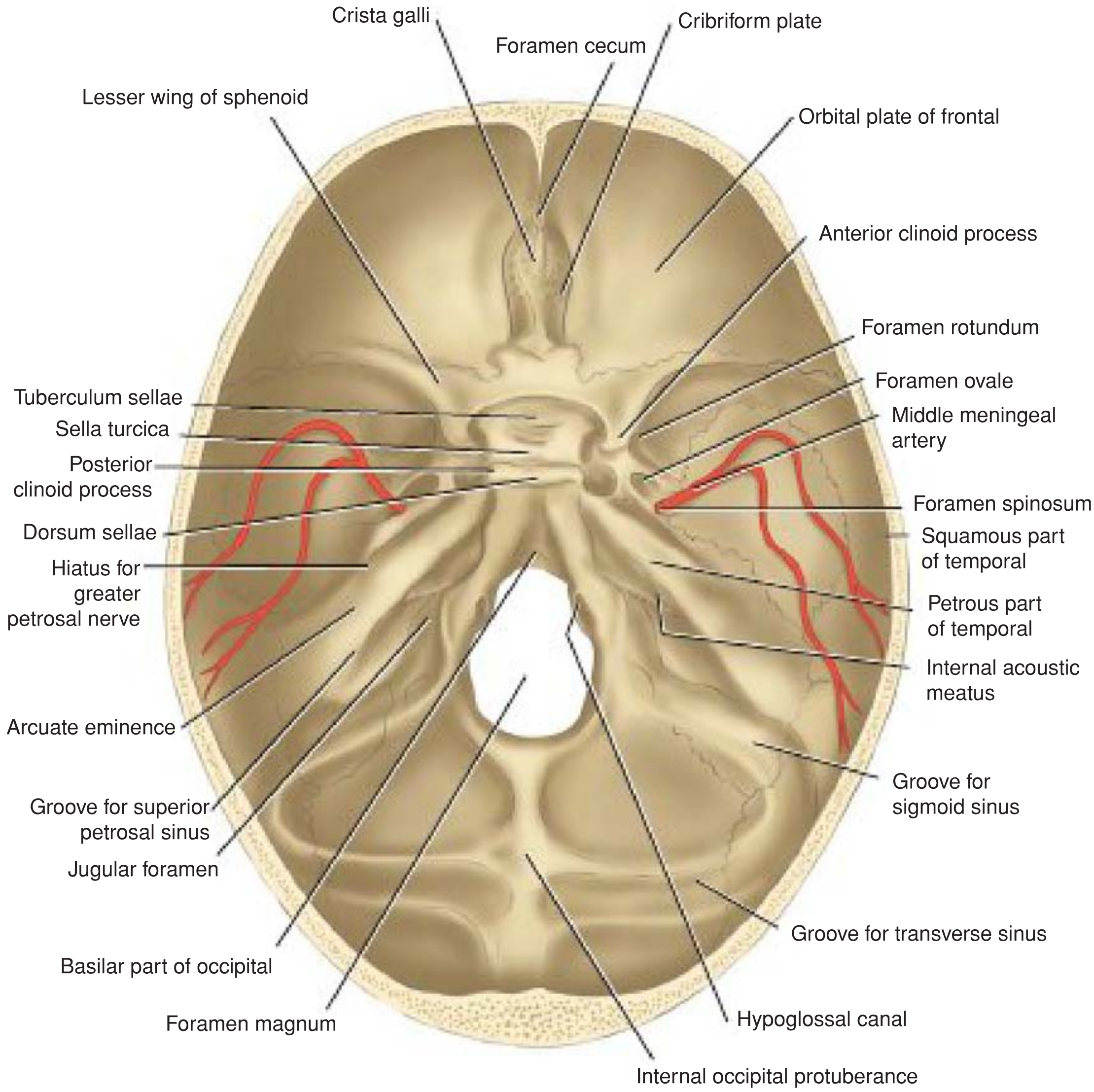


Figure 5-6 Internal surface of the base of the skull.

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

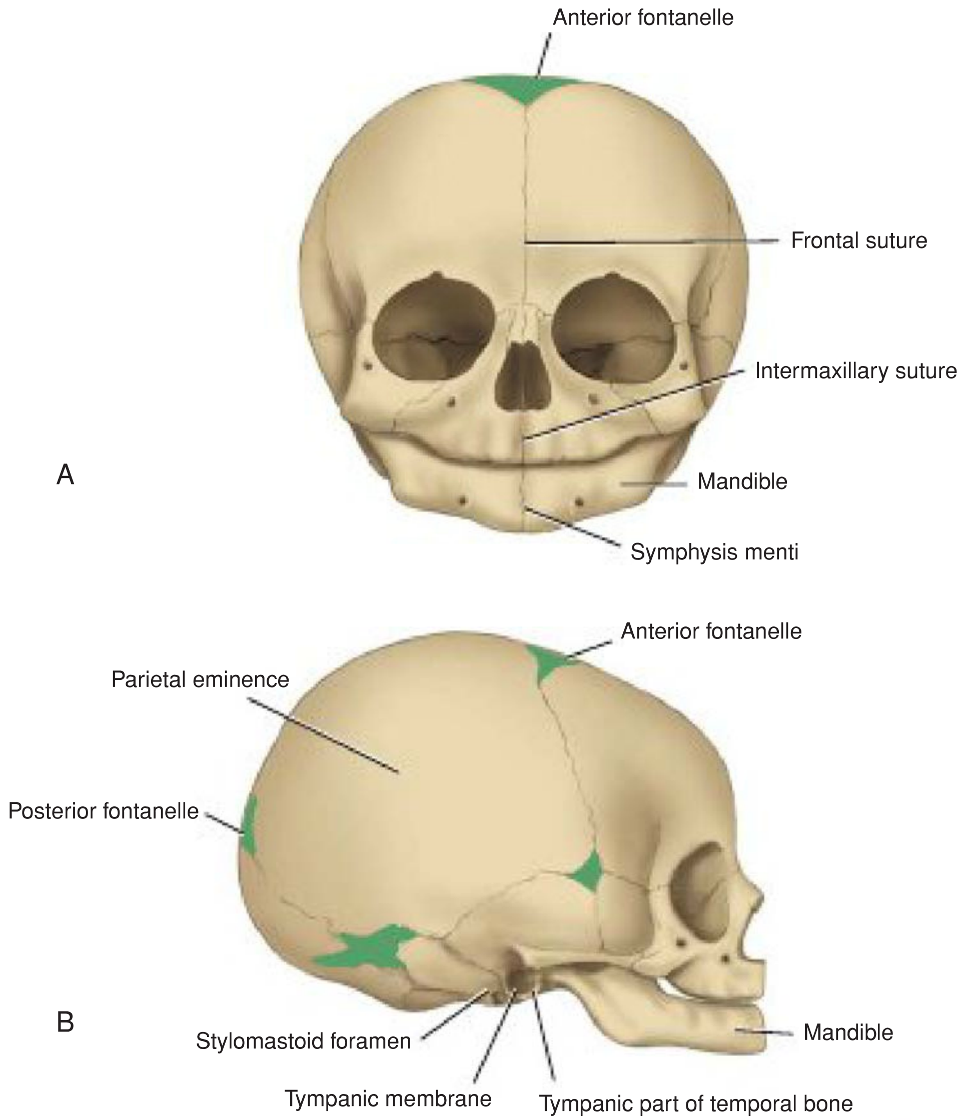


Figure 5-7 Neonatal skull as seen from the anterior (**A**) and lateral (**B**) aspects.

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.

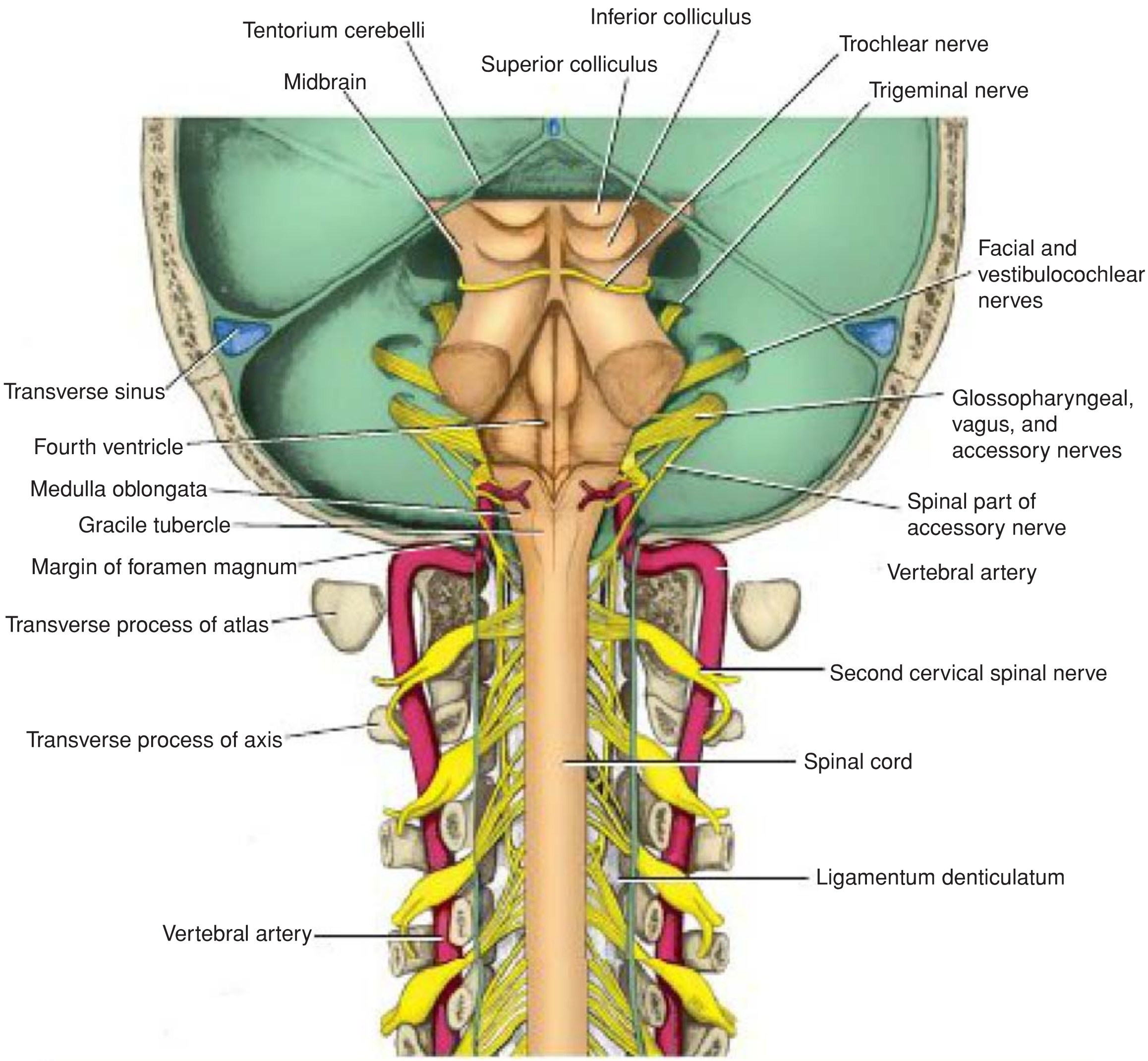


Figure 5-8 Posterior view of the brainstem after removal of the occipital and parietal bones and the cerebrum, the cerebellum, and the roof of the fourth ventricle. Laminae of the upper cervical vertebrae have also been removed.

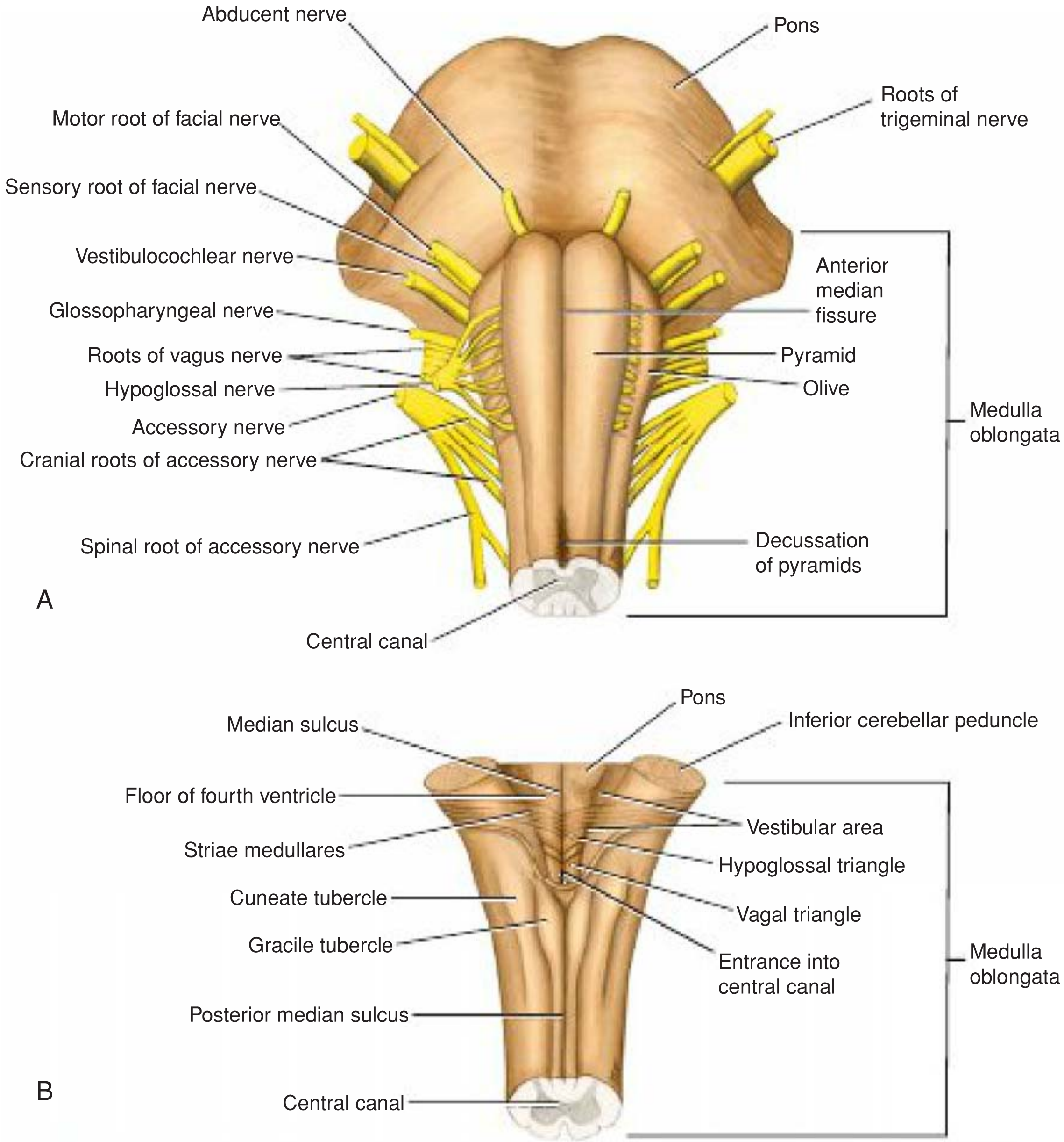


Figure 5-9 Medulla oblongata. **A:** Anterior view. **B:** Posterior view. Note that the roof of the fourth ventricle and the cerebellum have been removed.

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.

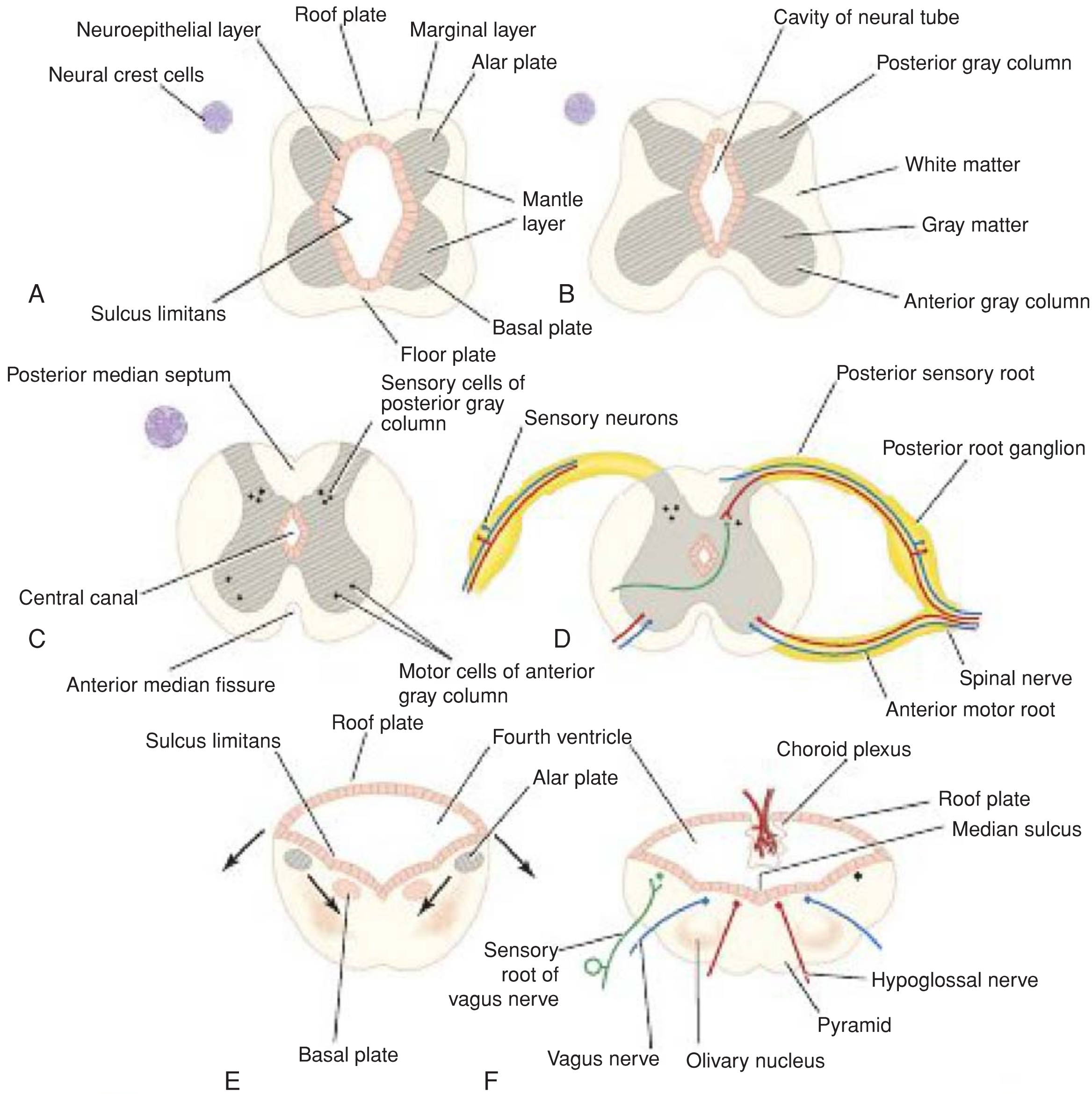


Figure 5-10 Stages in the development of the spinal cord (**A–D**) and the medulla oblongata (**E, F**). The neural crest cells will form the first afferent sensory neurons in the posterior root ganglia of the spinal nerves and the sensory ganglia of the cranial nerves.

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.

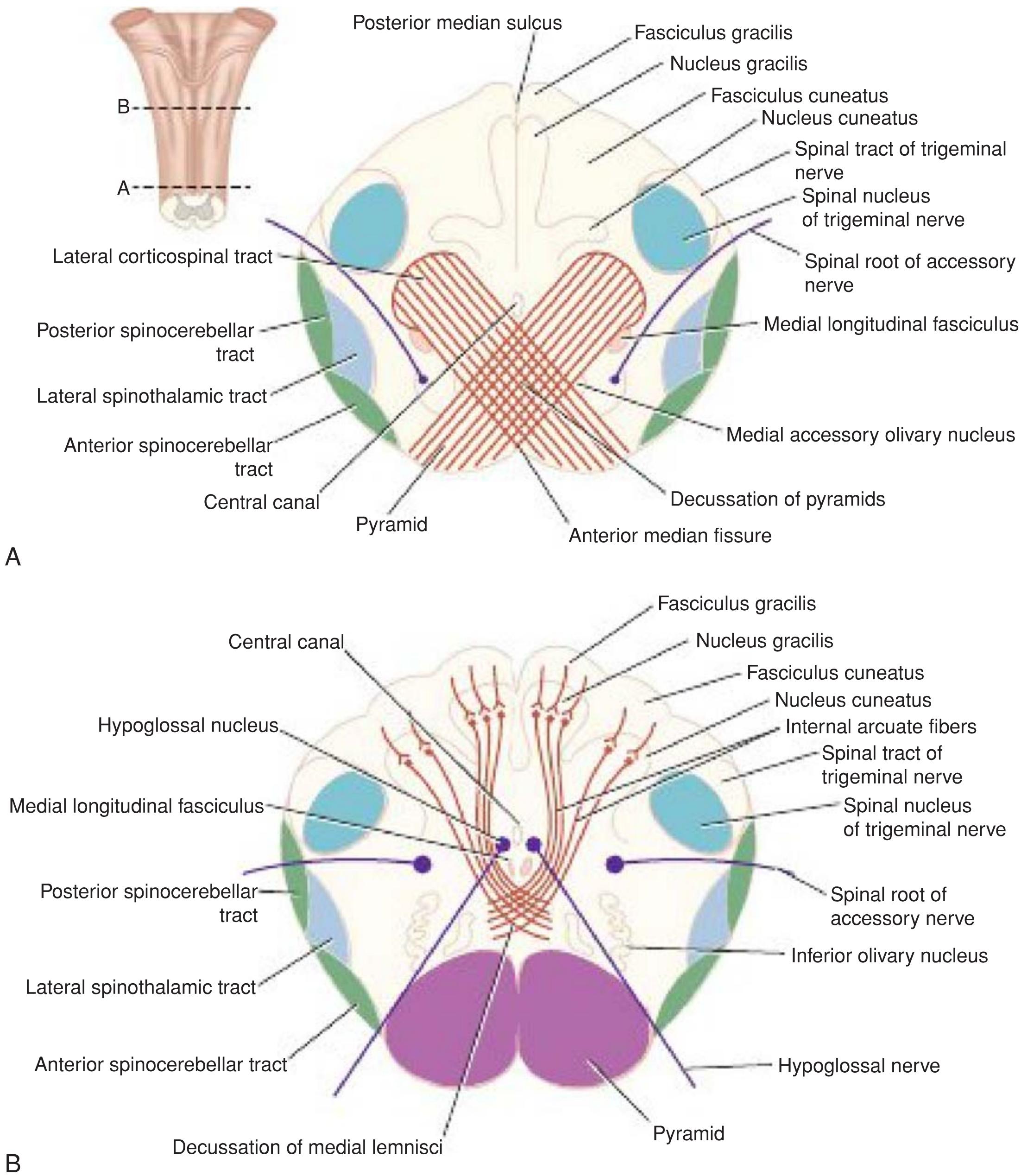


Figure 5-11 Transverse sections of the medulla oblongata. **A:** Level of decussation of the pyramids. **B:** Level of decussation of the medial lemnisci.

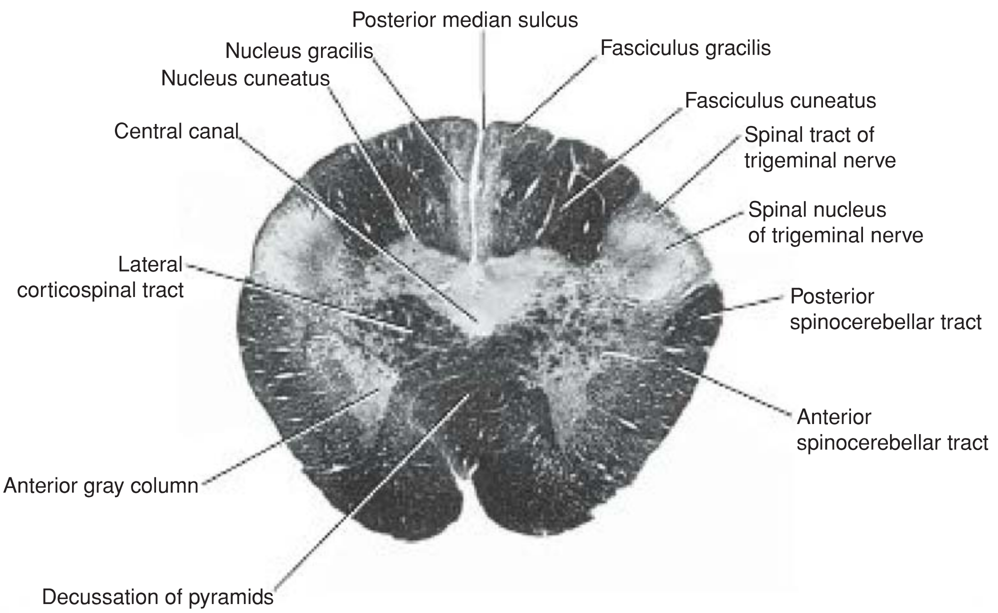


Figure 5-12 Transverse section of the medulla oblongata at the level of decussation of the pyramids. (Weigert stain.)

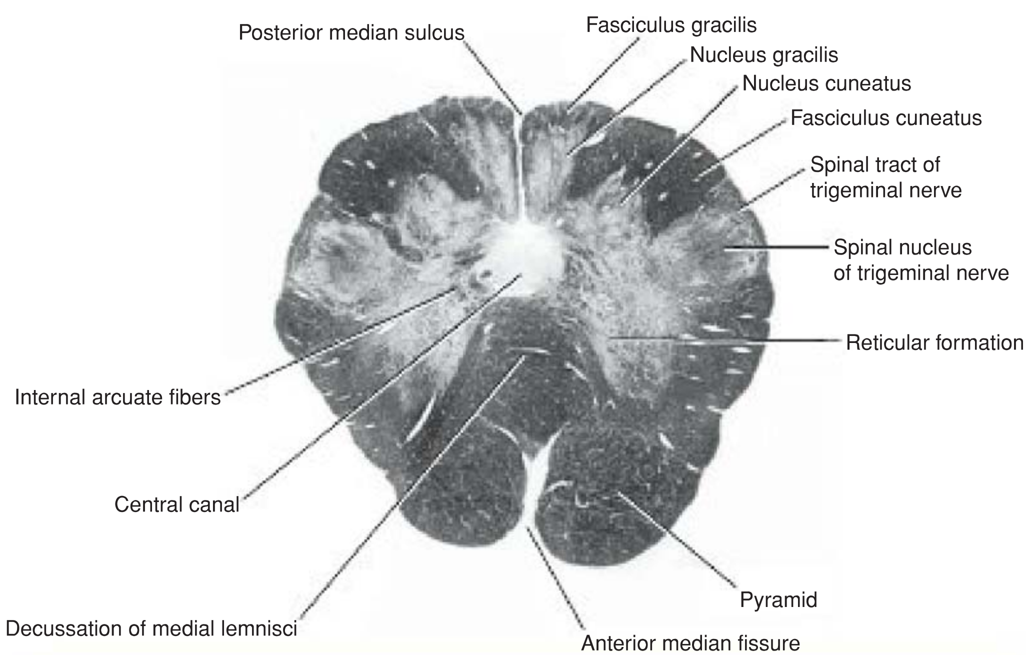


Figure 5-13 Transverse section of the medulla oblongata at the level of decussation of the medial lemnisci. (Weigert stain.)

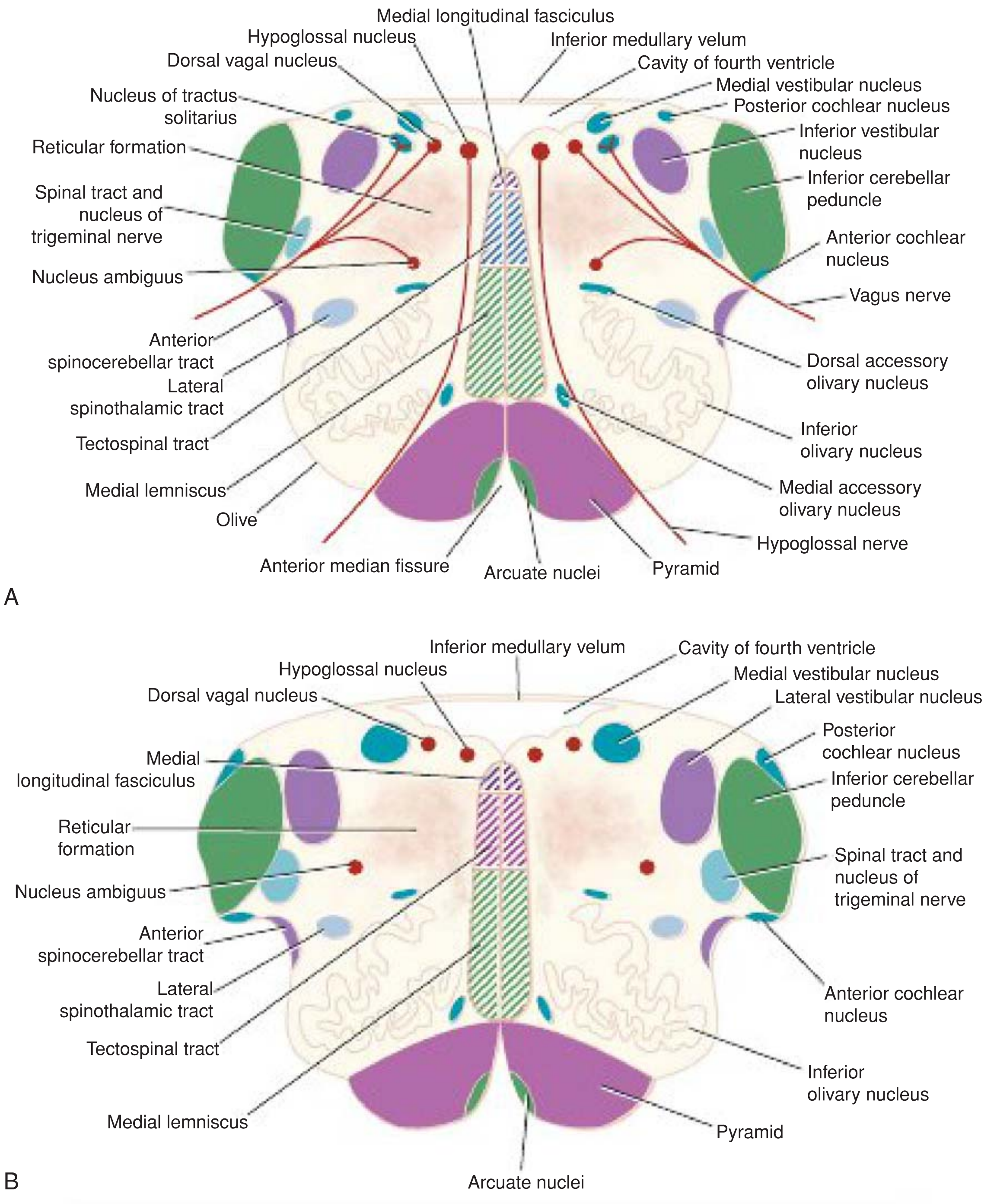


Figure 5-14 Transverse sections of the medulla oblongata at the level of the middle of the olivary nuclei (**A**) and the superior part of the olivary nuclei just inferior to the pons (**B**).

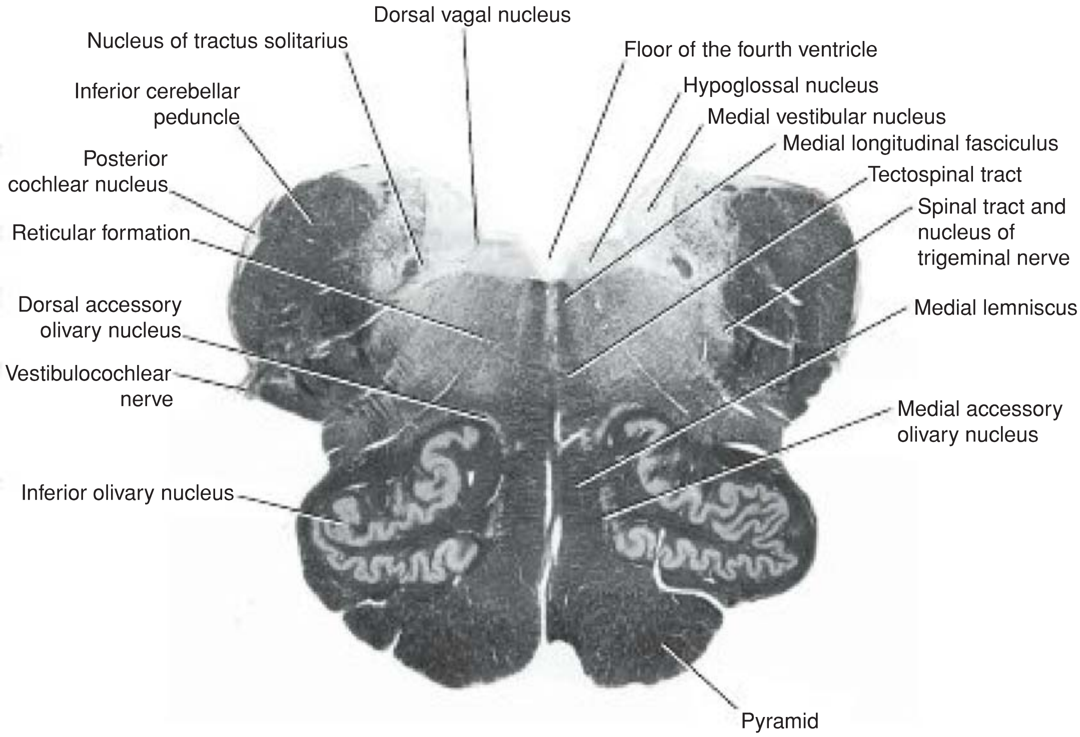


Figure 5-15 Transverse section of the medulla oblongata at the level of the middle of the olivary nuclei. (Weigert stain.)

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.

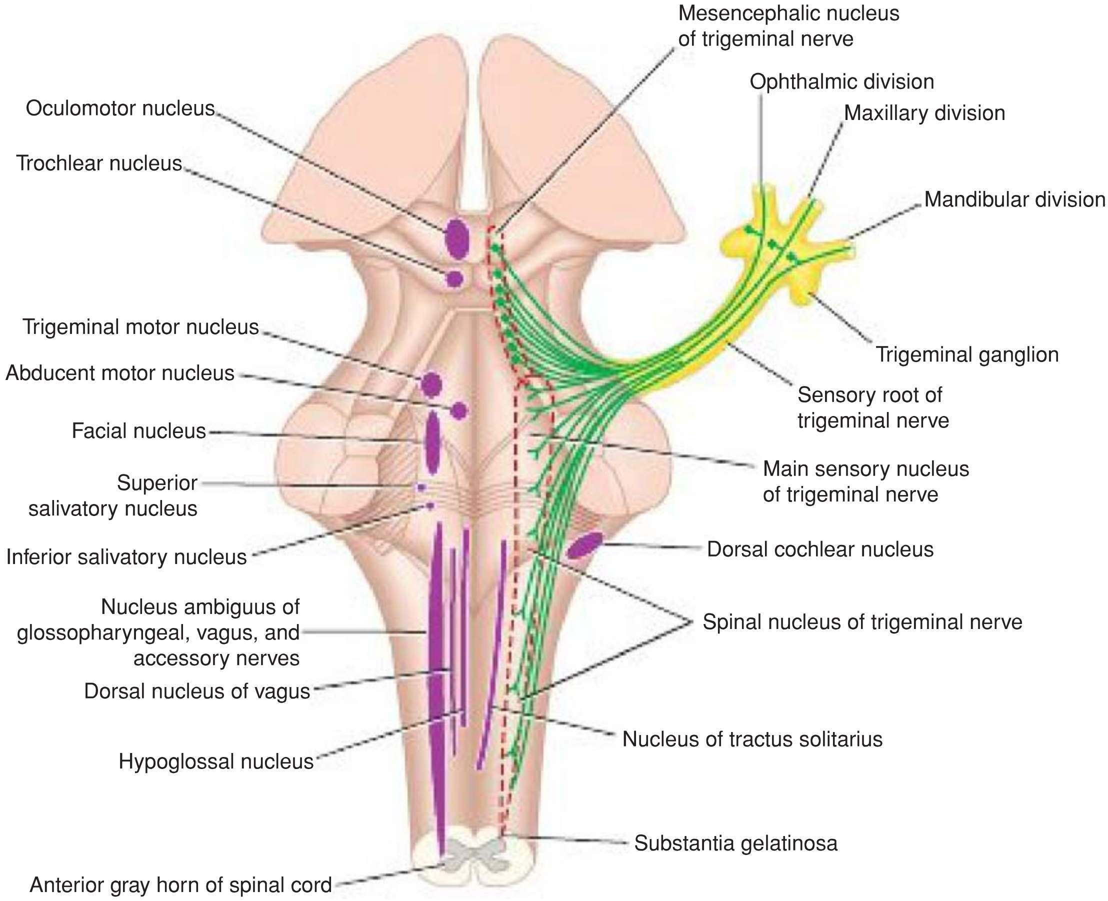


Figure 5-16 Position of the cranial nerve nuclei within the brainstem. The hatched area indicates the position of the vestibular nuclei.

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.

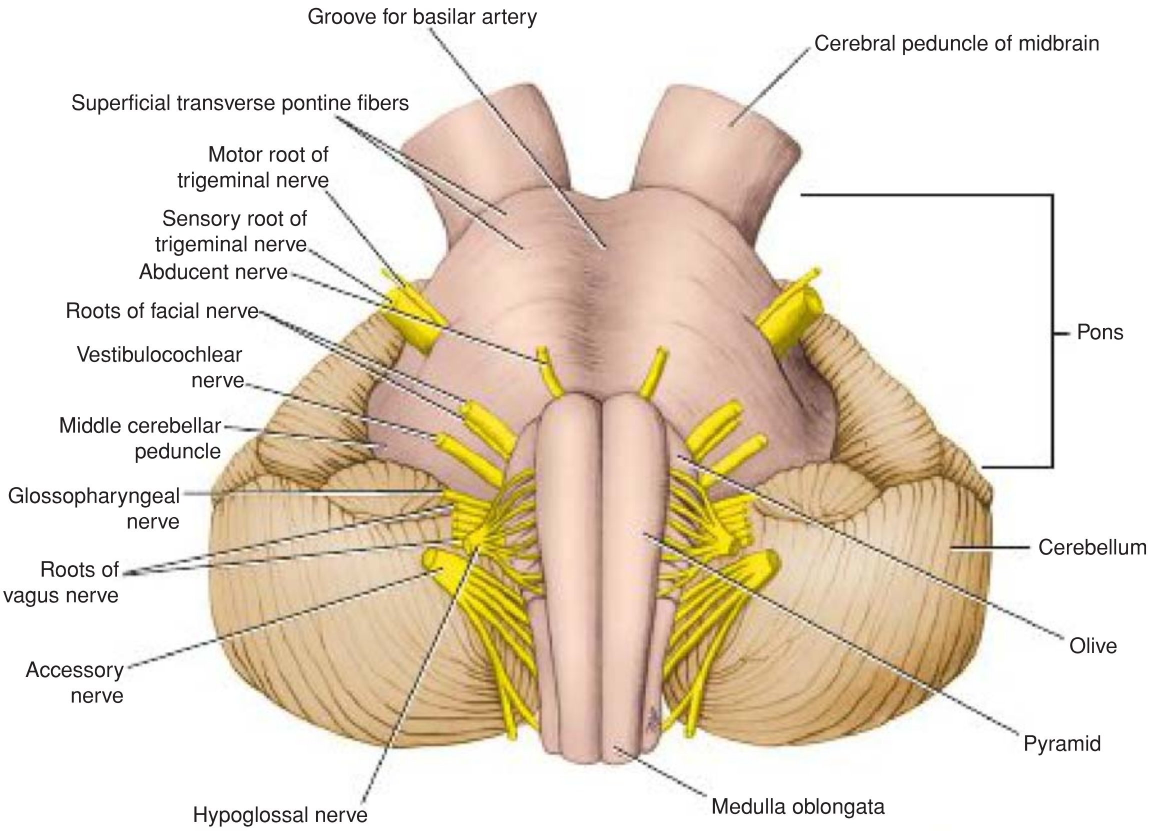


Figure 5-17 Anterior surface of the brainstem showing the pons.

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

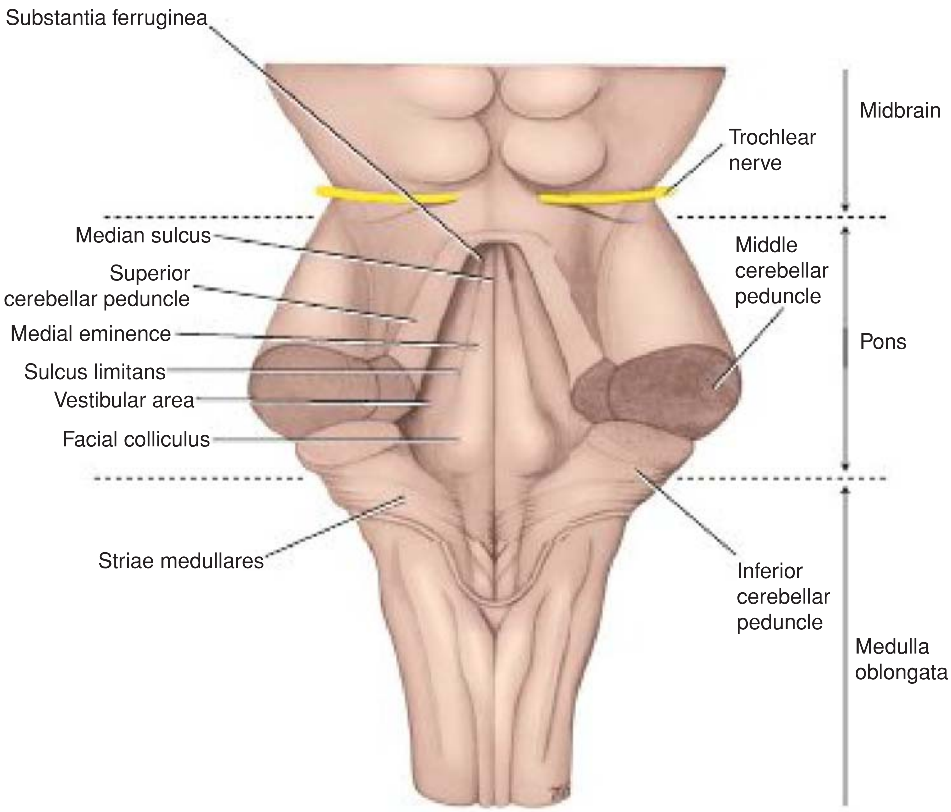


Figure 5-18 Posterior surface of the brainstem showing the pons. The cerebellum has been removed.

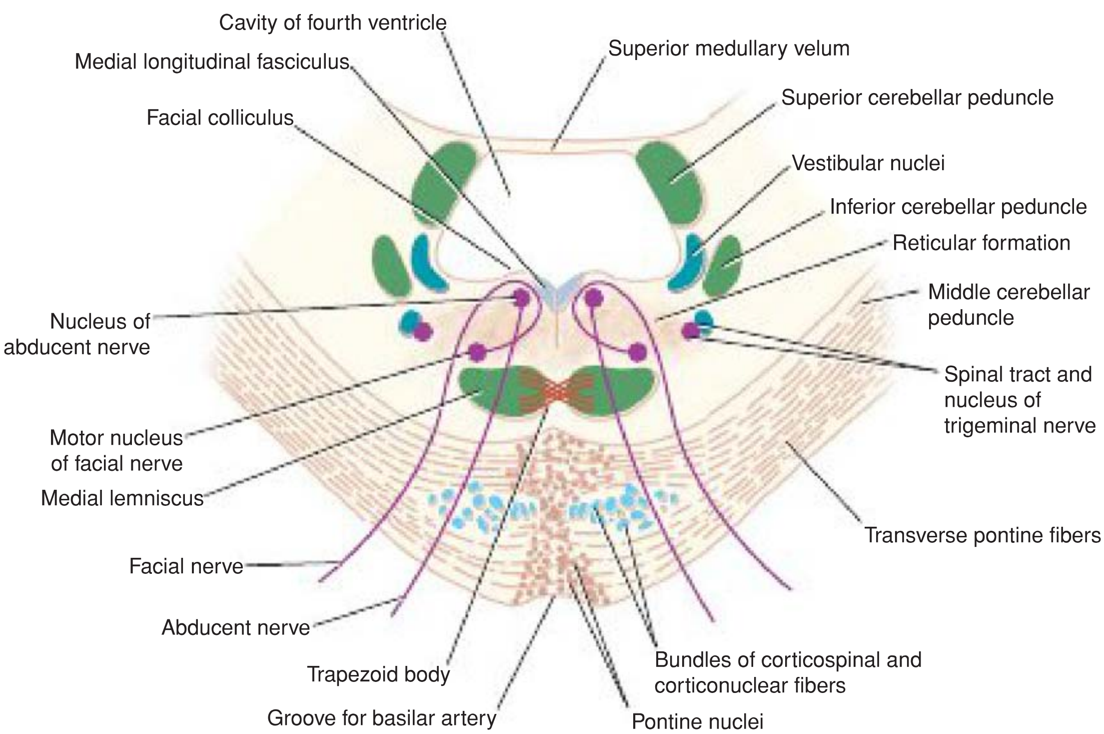


Figure 5-19 Transverse section through the caudal part of the pons at the level of the facial colliculus.

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

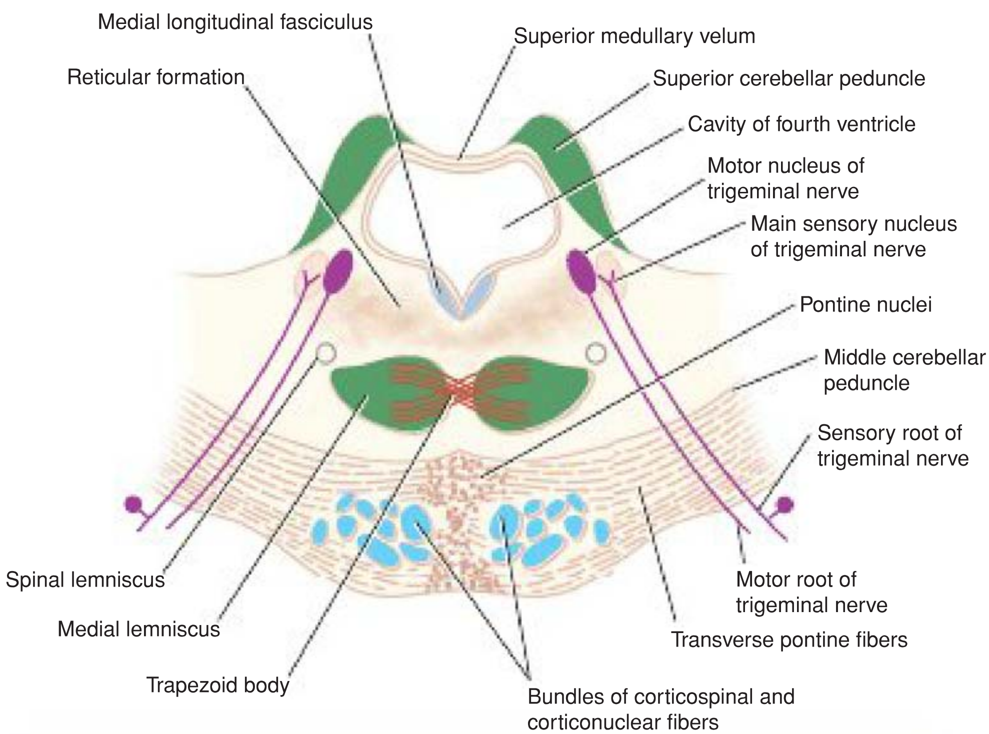


Figure 5-20 Transverse section through the pons at the level of the trigeminal nuclei.

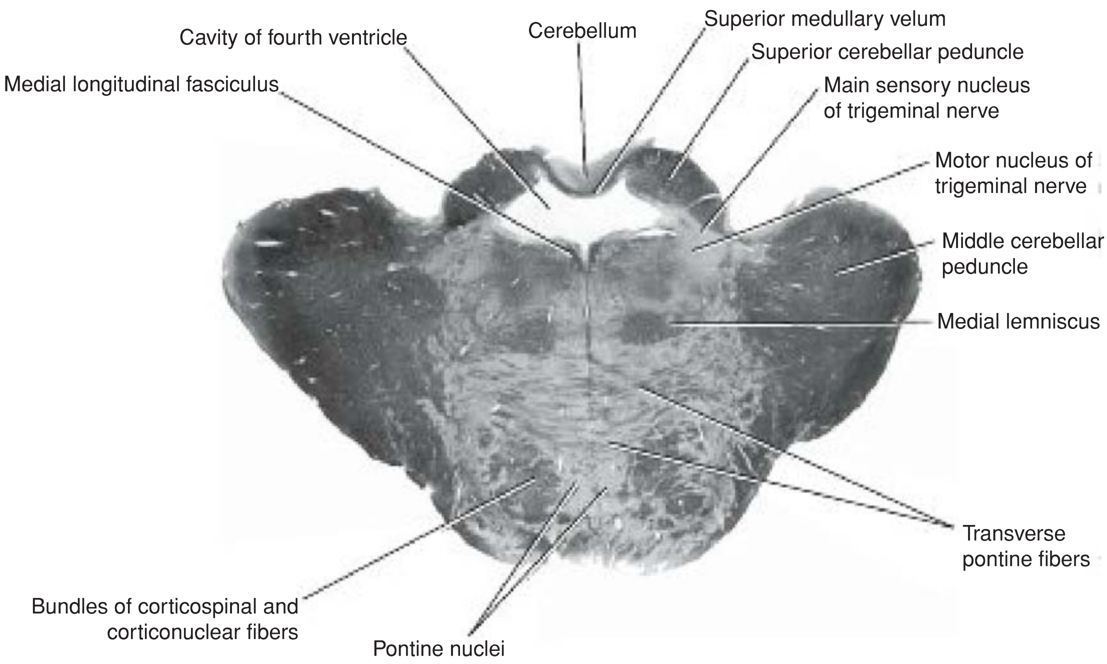


Figure 5-21 Photomicrograph of a transverse section of the pons at the level of the trigeminal nuclei.

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**.

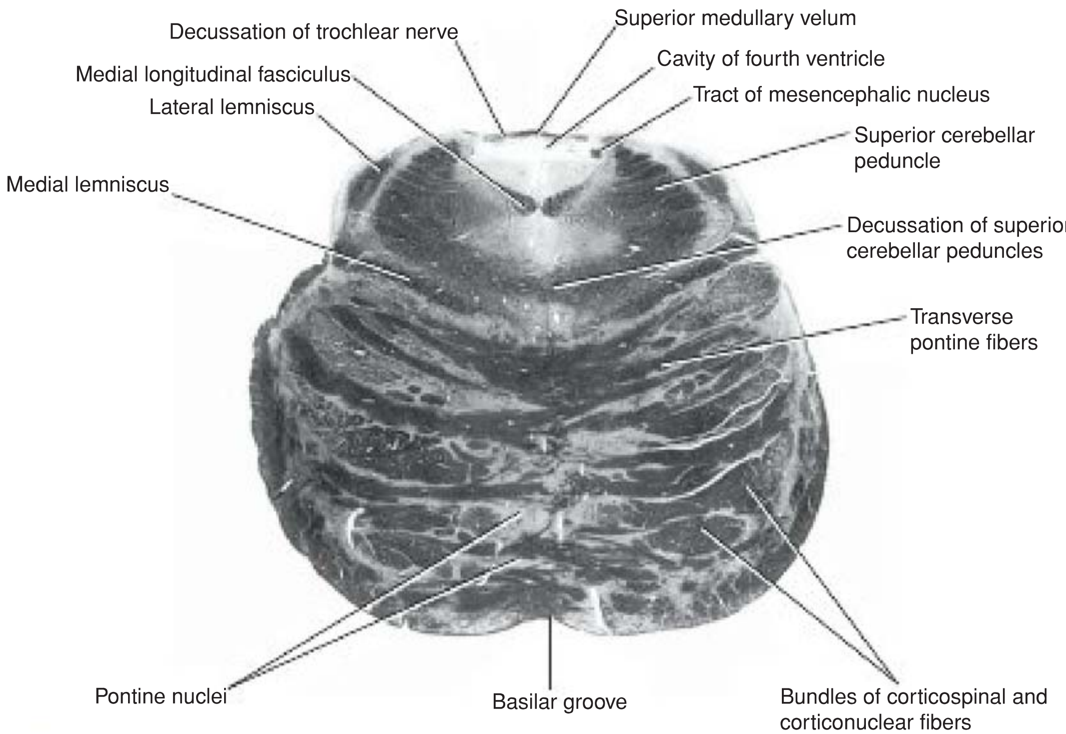


Figure 5-22 Photomicrograph of a transverse section of the most rostral part of the pons.

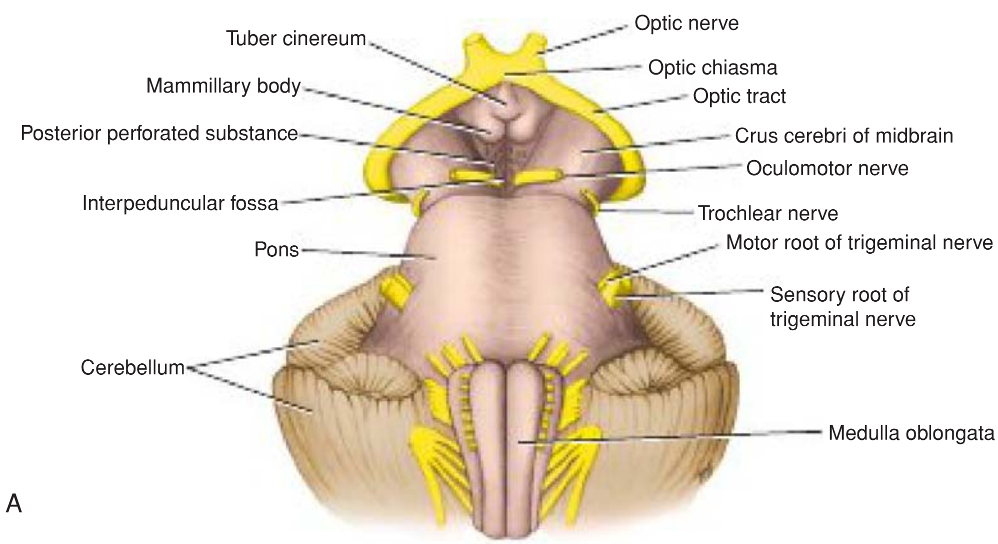
The **trapezoid body** and the **medial lemniscus** are situated in the same position as they were in the previous section (see Fig. 5-20). The **lateral** and **spinal lemnisci** lie at the lateral extremity of the medial lemniscus (see Figs. 5-20 and 5-22).

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**.



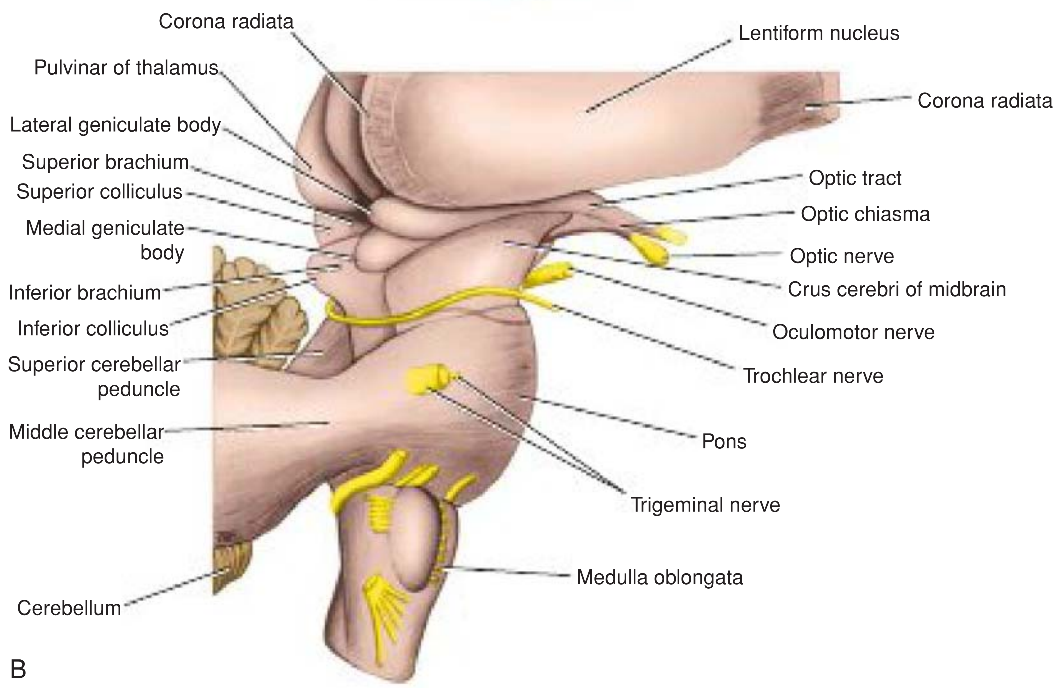


Figure 5-23 The midbrain. **A:** Anterior view. **B:** Lateral view.

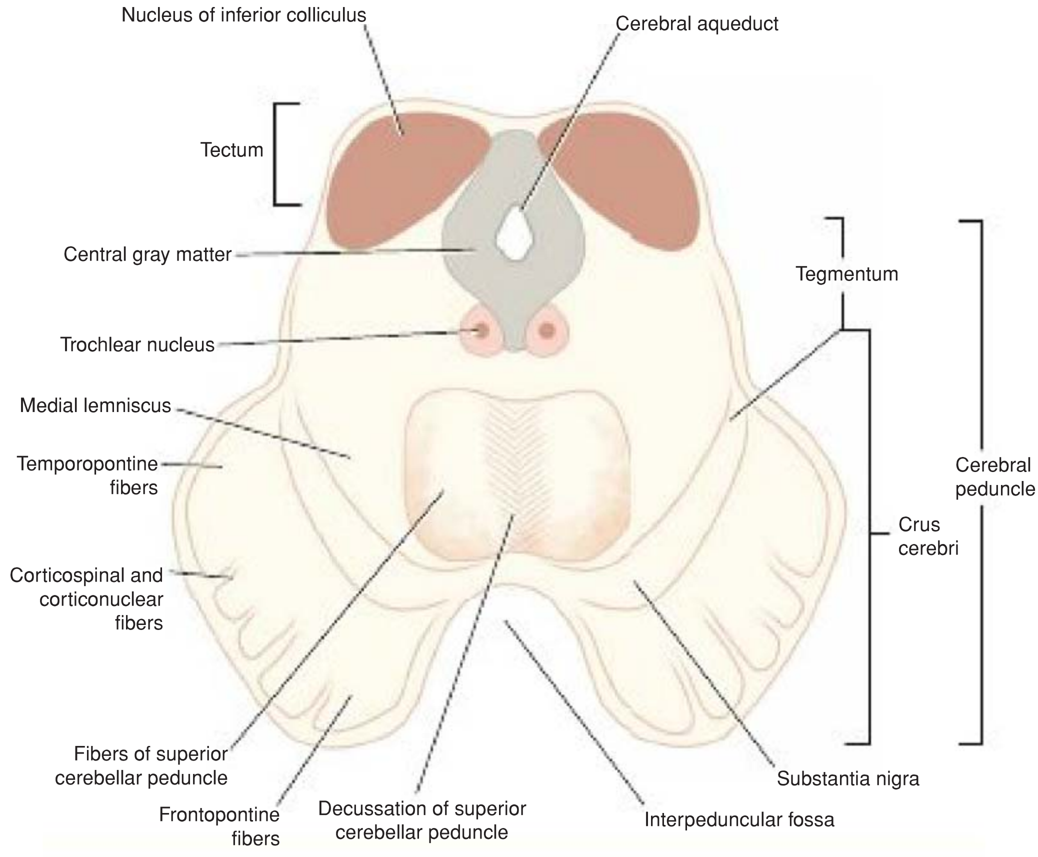


Figure 5-24 Transverse section of the midbrain through the inferior colliculi shows the division of the midbrain into the tectum and the cerebral peduncles. Note that the cerebral peduncles are subdivided by the substantia nigra into the tegmentum and the crus cerebri.

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.

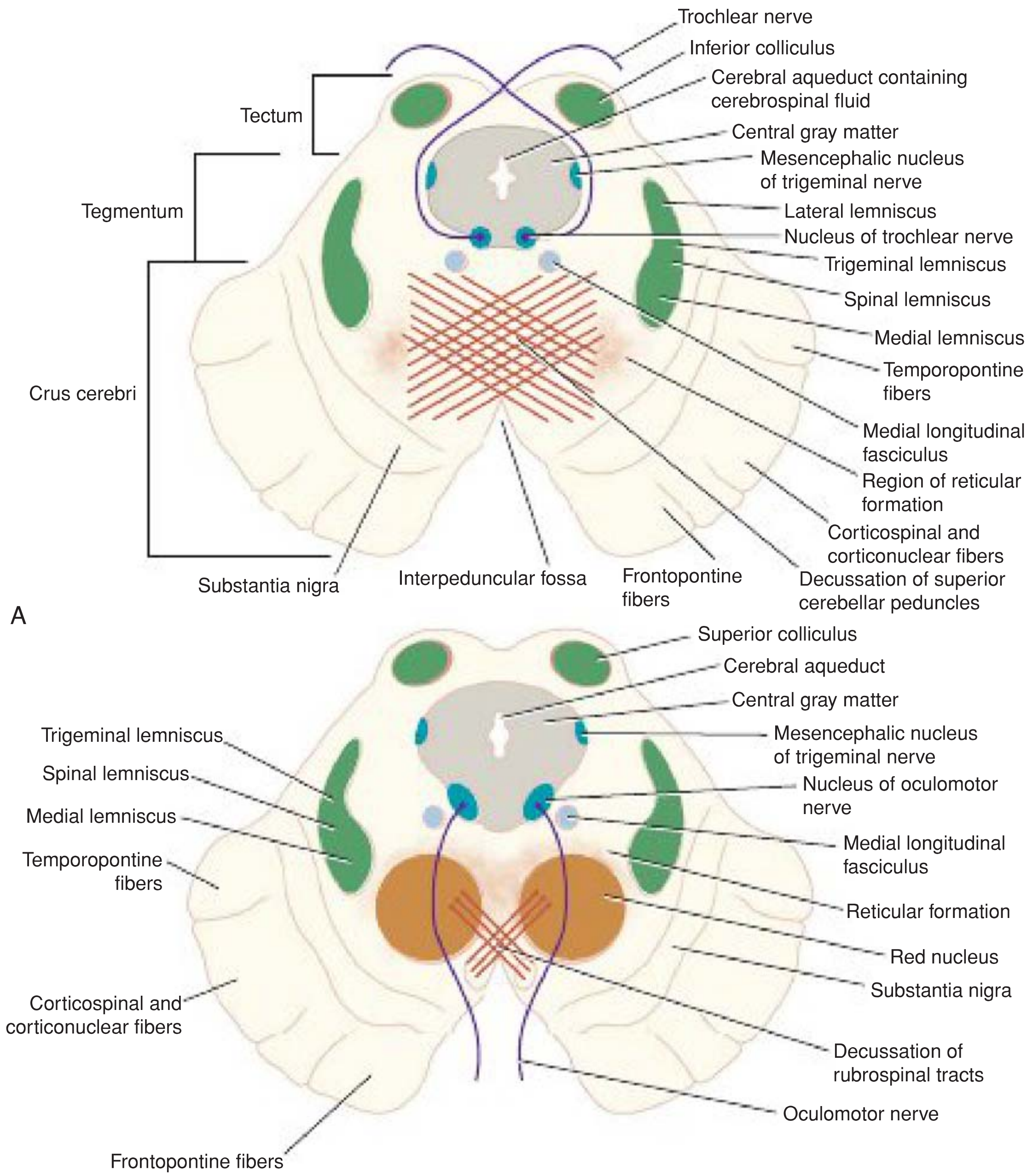


Figure 5-25 Transverse sections of the midbrain. **A:** At the level of the inferior colliculus. **B:** At the level of the superior colliculus. Note that trochlear nerves completely decussate within the superior medullary velum.

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

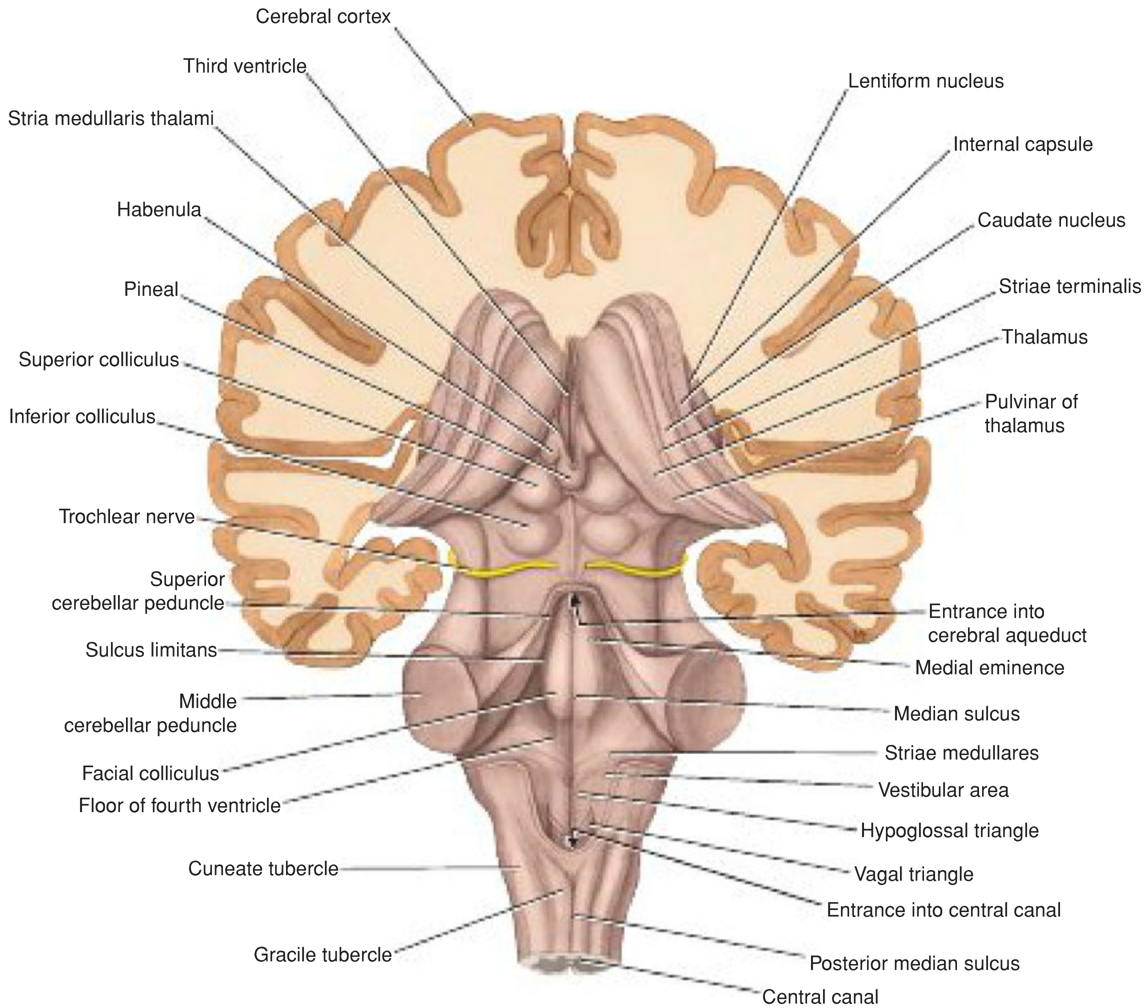


Figure 5-26 Posterior view of the brainstem showing the two superior and the two inferior colliculi of the tectum.

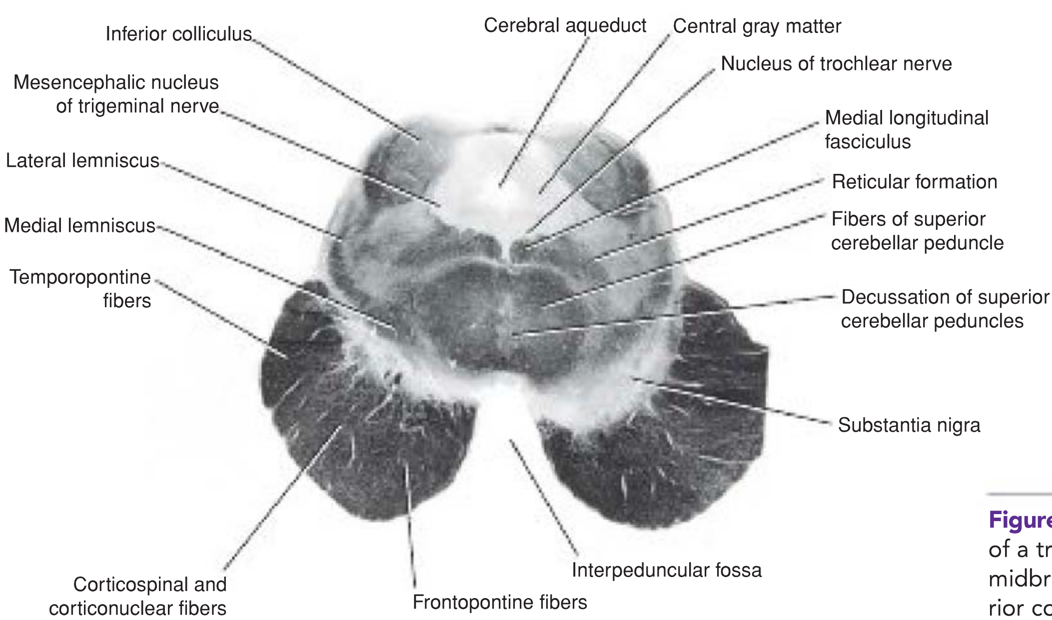


Figure 5-27 Photomicrograph of a transverse section of the midbrain at the level of the inferior colliculus. (Weigert stain.)

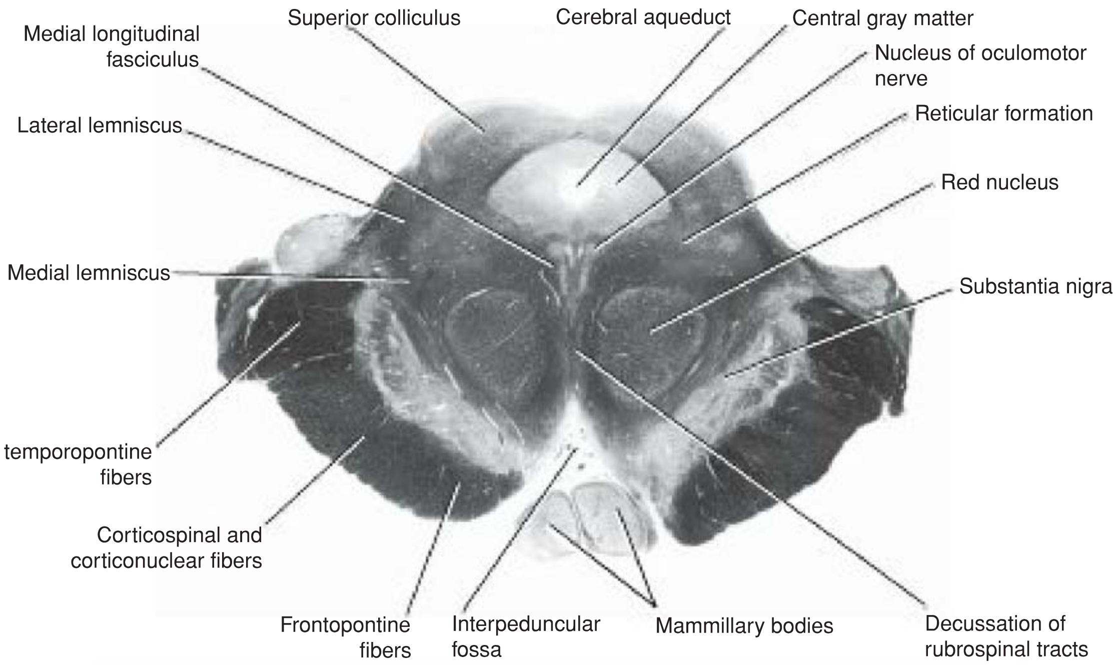


Figure 5-28 Photomicrograph of a transverse section of the midbrain at the level of the superior colliculus. (Weigert stain.)

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.

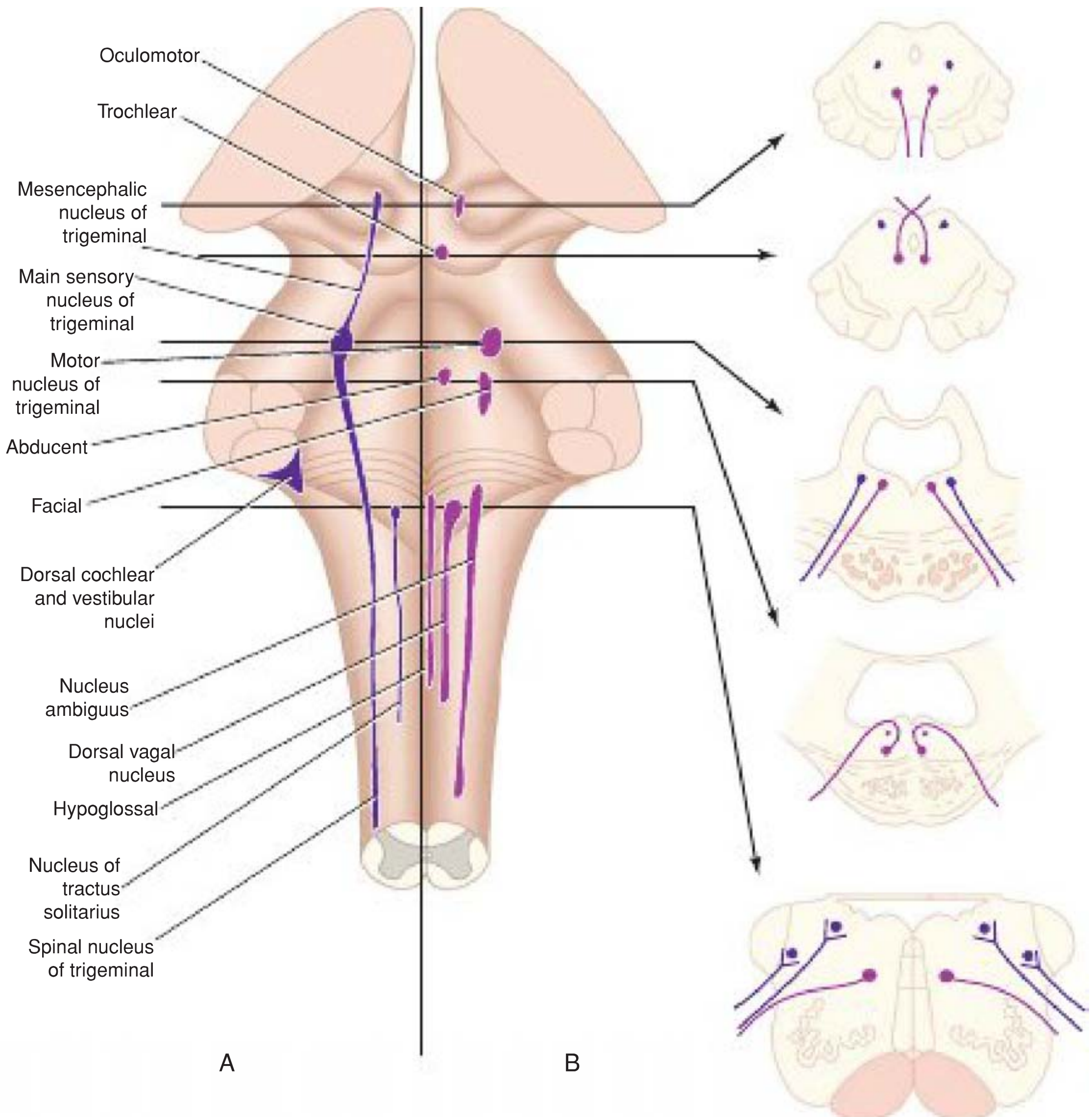


Figure 5-29 Position of some of the cranial nerve nuclei in the brainstem. **A:** Surface projection on the posterior aspect of the brainstem. **B:** Cross sections. The motor nuclei are in red and the sensory nuclei in blue.

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.

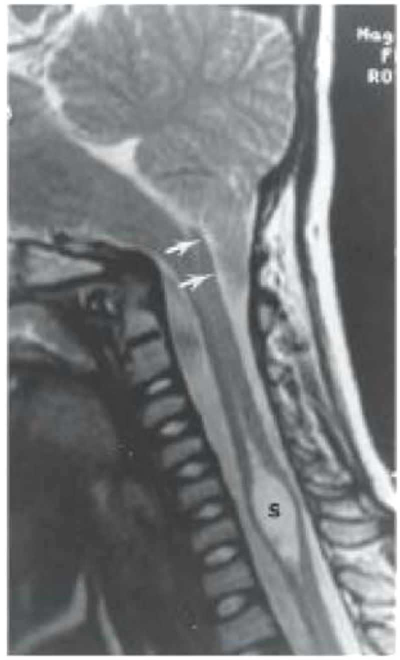


Figure 5-30 Arnold–Chiari phenomenon. This coronal section of the skull shows the herniation of the cerebellar tonsil and the medulla oblongata through the foramen magnum into the vertebral canal. (From Dudek, R. W., & Louis, T. M. [2015]. *High-yield gross anatomy* (5th ed.). Baltimore, MD: Wolters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

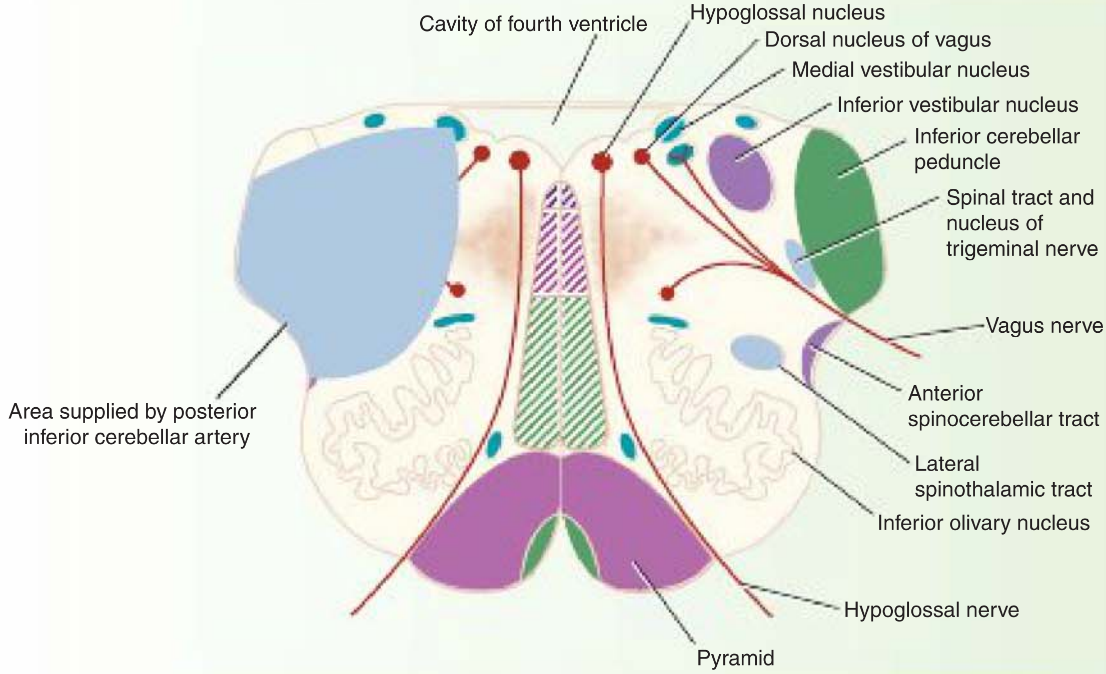


Figure 5-31 Transverse section of the medulla oblongata at the level of the inferior olivary nuclei showing the extent of the lesion producing the lateral medullary syndrome.

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

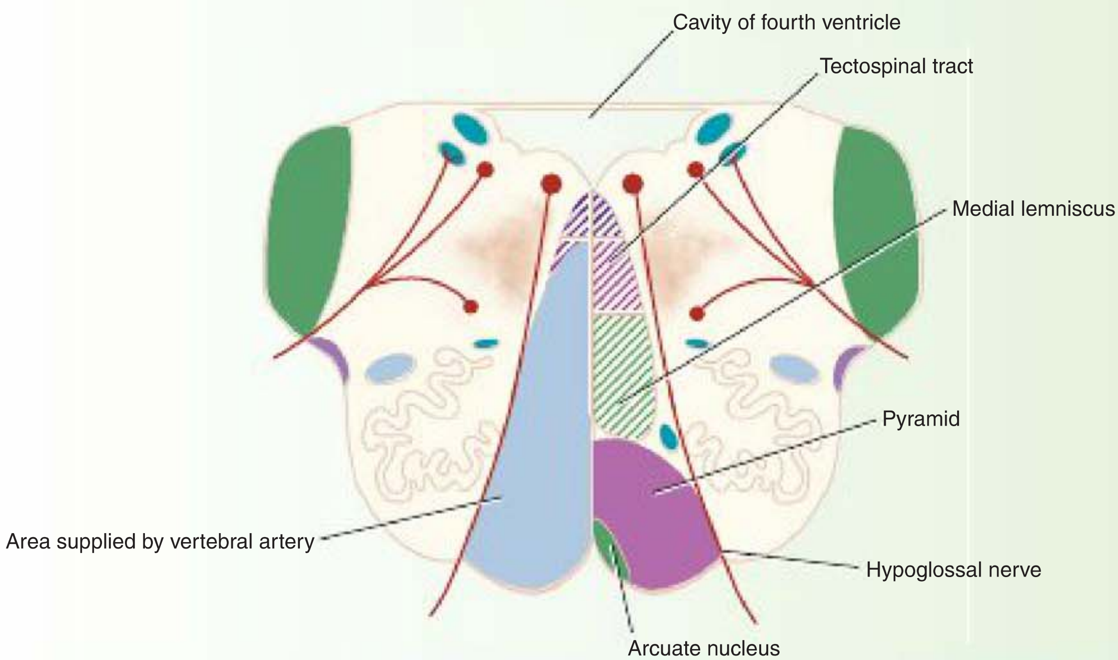


Figure 5-32 Transverse section of the medulla oblongata at the level of the inferior olivary nuclei showing the extent of the lesion producing the medial medullary syndrome.

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.

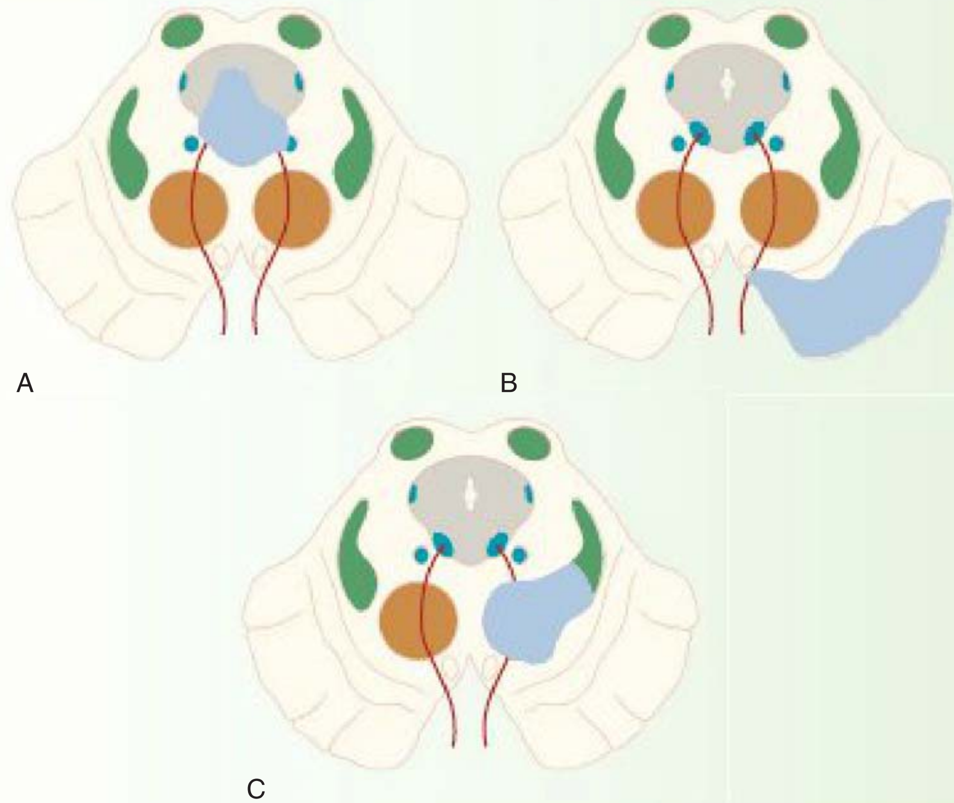


Figure 5-33 Pathology of the midbrain. **A:** Tumor of the midbrain blocking the cerebral aqueduct. **B:** Weber syndrome involving the oculomotor nerve and the crus cerebri following occlusion of the blood supply to the midbrain. **C:** Benedikt syndrome involving the red nucleus and the medial lemniscus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

On examination, he is found to have a slight right internal strabismus, a flattening of the skin furrows on the right side of his forehead, and a slight drooping of the right corner of his mouth. Hearing is impaired on the right side. On testing for sensory loss, sensory impairment is evident on the right side of the face in the areas supplied by the maxillary and mandibular divisions of the trigeminal nerve. Using your knowledge of anatomy, explain the symptoms and signs.

8. After a severe automobile accident that results in the death of the driver of one of the vehicles, an autopsy is performed, and the skull is opened. A massive subdural hematoma is found in the middle cranial fossa. The rapid accumulation of blood within the skull had exerted pressure on the brain above the tentorium cerebelli. The uncus of the temporal lobe has been forced inferiorly through the hiatus in the tentorium cerebelli. What effect do you think these intracranial changes had on the midbrain of this patient?
9. A 3-month-old girl is taken to a pediatrician because her mother is concerned about the large size of her head. The child is perfectly normal in every other respect. Examination of the child shows that the diameter of the head was larger than normal for the age; the fontanelles are larger than normal and are moderately tense. The scalp is shiny, and the scalp veins are dilated. The eyes are normal, and the mental and physical development of the child is within normal limits. Computed tomography and magnetic resonance imaging of the head reveal gross dilation of the third and lateral ventricles of the brain. What is your diagnosis? What possible treatment should be suggested to the mother of this child?
10. A 20-year-old man is seen by a neurologist because he has a 3-month history of double vision. On examination of the patient, both eyes at rest are turned downward and laterally. The patient is unable to move the eyes upward or medially. Both upper lids are drooping (ptosis). Examination of both pupils shows them to be dilated, and they do not constrict when a light is shone into either eye. Facial movements and sensation are normal. Movements of the upper and lower limbs are normal. Loss of or altered skin sensations is not evident in the upper or the lower limbs. Using your knowledge of neuroanatomy, make a diagnosis and accurately locate the site of the lesion. Is the lesion unilateral or bilateral?
11. A 57-year-old man with hypertension is admitted to the hospital with a diagnosis of hemorrhage into the midbrain, possibly from a branch of the posterior cerebral artery. He is found, on physical examination, to have paralysis on the right side of the levator palpebrae superioris, the superior rectus, medial rectus, inferior rectus, and inferior oblique muscles. Furthermore, his right pupil is dilated and fails to constrict on exposure to light or on accommodation. The left eye is normal in every respect. He displays hypersensitivity to touch on the skin of the left side of his face and has loss of skin sensation on the greater part of his left arm and left leg. The left leg also displays some spontaneous slow writhing movements (athetosis). Using your knowledge of neuroanatomy, explain the signs and symptoms exhibited by this patient.
12. A 41-year-old woman is diagnosed as having a lesion in the midbrain. Physical examination reveals an oculomotor nerve palsy on the left side (paralysis of the left extraocular muscles except the lateral rectus and the superior oblique muscles) and an absence of the light and accommodation reflexes on the left side. Some weakness is evident but no atrophy of the muscles of the lower part of the face and the tongue on the right side. The right arm and leg show spastic paralysis. Sensory loss on either side of the head, trunk, or limbs is not noted. Using your knowledge of neuroanatomy, precisely place the lesion in the midbrain of this patient.

Answers and Explanations to Clinical Problem Solving

1. Until involvement of one of the last four cranial nerves occurs, localization of a lesion to the medulla oblongata remains uncertain. For example, involvement of the main ascending sensory pathways or descending pathways may be caused by a lesion in the medulla, the pons, the midbrain, or the spinal cord. Involvement of the glossopharyngeal nerve can be detected by inadequacy of the gag reflex and loss of taste sensation on the posterior third of the tongue. Involvement of the vagus nerve can be assumed if the patient demonstrates some or all of the following symptoms: impairment of pharyngeal sensibility, difficulty in swallowing, nasal regurgitation of fluids with asymmetry of movement of the soft palate, and hoarseness of the voice with paralysis of the laryngeal muscles. The cranial part of the accessory nerve is distributed within the vagus nerve so that testing for this nerve alone is not possible. The spinal part of the accessory nerve, which supplies the sternocleidomastoid and trapezius muscles, arises from the spinal cord and is therefore unaffected by tumors of the medulla. The hypoglossal nerve involvement may be tested by looking for wasting, fasciculation, and paralysis of half of the tongue.
2. (a) The malformation in which the cerebellum and the medulla oblongata are found in the cervical part of the vertebral canal is known as the Arnold–Chiari malformation. (b) Yes. Hydrocephalus is common in this condition. The hydrocephalus may be due to distortion or malformation of the openings in the roof of the fourth ventricle, which normally allow the cerebrospinal fluid to escape into the subarachnoid space. (c) Yes. A myelocele is commonly

associated with this malformation. The reason for this is not exactly known, although several investigators believe that the myelocele is the primary cause and that it tethers the lower part of the spinal cord to the surrounding tissues at the time when disproportionate growth of the spinal cord and the vertebral column occurs. This would serve to pull the medulla oblongata and the cerebellum inferiorly through the foramen magnum into the vertebral canal.

3. This patient is suffering from a thrombosis of the posterior inferior cerebellar artery or vertebral artery on the right side. The vertigo is caused by the involvement of the cerebellum or the vestibular nuclei or both. The hot, painful skin sensations are due to the involvement of the spinal tract and nucleus of the trigeminal nerve on the right side. The abnormal movement of the soft palate and the fixation of the right vocal cord are due to involvement of the nucleus of the vagus and accessory nerve on the right side. The ptosis, enophthalmos, and myosis (Horner syndrome) are due to involvement of the descending fibers of the sympathetic part of the autonomic nervous system. The tongue pointing to the right is caused by involvement of the right hypoglossal nucleus (the right genioglossus muscle is paralyzed). The loss of pain and temperature sensations on the opposite side of the body is due to involvement of the ascending lateral spinothalamic tracts. This characteristic clinical syndrome results from cutting off the arterial supply to a wedge-shaped area in the posterolateral part of the medulla oblongata and the inferior surface of the cerebellum.
4. The 9th, the 10th, and the cranial part of the 11th cranial nerves emerge from the medulla oblongata in a groove between the olives and the inferior cerebellar peduncles.
5. This 10-year-old girl later was found to have an astrocytoma of the pons. The right unilateral facial weakness, together with weakness of the right lateral rectus muscle of the eye, was due to involvement of the right facial and abducens nuclei by the tumor. The absence of paresthesia of the face indicated that the principal sensory nucleus of the trigeminal nerve was intact on both sides. The weakness in the movements of the left arm and left leg was due to the involvement of the corticospinal fibers in the pons. (Remember that most of these fibers cross over to the opposite side at the decussation of the pyramids in the medulla.)
6. "Pinpoint" pupils indicate that the constrictor pupillae muscles are strongly contracted and the dilator pupillae muscles are paralyzed. The dilator pupillae muscles are supplied by the sympathetic fibers, which descend through the pons (position not precisely known) to the lateral gray columns of the thoracic part of the spinal cord. Here, the fibers synapse, and the thoracolumbar sympathetic outflow occurs.
7. The deafness and vertigo were due to lesions in the cochlear and vestibular nuclei in the upper part of the pons. The double vision (diplopia) was produced by the involvement of the abducens nerve nucleus on the right side of the pons. The history of severe headaches and vomiting was due to a progressive rise in intracranial pressure caused by a tumor of the pons. The right unilateral facial palsy was due to the involvement of the right facial nerve nucleus. The sensory impairment of the skin of the middle and lower part of the right side of the face was due to the tumor involvement of the principal sensory nucleus of the right trigeminal nerve.
8. The herniated uncus and the subdural hemorrhage caused pressure of the opposite crus cerebri of the midbrain against the sharp edge of the tentorium. The distortion of the midbrain caused narrowing of the cerebral aqueduct, further raising the supratentorial pressure by blocking the passage of cerebrospinal fluid from the third to the fourth ventricle. Under these circumstances, severe hemorrhage may occur within the midbrain and affect the third and fourth cranial nerve nuclei and various important descending and ascending tracts.
9. This child had hydrocephalus. The physical examination and the special tests showed that the third and lateral ventricles of the brain were grossly dilated owing to the accumulation of cerebrospinal fluid (CSF) in these cavities. Mechanical obstruction to CSF flow from the third into the fourth ventricle through the cerebral aqueduct was present. After the possibility of the presence of cysts or resectable tumors had been excluded, it was assumed that the cause of the obstruction was a congenital atresia or malformation of the cerebral aqueduct. If the condition were progressing—that is, the block in the aqueduct was complete and the head continued to increase in size at an abnormal rate—some form of neurosurgical procedure should have been performed to shunt CSF from the third or lateral ventricles into the subarachnoid space or into the venous system of the neck.
10. Two years later, the patient died. At autopsy, a large astrocytoma that involved the central part of the tegmentum at the level of the superior colliculi was found. The patient had exhibited all signs and symptoms associated with a raised intracranial pressure. The raised pressure was due in part to the expanding tumor, but the problem was compounded by the developing hydrocephalus resulting from blockage of the cerebral aqueduct.

    The symptoms and signs exhibited by the patient when he was first seen by the neurologist could be explained by the presence of the tumor in the central gray matter at the level of the superior colliculi and involving the third cranial nerve nuclei on both sides. This resulted in bilateral ptosis; bilateral ophthalmoplegia; and bilateral fixed, dilated pupils. The resting position of the eyes in a downward and lateral position was due to the action of the superior oblique muscle (trochlear nerve) and lateral rectus muscle (abducens nerve).

11. The patient had a hemorrhage in the right side of the tegmentum of the midbrain that involved the right third cranial nerve. The ascending tracts of the left trigeminal nerve also were involved. After emerging from the sensory nuclei of the left trigeminal nerve, they cross the midline and ascend through the trigeminal lemniscus on the right side. The loss of sensation seen in the left upper and lower limbs was due to involvement of the right medial and spinal lemnisci. The athetoid movements of the left leg could be explained on the basis of the involvement of the right red nucleus. The absence of spasticity of the left arm and leg would indicate that the lesion did not involve the right descending tracts. For further clarification, consult the descriptions of the various tracts (see Chapter 4).
12. Autopsy later revealed a vascular lesion involving a branch of the posterior cerebral artery. Considerable brain softening was found in the region of the substantia nigra and crus cerebri on the left side of the midbrain. The left oculomotor nerve was involved as it passed through the infarcted area. The corticonuclear fibers that pass to the facial nerve nucleus and the hypoglossal nucleus were involved as they descended through the left crus cerebri (they cross the midline at the level of the nuclei). The corticospinal fibers on the left side were also involved (they cross in the medulla oblongata), hence the spastic paralysis of the right arm and leg. The left trigeminal and left medial lemnisci were untouched, which explains the absence of sensory changes on the right side of the body. This is a good example of Weber syndrome.

Review Questions

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

1. The following statements concern the anterior surface of the medulla oblongata:
   (a) The pyramids taper inferiorly and give rise to the decussation of the pyramids.
   (b) On each side of the midline, an ovoid swelling called the olive contains the corticospinal fibers.
   (c) The hypoglossal nerve emerges between the olive and the inferior cerebellar peduncle.
   (d) The vagus nerve emerges between the pyramid and the olive.
   (e) The abducens nerve emerges between the pons and the midbrain.
2. The following general statements concern the medulla oblongata:
   (a) The caudal half of the floor of the fourth ventricle is formed by the rostral half of the medulla.
   (b) The central canal extends throughout the length of the medulla oblongata.
   (c) The nucleus gracilis is situated beneath the gracile tubercle on the anterior surface of the medulla.
   (d) The decussation of the medial lemnisci takes place in the rostral half of the medulla.
   (e) The cerebellum lies anterior to the medulla.
3. The following statements concern the interior of the lower part of the medulla:
   (a) The decussation of the pyramids represents the crossing over from one side of the medulla to the other of a quarter of the corticospinal fibers.
   (b) The central canal of the spinal cord is not continuous upward into the medulla.
   (c) The substantia gelatinosa is not continuous with the nucleus of the spinal tract of the trigeminal nerve.
   (d) The medial lemniscus is formed by the anterior spinothalamic tract and the spinotectal tract.
   (e) The internal arcuate fibers emerge from the nucleus gracilis and nucleus cuneatus.
4. The following statements concern the interior of the upper part of the medulla:
   (a) The reticular formation consists of nerve fibers but no nerve cells.
   (b) The nucleus ambiguus constitutes the motor nucleus of the vagus, cranial part of the accessory, and hypoglossal nerves.
   (c) Beneath the floor of the fourth ventricle are located the dorsal nucleus of the vagus and the vestibular nuclei.
   (d) The medial longitudinal fasciculus is a bundle of ascending fibers on each side of the midline.
   (e) The inferior cerebellar peduncle connects the pons to the cerebellum.
5. The following statements concern the Arnold–Chiari phenomenon:
   (a) It is an acquired anomaly.
   (b) The exits in the roof of the fourth ventricle may be blocked.
   (c) The cerebellum never herniates through the foramen magnum.
   (d) It is not associated with various forms of spina bifida.
   (e) Performing a spinal tap in this condition is safe.
6. The following statements concern the medial medullary syndrome:
   (a) The tongue is paralyzed on the contralateral side.
   (b) Ipsilateral hemiplegia is evident.
   (c) Ipsilateral sensations of position and movement are impaired.
   (d) It is commonly caused by thrombosis of a branch of the vertebral artery to the medulla oblongata.
   (e) Contralateral facial paralysis is evident.

7. The following statements concern the lateral medullary syndrome:
   (a) It may be caused by a thrombosis of the anterior inferior cerebellar artery.
   (b) The nucleus ambiguus of the same side may be damaged.
   (c) Analgesia and thermoanesthesia may be evident on the contralateral side of the face.
   (d) Contralateral trunk and extremity hypalgesia and thermoanesthesia may occur.
   (e) Seizures may occur.

Directions: Matching Questions. The following questions apply to Figure 5-34. Match the numbers listed on the left with the appropriate lettered structure listed on the right. Each lettered option may be selected once, more than once, or not at all.

8. Number 1	(a) Inferior cerebellar peduncle
9. Number 2	(b) Medial lemniscus
10. Number 3	(c) Hypoglossal nucleus
11. Number 4	(d) Reticular formation
12. Number 5	(e) None of the above
13. Number 6	

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

14. The following statements concern the pons:
    (a) The trigeminal nerve emerges on the lateral aspect of the pons.
    (b) The glossopharyngeal nerve emerges on the anterior aspect of the brainstem in the groove between the pons and the medulla oblongata.
    (c) The basilar artery lies in a centrally placed groove on the anterior aspect of the pons.
    (d) Many nerve fibers present on the posterior aspect of the pons converge laterally to form the middle cerebellar peduncle.
    (e) The pons forms the lower half of the floor of the fourth ventricle.
15. The following important structures are located in the brainstem at the level stated:
    (a) The red nucleus lies within the midbrain.
    (b) The facial colliculus lies in the cranial part of the pons.
    (c) The motor nucleus of the trigeminal nerve lies within the caudal part of the pons.
    (d) The abducens nucleus lies within the cranial part of the pons.
    (e) The trochlear nucleus lies within the midbrain at the level of the superior colliculus.
16. The following statements concern the posterior surface of the pons:
    (a) Lateral to the median sulcus is an elongated swelling called the lateral eminence.
    (b) The facial colliculus is produced by the root of the facial nerve winding around the nucleus of the abducens nerve.
    (c) The floor of the inferior part of the sulcus limitans is pigmented and is called the substantia ferruginea.
    (d) The vestibular area lies medial to the sulcus limitans.
    (e) The cerebellum lies anterior to the pons.
17. The following statements concern a transverse section through the caudal part of the pons:
    (a) The pontine nuclei lie between the transverse pontine fibers.
    (b) The vestibular nuclei lie medial to the abducens nucleus.

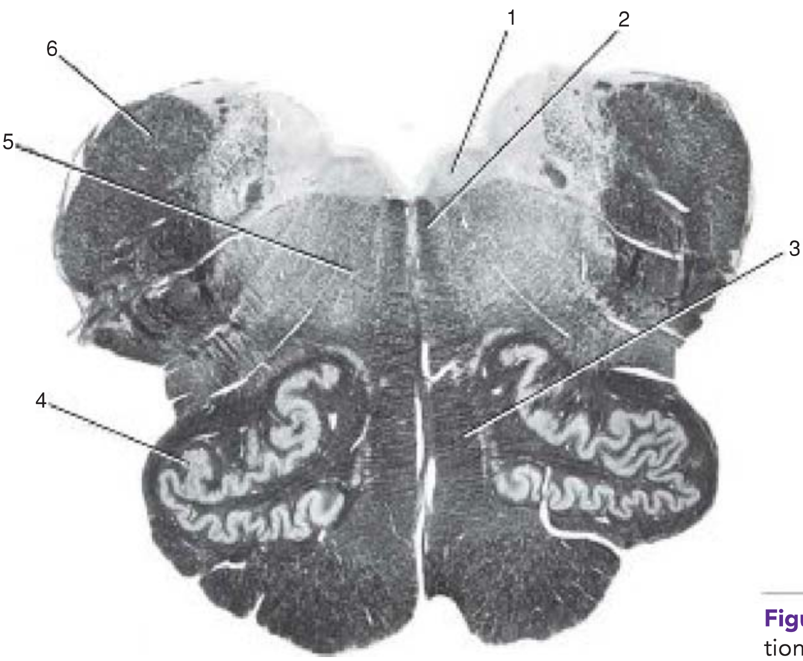


Figure 5-34 Photomicrograph of transverse section of the medulla oblongata. (Weigert stain.)

(c) The trapezoid body is made up of fibers derived from the facial nerve nuclei.
(d) The tegmentum is the part of the pons lying anterior to the trapezoid body.
(e) The medial longitudinal fasciculus lies above the floor of the fourth ventricle on either side of the midline.

18. The following statements concern a transverse section through the cranial part of the pons:
(a) The motor nucleus of the trigeminal nerve lies lateral to the main sensory nucleus in the tegmentum.
(b) The medial lemniscus has rotated so that its long axis lies vertically.
(c) Bundles of corticospinal fibers lie among the transverse pontine fibers.
(d) The medial longitudinal fasciculus joins the thalamus to the spinal nucleus of the trigeminal nerve.
(e) The motor root of the trigeminal nerve is much larger than the sensory root.

19. The following statements concern the pons:
(a) It is related superiorly to the dorsum sellae of the sphenoid bone.
(b) It lies in the middle cranial fossa.
(c) Glial tumors of the pons are rare.
(d) The corticopontine fibers terminate in the pontine nuclei.
(e) The pons receives its blood supply from the internal carotid artery.

Directions: Matching Questions. The following questions apply to Figure 5-35. Match the numbers listed on the left with the appropriate lettered structure listed on the right. Each lettered option may be selected once, more than once, or not at all.

20. Number 1	(a) Basilar groove
21. Number 2	(b) Medial longitudinal fasciculus
22. Number 3	(c) Superior cerebellar peduncle
23. Number 4	(d) Superior medullary velum
24. Number 5	(e) None of the above
25. Number 6	

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

26. The following statements concern the midbrain:
(a) It passes superiorly between the fixed and free borders of the tentorium cerebelli.
(b) The oculomotor nerve emerges from the posterior surface below the inferior colliculi.
(c) The superior brachium passes from the superior colliculus to the medial geniculate body.
(d) The cavity of the midbrain is called the cerebral aqueduct.
(e) The interpeduncular fossa is bounded laterally by the cerebellar peduncles.

27. The following statements concern the midbrain:
(a) The oculomotor nucleus is found within it at the level of the inferior colliculus.
(b) The trochlear nerve emerges on the anterior surface of the midbrain and decussates completely in the superior medullary velum.
(c) The trochlear nucleus is situated in the central gray matter at the level of the inferior colliculus.

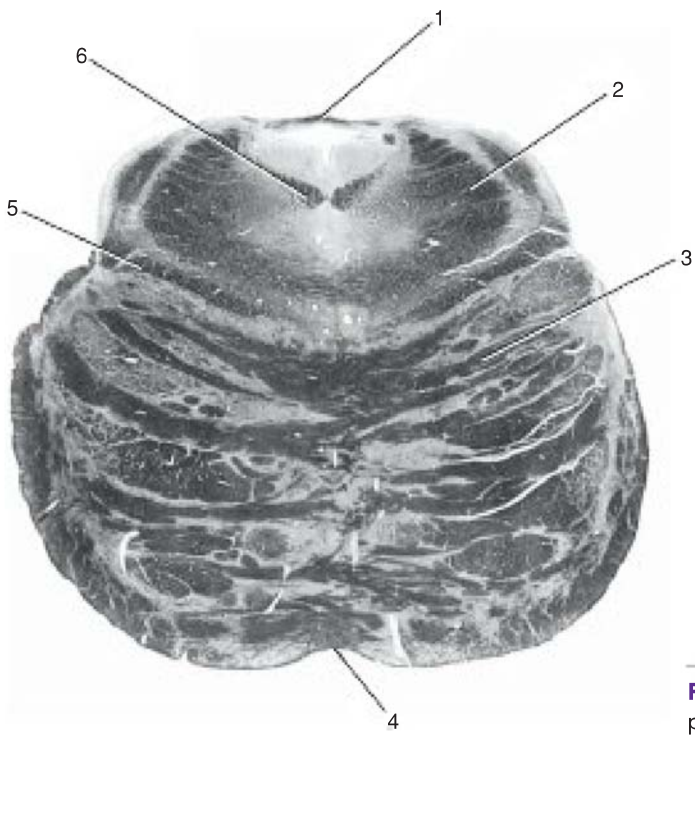


Figure 5-35 Photomicrograph of transverse section of the pons. (Weigert stain.)

(d) The lemnisci are situated medial to the central gray matter.
(e) The trigeminal lemniscus lies anterior to the medial lemniscus.

28. The following statements concern the internal structures of the midbrain:
    (a) The tectum is the part situated posterior to the cerebral aqueduct.
    (b) The crus cerebri on each side lies posterior to the substantia nigra.
    (c) The tegmentum lies anterior to the substantia nigra.
    (d) The central gray matter encircles the red nuclei.
    (e) The reticular formation is limited to the lower part of the midbrain.
29. The following statements concern the colliculi of the midbrain:
    (a) They are located in the tegmentum.
    (b) The superior colliculi are concerned with sight reflexes.
    (c) The inferior colliculi lie at the level of the oculomotor nerve nuclei.
    (d) The inferior colliculi are concerned with reflexes of smell.
    (e) The superior colliculi lie at the level of the trochlear nuclei.
30. The following statements concern the third cranial nerve nuclei:
    (a) The oculomotor nucleus is situated lateral to the central gray matter.
    (b) The sympathetic part of the oculomotor nucleus is called the Edinger–Westphal nucleus.
    (c) The oculomotor nucleus lies posterior to the cerebral aqueduct.
    (d) The nerve fibers from the oculomotor nucleus pass through the red nucleus.
    (e) The oculomotor nucleus lies close to the lateral longitudinal fasciculus.

Directions: Matching Questions. The following questions apply to Figure 5-36. Match the numbers listed on the left with the appropriate lettered structure listed on the right. Each lettered option may be selected once, more than once, or not at all.

31. Number 1	(a) Medial longitudinal fasciculus
32. Number 2	(b) Inferior colliculus
33. Number 3	(c) Medial lemniscus
34. Number 4	(d) Trochlear nucleus
35. Number 5	(e) None of the above
36. Number 6	

Directions: Each case history is followed by questions. Read the case history, then select the ONE BEST lettered answer.

A 63-year-old man complaining of difficulty in swallowing, some hoarseness of his voice, and giddiness was seen by a neurologist. All these symptoms started suddenly 4 days previously. On physical examination, he was found to have a loss of the pharyngeal gagging reflex on the left side, left-sided facial analgesia, and left-sided paralysis of the vocal cord.

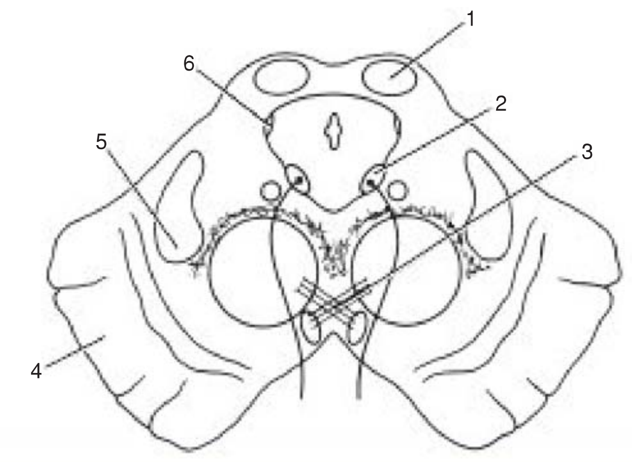


Figure 5-36 Transverse section of the midbrain.

37. Based on the clinical history and the results of the physical examination, select the **most likely** diagnosis.
    (a) Meningeal tumor in the posterior cranial fossa on the right side
    (b) Lateral medullary syndrome on the left side
    (c) Medial medullary syndrome on the left side
    (d) Lateral medullary syndrome on the right side
    (e) Medial medullary syndrome on the right side

A 7-year-old girl was seen by a neurologist because she complained to her mother that she was seeing double. Careful physical examination revealed that the double vision became worse when she looked toward the left. The patient also had evidence of a mild motor paralysis of her right lower limb without spasticity. There was also a slight facial paralysis involving the whole left side of the face.

38. Based on the clinical history and the clinical examination, the following neurologic deficits could have been present **except:**
    (a) The double vision caused by weakness of the left lateral rectus muscle.
    (b) The complete left-sided facial paralysis caused by involvement of the left seventh cranial nerve nucleus or its nerve.
    (c) The mild right hemiparesis produced by damage to the corticospinal tract on the right side.
    (d) Magnetic resonance imaging revealed the presence of a tumor of the lower part of the pons on the left side.
    (e) The left sixth cranial nerve nucleus was damaged.

A 42-year-old woman complaining of a severe, persistent headache visited her physician. At first, the headache was not continuous and tended to occur during the night. Now, the headache was present all the time and was felt over the whole head. Recently, she has begun to feel nauseous, and this has resulted in several episodes of vomiting. Last week, on looking in the mirror, she noted that her right pupil looked much larger than the left. Her right upper lid appeared to droop.

39. The physical examination revealed the following most likely findings **except:**
    (a) Weakness in raising the right eyelid upward
    (b) Severe ptosis of the right eye
    (c) Obvious dilatation of the right pupil
    (d) Ophthalmoscopic examination revealing bilateral papilledema
    (e) Evidence of paralysis of either superior oblique muscle
    (f) Examination of the lower limbs revealing mild spasticity of the left lower limb muscles
    (g) Ataxia of the right upper limb
    (h) Loss of taste sensation on the posterior third of the tongue on the left side
40. The combination of the clinical history and the findings in the physical examination enabled the physician to make the following **most likely** diagnosis.
    (a) Tumor involving the left cerebral hemisphere
    (b) Tumor involving the right side of the midbrain at the level of the superior colliculi
    (c) Severe migraine
    (d) Cerebral hemorrhage involving the left cerebral hemisphere
    (e) Tumor of the left side of the midbrain

Answers and Explanations to Review Questions

1. A is correct. The pyramids of the medulla oblongata taper inferiorly and give rise to the decussation of the pyramids (see Fig. 5-9). B. On each side of the midline on the anterior surface of the medulla lateral to the pyramids, an ovoid swelling called the olive contains the olivary nucleus and does not contain the corticospinal fibers. C. The hypoglossal nerve emerges between the pyramid and the olive. D. The vagus nerve emerges between the olive and the inferior cerebellar peduncle. E. The abducens nerve emerges between the pons and the medulla oblongata (see Fig. 5-9).
2. A is correct. The caudal half of the floor of the fourth ventricle is formed by the rostral half of the medulla oblongata (see Fig. 5-9). B. The central canal in the medulla oblongata is limited to the caudal half. C. The nucleus gracilis is situated beneath the gracile tubercle on the posterior surface of the medulla. D. The decussation of the medial lemnisci takes place in the caudal half of the medulla. E. The cerebellum lies posterior to the medulla.
3. E is correct. The internal arcuate fibers emerge from the nucleus gracilis and nucleus cuneatus (see Fig. 4-16). A. The decussation of the pyramids represents the crossing over from one side of the medulla to the other of three fourths of the corticospinal fibers. B. The central canal of the spinal cord is continuous upward into the medulla. C. The substantia gelatinosa becomes continuous with the nucleus of the spinal part of the trigeminal nerve. D. The medial lemniscus is formed by the axons of cells in the nucleus gracilis and the nucleus cuneatus; the axons leave the nuclei and cross the midline as the internal arcuate fibers and then ascend to the thalamus (see Fig. 4-16).
4. C is correct. Beneath the floor of the fourth ventricle are located the dorsal nucleus of the vagus and the vestibular nuclei (see Fig. 5-14). A. The reticular formation in the upper part of the medulla oblongata consists of a mixture of nerve fibers and small nerve cells. B. The nucleus ambiguus constitutes the motor nucleus of the glossopharyngeal, vagus, and the cranial part of the accessory nerves. D. The medial longitudinal fasciculus is a bundle of ascending and descending fibers that lie posterior to the medial lemniscus on each side of the midline (see Fig. 5-14). E. The inferior cerebellar peduncle connects the medulla to the cerebellum.
5. B is correct. In the Arnold–Chiari phenomenon, the exits in the roof of the fourth ventricle may be blocked. A. It is a congenital anomaly. C. The tonsil of the cerebellum may herniate through the foramen magnum (see Fig. 5-30). D. The Arnold–Chiari phenomenon is commonly associated with various forms of spina bifida. E. Performing a spinal tap in the setting of this condition is very dangerous.
6. D is correct. The medial medullary syndrome is commonly caused by thrombosis of a branch of the vertebral artery to the medulla oblongata. A. The tongue is paralyzed on the ipsilateral side. B. Contralateral hemiplegia is evident. C. Contralateral impaired sensations of position and movement are evident. E. Facial paralysis is not evident.
7. B is correct. In the lateral medullary syndrome, the nucleus ambiguus of the same side may be damaged. A. The condition may be caused by thrombosis of the posterior inferior cerebellar artery. C. Analgesia and thermoanesthesia on the ipsilateral side of the face may occur. D. Ipsilateral trunk and extremity hypalgesia and thermoanesthesia may occur. E. Seizures usually do not occur.
8. C is correct.
9. E is correct. The structure is the medial longitudinal fasciculus.
10. B is correct.
11. E is correct. The structure is the inferior olivary nucleus.
12. D is correct.
13. A is correct.
14. C is correct. The basilar artery lies in a centrally placed groove on the anterior aspect of the pons.

A. The trigeminal nerve emerges on the anterior aspect of the pons. B. The glossopharyngeal nerve emerges on the anterior aspect of the medulla oblongata in the groove between the olive and the inferior cerebellar peduncle (see Fig. 5-9). D. The nerve fibers on the anterior aspect of the pons converge laterally to form the middle cerebellar peduncle. E. The pons forms the upper half of the floor of the fourth ventricle (see Fig. 5-18).

15. A is correct. The red nucleus lies within the midbrain (see Fig. 5-25). B. The facial colliculus lies in the caudal part of the pons (see Fig. 5-18). C. The motor nucleus of the trigeminal nerve lies within the cranial part of the pons (see Fig. 5-20). D. The abducens nucleus lies within the caudal part of the pons (see Fig. 5-19). E. The trochlear nucleus lies within the midbrain at the level of the inferior colliculus (see Fig. 5-25).
16. B is correct. On the posterior surface of the pons is the facial colliculus, which is produced by the root of the facial nerve winding around the nucleus of the abducens nerve (see Fig. 5-19). A. The medial eminence is an elongated swelling lateral to the median sulcus (see Fig. 5-26). C. The floor of the superior part of the sulcus limitans is pigmented and is called the substantia ferruginea (see Fig. 5-18). D. The vestibular area lies lateral to the sulcus limitans (see Fig. 5-18). E. The cerebellum lies posterior to the pons.
17. A is correct. The pontine nuclei lie between the transverse pontine fibers (see Fig. 5-12). B. The vestibular nuclei lie lateral to the abducens nucleus (see Fig. 5-19). C. The trapezoid body is made up of fibers derived from the cochlear nuclei and the nuclei of the trapezoid body. D. The tegmentum is the part of the pons lying posterior to the trapezoid body. E. The medial longitudinal fasciculus lies below the floor of the fourth ventricle on either side of the midline (see Fig. 5-19).
18. C is correct. In the pons, bundles of corticopontine fibers lie among the transverse pontine fibers (see Fig. 5-19). A. The motor nucleus of the trigeminal nerve lies medial to the main sensory nucleus in the tegmentum of the pons (see Fig. 5-20). B. In the cranial part of the pons, the medial lemniscus has rotated so that its long axis lies transversely (see Fig. 5-20). D. 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). E. The motor root of the trigeminal nerve is much smaller than the sensory root.
19. D is correct. In the pons, the corticopontine fibers terminate in the pontine nuclei. A. The pons is related anteriorly to the dorsum sellae of the sphenoid bone. B. The pons lies in the posterior cranial fossa. C. Astrocytoma of the pons is the most common tumor of the brainstem. E. The pons receives its blood supply from the basilar artery.
20. D is correct.
21. C is correct.
22. E is correct. The structure is the transverse pontine fibers.
23. A is correct.
24. E is correct. The structure is the medial lemniscus.
25. B is correct.
26. D is correct. The cavity of the midbrain is called the cerebral aqueduct (see Fig. 5-28). A. The midbrain passes superiorly through the opening in the tentorium cerebelli posterior to the dorsum sellae. B. The oculomotor nerve emerges from the anterior surface of the midbrain at the level of the superior colliculi (see Fig. 5-25). C. The superior brachium passes from the superior colliculus to the lateral geniculate body and the optic tract and is associated with visual functions (see Fig. 5-23). E. The interpeduncular fossa is bounded laterally by the crus cerebri (see Fig. 5-25).
27. C is correct. The trochlear nucleus is situated in the central gray matter of the midbrain at the level of the inferior colliculus (see Fig. 5-25). A. In the midbrain, the oculomotor nucleus is found at the level of the superior colliculus (see Fig. 5-25). B. The trochlear nerve emerges on the posterior surface of the midbrain and decussates completely in the superior medullary velum (see Fig. 5-25). D. The lemnisci are situated lateral to the central gray matter (see Fig. 5-25). E. The trigeminal lemniscus lies posterior to the medial lemniscus (see Fig. 5-25).
28. A is correct. The tectum is the part of the midbrain situated posterior to the cerebral aqueduct (see Fig. 5-24). B. In the midbrain, the crus cerebri lies anterior to the substantia nigra (see Fig. 5-25). C. The tegmentum lies posterior to the substantia nigra (see Fig. 5-25). D. The central gray matter encircles the cerebral aqueduct (see Fig. 5-25). E. The reticular formation is present throughout the midbrain.
29. B is correct. The superior colliculi of the midbrain are concerned with site reflexes. A. The colliculi are located in the tectum (see Fig. 5-25). C. The inferior colliculi lie at the level of the trochlear nerve nuclei (see Fig. 5-25). D. The inferior colliculi are concerned with auditory reflexes. E. The superior colliculi lie at the level of the red nuclei (see Fig. 5-25).
30. D is correct. The nerve fibers from the oculomotor nucleus pass through the red nucleus (see Fig. 5-25). A. The oculomotor nucleus is situated in the central gray matter (see Fig. 5-25). B. The parasympathetic part of the oculomotor nucleus is called the Edinger–Westphal nucleus. C. The oculomotor nucleus lies anterior to the cerebral aqueduct (see Fig. 5-25). E. The oculomotor nucleus lies close to the medial longitudinal fasciculus (see Fig. 5-25).
31. E is correct. The structure is the superior colliculus.
32. E is correct. The structure is the oculomotor nucleus.
33. E is correct. The structure is decussation of the rubrospinal tract.
34. E is correct. The structures are corticospinal and corticonuclear fibers.
35. C is correct.
36. E is correct. The structure is the mesencephalic nucleus of cranial nerve V.

37. B is correct.
38. C is correct. The right-sided hemiparesis was caused by damage to the corticospinal tract on the left side of the pons. The corticospinal tract descends through the medulla and crosses to the right side of the midline at the decussation of the pyramids. The patient was later discovered to have a glioma involving the left side of the lower pons.
39. H is correct. The sensation of taste on the posterior third of the tongue is supplied by the glossopharyngeal nerve, which originates in the medulla oblongata.
40. B is correct. The combination of raised intracranial pressure (headache, vomiting, and bilateral papilledema), the involvement of the right third cranial nerve (right-sided ptosis, right pupillary dilatation, and right-sided weakness of ocular deviation upward), spasticity of the left leg (right-sided corticospinal tracts), and ataxia of the right upper limb (cerebellar connections on the right side) led the physician to make a tentative diagnosis of an intracranial tumor in the right side of the midbrain at the level of the superior colliculi. An MRI confirmed the diagnosis.

6 Cerebellum and Its Connections

CHAPTER OBJECTIVES

- To review the structure and functions of the cerebellum
- To describe the afferent and efferent connections of the cerebellum within the central nervous system

A 56-year-old woman is examined by a neurologist for a variety of complaints, including an irregular swaying gait and a tendency to drift to the right when walking. Her family recently noticed that she has difficulty in keeping her balance when standing still, and she finds that standing with her feet apart helps her keep her balance.

On examination, she has diminished tone of the muscles of her right upper limb, as seen when the elbow and wrist joints are passively flexed and extended. Similar evidence is found in the right lower limb. When asked to stretch out her arms in front of her and hold them in position, she demonstrates obvious signs of right-sided tremor. When asked to touch the tip of her nose with the left index finger, she performs the movement without any difficulty, but when she repeats the movement with her right index finger, she either misses her nose or hits it due to the irregularly contracting muscles. When she is asked to quickly pronate and supinate the forearms, the movements are normal on the left side but jerky and slow on the right side. A mild papilledema of both eyes is found. No other abnormal signs are seen.

The right-sided hypotonia, static tremor, and intention tremor associated with voluntary movements, right-sided dysdiadochokinesia, and the history are characteristic of right-sided cerebellar disease. A computed tomography scan reveals a tumor in the right cerebellar hemisphere.

Understanding the structure and the nervous connections of the cerebellum and, in particular, knowing that the right cerebellar hemisphere influences voluntary muscle tone on the same side of the body enable the neurologist to make an accurate diagnosis and institute treatment.

The cerebellum plays a very important role in the control of posture and voluntary movements. It unconsciously influences the smooth contraction of voluntary muscles and carefully coordinates their actions, together with the relaxation of their antagonists. Students should commit the functions of the connections of the cerebellum to the remainder of the central nervous system (CNS) to memory, as this will greatly assist in the retention of the material. In this chapter, great emphasis is placed on the fact that each cerebellar hemisphere controls muscular movements on the same side of the body and that the cerebellum has no direct pathway to the lower motor neurons but exerts its control via the cerebral cortex and the brainstem.

GROSS APPEARANCE

The cerebellum is situated in the posterior cranial fossa and is covered superiorly by the tentorium cerebelli. It is the largest part of the hindbrain and lies posterior to the fourth ventricle, the pons, and the medulla oblongata (Fig. 6-1). The cerebellum is somewhat ovoid in shape and constricted in its median part. It consists of two **cerebellar hemispheres** joined by a narrow median **vermis**. The cerebellum is connected to the posterior aspect of the brainstem by three symmetrical bundles of nerve fibers called the **superior**, **middle**, and **inferior cerebellar peduncles** (see Figures 1-12 and 5-18).

The cerebellum is divided into three main lobes: the **anterior lobe**, the **middle lobe**, and the **flocculonodular lobe**. The **anterior lobe** may be seen on the superior surface of the cerebellum and is separated from the middle lobe by a wide V-shaped fissure called the **primary fissure** (Figs. 6-2 and 6-3). The **middle lobe** (sometimes called the posterior lobe), which is the largest part of the cerebellum, is situated between the primary and **uvulonodular fissures**. The **flocculonodular lobe** is situated posterior to the uvulonodular fissure (Fig. 6-3). A deep **horizontal fissure** that is found along the margin of the cerebellum separates the superior from the inferior surfaces but has

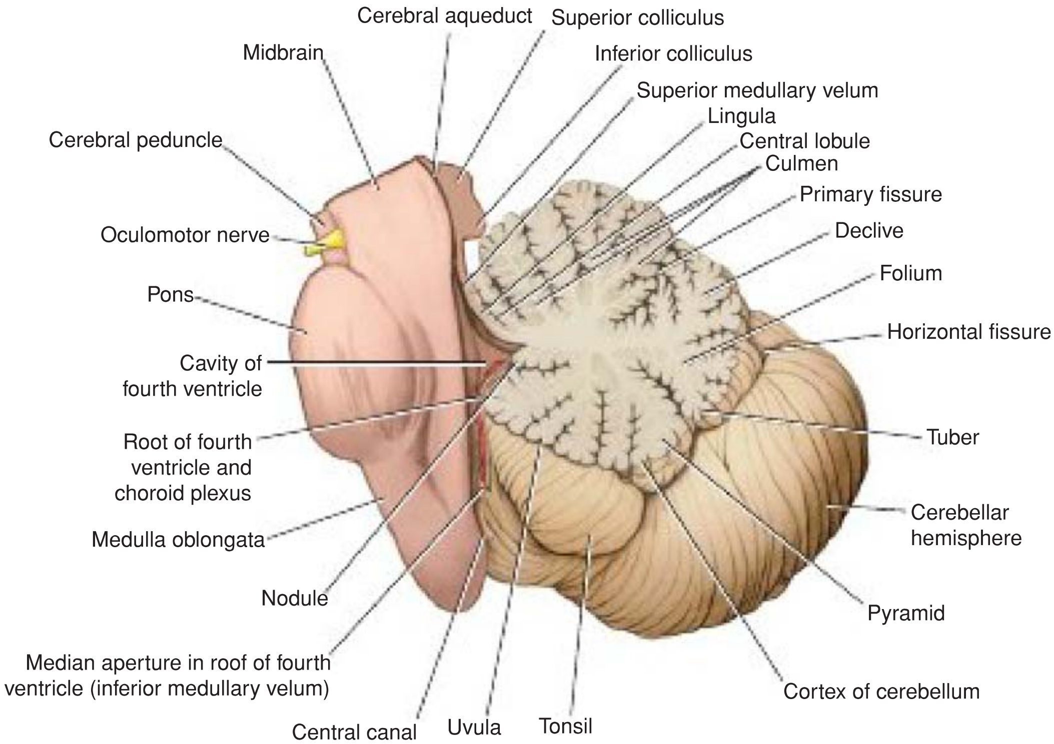


Figure 6-1 Sagittal section through the brainstem and the vermis of the cerebellum.

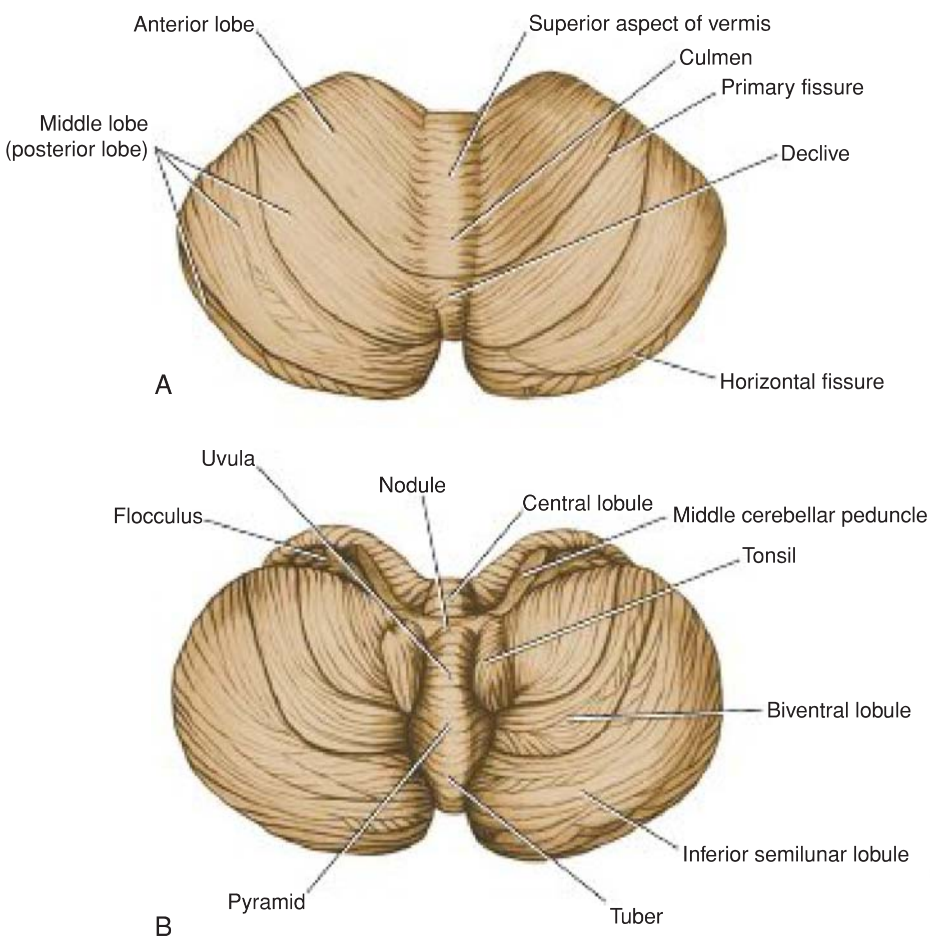


Figure 6-2 The cerebellum. **A:** Superior view. **B:** Inferior view.

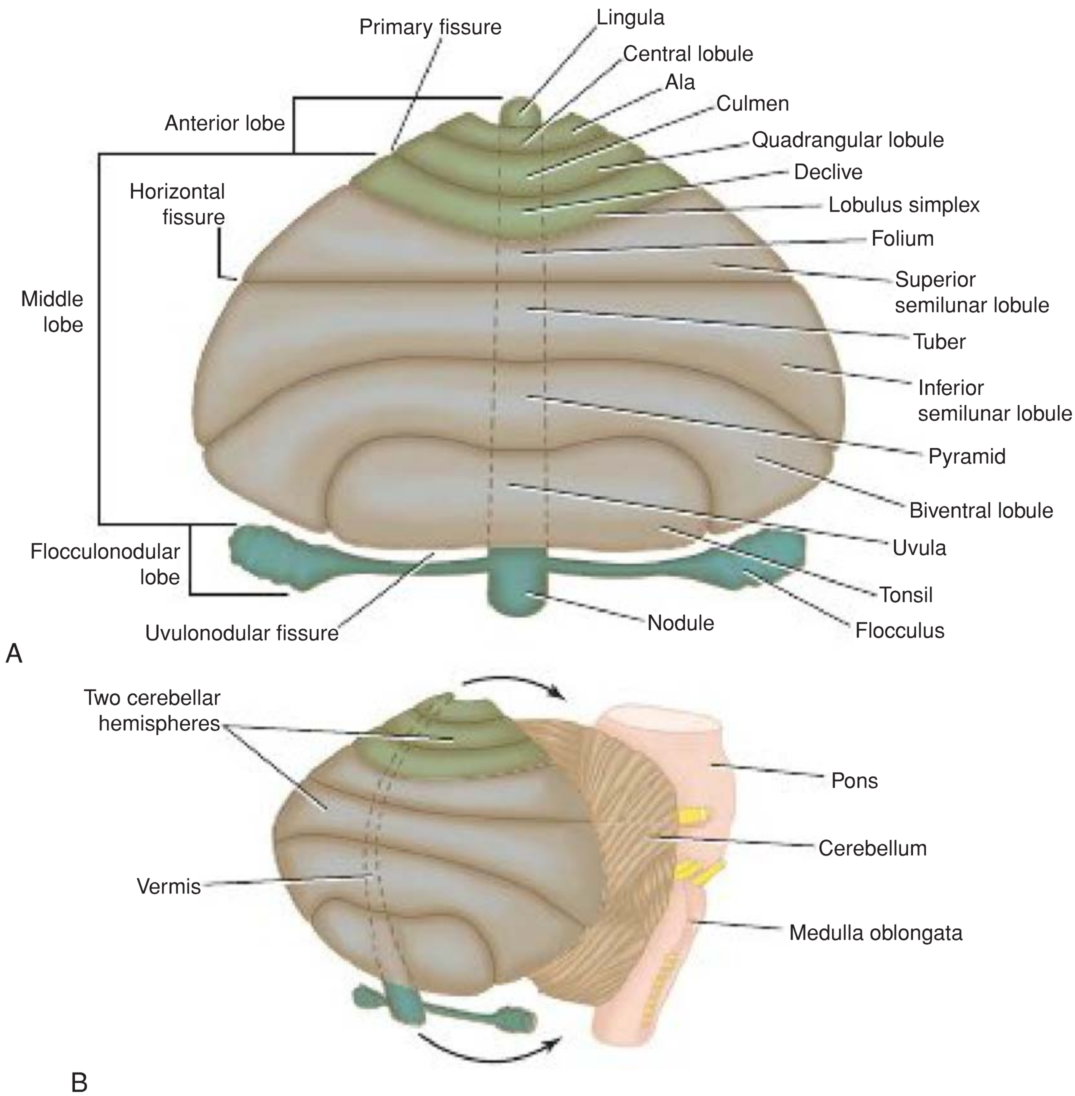


Figure 6-3 **A:** Flattened view of the cerebellar cortex showing the main cerebellar lobes, lobules, and fissures. **B:** Relationship between the diagram in (**A**) and the cerebellum.

no morphologic or functional significance (Figs. 6-2 and 6-3).

STRUCTURES

The cerebellum is composed of an outer covering of gray matter called the **cortex** and inner white matter. Embedded in the white matter of each hemisphere are three masses of gray matter forming the **intracerebellar nuclei**.

Cerebellar Cortex

The cerebellar cortex can be regarded as a large sheet with folds lying in the coronal or transverse plane. Each fold or folium contains a core of white matter covered superficially by gray matter (see Fig. 6-1).

A section made through the cerebellum parallel with the median plane divides the folia at right angles, and the cut surface has a branched appearance, called the **arbor vitae**.

The gray matter of the cortex throughout its extent has a uniform structure. It may be divided into three layers: (1) an external layer, the **molecular layer**; (2) a middle layer, the **Purkinje cell layer**; and (3) an internal layer, the **granular layer** (Figs. 6-4 and 6-5).

Molecular Layer

The molecular layer contains two types of neurons: the outer **stellate cell** and the inner **basket cell** (see Fig. 6-4). These neurons are scattered among dendritic arborizations and numerous thin axons that run parallel to the long axis of the folia. Neuroglial cells are found between these structures.

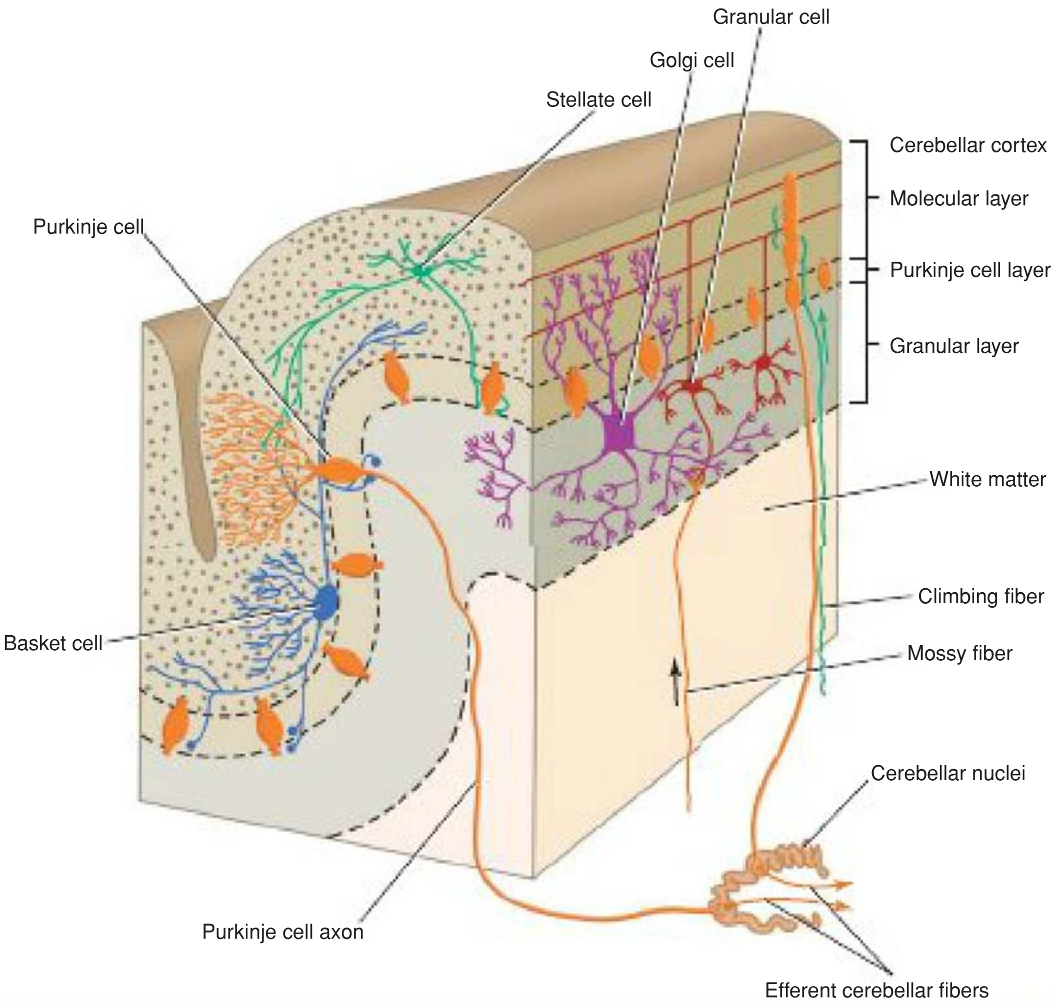


Figure 6-4 Cellular organization of the cerebellar cortex. Note the afferent and efferent fibers.

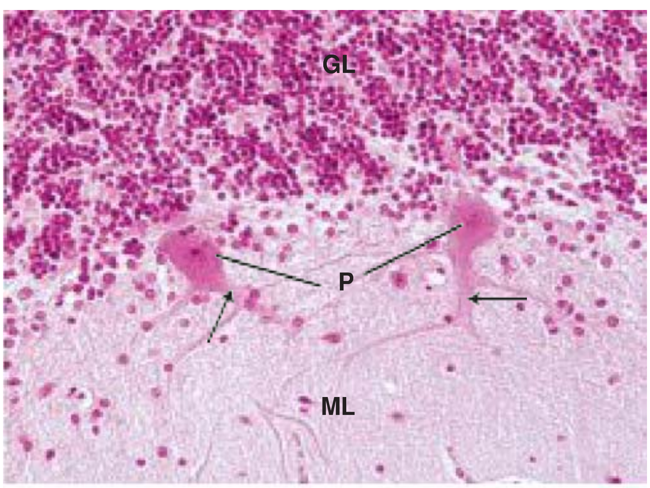


Figure 6-5 Light micrograph of the cerebellum (×132). Observe the Purkinje cells (P) with their dendritic trees (arrows) protruding into the molecular layer (ML). The heavily populated and deeply stained region is the granular layer (GL) of the cerebellum. (From Gartner, L. P. [2018]. *Color atlas and text of histology* [7th ed.]. Baltimore, MD: Wolters Kluwer.)

Purkinje Cell Layer

The Purkinje cells are large Golgi type I neurons. They are flask shaped and are arranged in a single layer (see Figs. 6-4 and 6-5). In a plane transverse to the folium, the dendrites of these cells are seen to pass into the molecular layer, where they undergo profuse branching. The primary and secondary branches are smooth, and subsequent branches are covered by short, thick **dendritic spines**. It has been shown that the spines form synaptic contacts with the parallel fibers derived from the granule cell axons.

At the base of the Purkinje cell, the axon arises and passes through the granular layer to enter the white matter. On entering the white matter, the axon acquires a myelin sheath, and it terminates by synapsing with cells of one of the intracerebellar nuclei. Collateral branches of the Purkinje axon make synaptic contacts with the dendrites of basket and stellate cells of the granular layer in the same area or in distant folia. A few of the Purkinje cell axons pass directly to end in the vestibular nuclei of the brainstem.

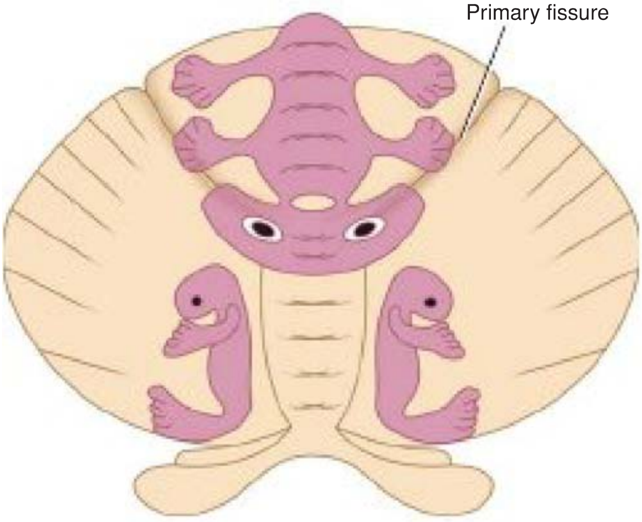


Figure 6-6 Somatosensory projection areas in the cerebellar cortex.

Granular Layer

The granular layer is packed with small cells with densely staining nuclei and scanty cytoplasm. Each cell gives rise to four or five dendrites, which make claw-like endings and have synaptic contact with mossy fiber input (see Fig. 6-4). The axon of each granule cell passes into the molecular layer, where it bifurcates at a T junction, the branches running parallel to the long axis of the cerebellar folium (see Fig. 6-4). These fibers, known as **parallel fibers**, run at right angles to the dendritic processes of the Purkinje cells. Most of the parallel fibers make synaptic contacts with the spinous processes of the dendrites of the Purkinje cells. Neuroglial cells are found throughout this layer. Scattered throughout the granular layer are Golgi cells. Their dendrites ramify in the molecular layer, and their axons terminate by splitting up into branches that synapse with the dendrites of the granular cells (see Fig. 6-5).

Functional Areas

Clinical observations by neurologists and neurosurgeons and the experimental use of positron emission tomography have shown that the cerebellar cortex can be divided into three functional areas.

The cortex of the vermis influences the movements of the long axis of the body, namely, the neck, the shoulders, the thorax, the abdomen, and the hips (Fig. 6-6). Immediately lateral to the vermis is a so-called intermediate zone of the cerebellar hemisphere. This area has been shown to control the muscles of the distal parts of the limbs, especially the hands and feet. The lateral zone of each cerebellar hemisphere appears to be concerned with the planning of sequential movements of the entire body and is involved with the conscious assessment of movement errors.

Intracerebellar Nuclei

Four masses of gray matter are embedded in the white matter of the cerebellum on each side of the midline (Fig. 6-7). From lateral to medial, these nuclei are the **dentate**, the **emboliform**, the **globose**, and the **fastigial**.

The **dentate nucleus** is the largest of the cerebellar nuclei. It has the shape of a crumpled bag with the opening facing medially. The interior of the bag is filled with white matter made up of efferent fibers that leaves the nucleus through the opening to form a large part of the superior cerebellar peduncle.

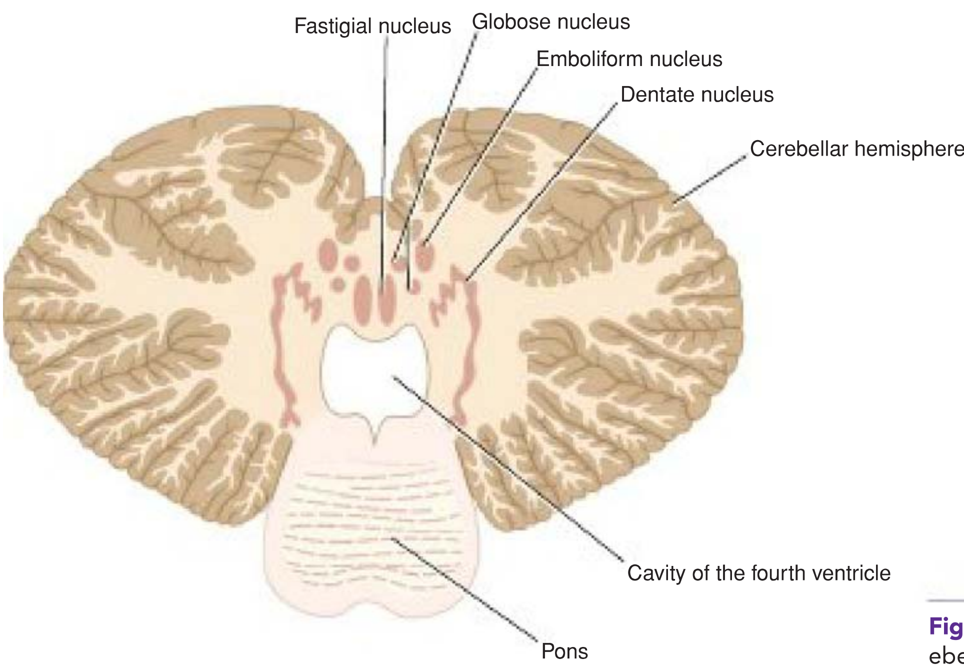


Figure 6-7 Position of the intracerebellar nuclei.

The **emboliform nucleus** is ovoid and is situated medial to the dentate nucleus, partially covering its hilus.

The **globose nucleus** consists of one or more rounded cell groups that lie medial to the emboliform nucleus.

The **fastigial nucleus** lies near the midline in the vermis and close to the roof of the fourth ventricle; it is larger than the globose nucleus.

The intracerebellar nuclei are composed of large, multipolar neurons with simple branching dendrites. The axons form the cerebellar outflow in the superior and inferior cerebellar peduncles.

White Matter

There is a small amount of white matter in the vermis; it closely resembles the trunk and branches of a tree and thus is termed the **arbor vitae** (see Fig. 6-1). There is a large amount of white matter in each cerebellar hemisphere.

The white matter is made up of three groups of fibers: (1) intrinsic, (2) afferent, and (3) efferent.

The **intrinsic fibers** do not leave the cerebellum but connect different regions of the organ. Some interconnect folia of the cerebellar cortex and vermis on the same side; others connect the two cerebellar hemispheres together.

The **afferent fibers** form the greater part of the white matter and proceed to the cerebellar cortex. They enter the cerebellum mainly through the inferior and middle cerebellar peduncles.

The **efferent fibers** constitute the output of the cerebellum and commence as the axons of the Purkinje cells of the cerebellar cortex. The great majority of the Purkinje cell axons pass to and synapse with the neurons of the cerebellar nuclei (fastigial, globose, emboliform, and dentate). The axons of the neurons then leave the cerebellum. A few Purkinje cell axons in the flocculonodular lobe and in parts of the vermis bypass the cerebellar nuclei and leave the cerebellum without synapsing.

Fibers from the dentate, emboliform, and globose nuclei leave the cerebellum through the superior cerebellar peduncle. Fibers from the fastigial nucleus leave through the inferior cerebellar peduncle.

CEREBELLAR CORTICAL MECHANISMS

As a result of extensive cytologic and physiologic research, certain basic mechanisms have been attributed to the cerebellar cortex. The climbing and the mossy fibers constitute the two main lines of input to the cortex and are **excitatory** to the Purkinje cells (Fig. 6-8).

The **climbing fibers** are the terminal fibers of the olivocerebellar tracts. They are so named because they ascend through the layers of the cortex like a

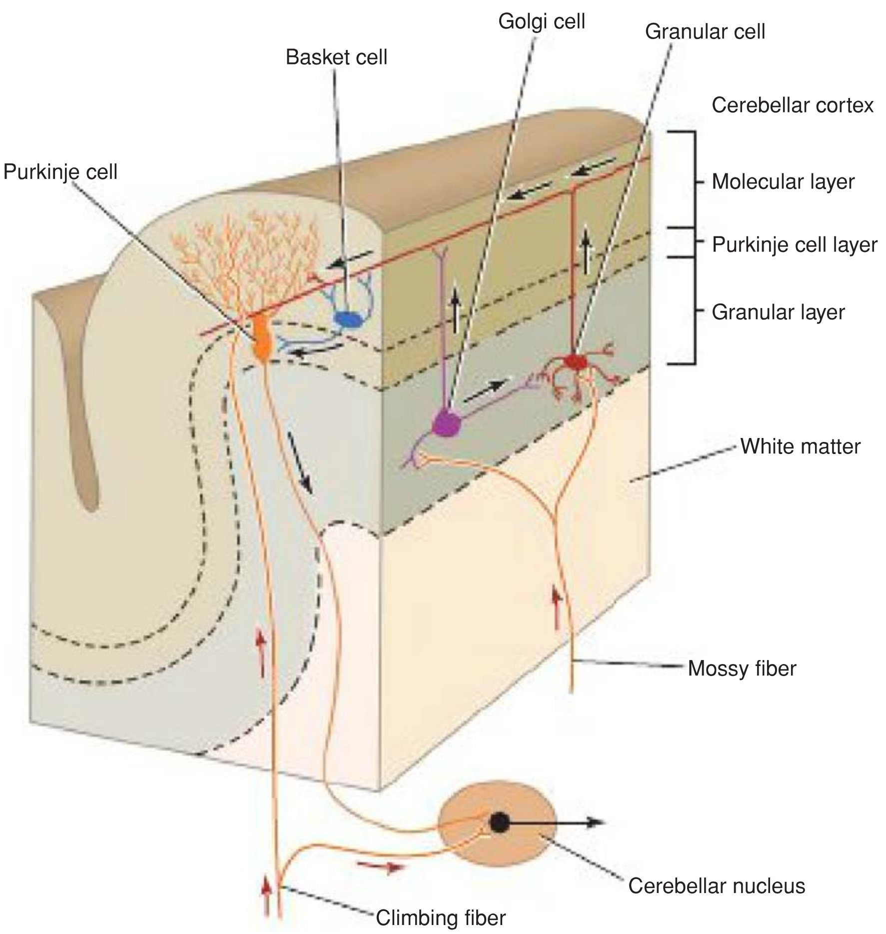


Figure 6-8 Functional organization of the cerebellar cortex. The *arrows* indicate the direction taken by the nervous impulses. The red *arrows* indicate information entering the cerebellum.

vine on a tree. They pass through the granular layer of the cortex and terminate in the molecular layer by dividing repeatedly. Each climbing fiber wraps around and makes a large number of synaptic contacts with the dendrites of a Purkinje cell. A **single** Purkinje neuron makes synaptic contact with only one climbing fiber. However, one climbing fiber makes contact with 1 to 10 Purkinje neurons. A few side branches leave each climbing fiber and synapse with the stellate cells and basket cells.

The **mossy fibers** are the terminal fibers of all other cerebellar afferent tracts. They have multiple branches and exert a much more diffuse excitatory effect. A single mossy fiber may stimulate **thousands** of Purkinje cells through the granule cells. What then is the function of the remaining cells of the cerebellar cortex, namely, the stellate, basket, and Golgi cells? Neurophysiologic research, using microelectrodes, would indicate that they serve as **inhibitory** interneurons. They not only limit the area of cortex excited but also probably influence the degree of Purkinje cell excitation produced by the climbing and mossy fiber input. By this means, fluctuating **inhibitory** impulses are transmitted by the Purkinje cells to the intracerebellar nuclei, which, in turn, modify muscular activity through the motor control areas of the brainstem and cerebral cortex. Thus, the Purkinje cells form the center of a **functional unit** of the cerebellar cortex.

Intracerebellar Nuclear Mechanisms

The deep cerebellar nuclei receive afferent nervous information from two sources: (1) the inhibitory axons from the Purkinje cells of the overlying cortex and (2) the excitatory axons that are branches of the afferent climbing and mossy fibers that are passing to the overlying cortex. In this manner, a given sensory input to the cerebellum sends excitatory information to the nuclei, which a short time later receive cortical processed inhibitory information from the Purkinje cells. Efferent information from the deep cerebellar nuclei leaves the cerebellum to be distributed to the remainder of the brain and spinal cord.

Cerebellar Cortical Neurotransmitters

Pharmacologic research has suggested that the excitatory climbing and mossy afferent fibers use **glutamate** (γ -aminobutyric acid [GABA]) as the excitatory transmitter on the dendrites of the Purkinje cells. Further research has indicated that other afferent fibers entering the cortex liberate **norepinephrine** and **serotonin** at their endings that possibly modify the action of the glutamate on the Purkinje cells.

Cerebellar Peduncles

The cerebellum is linked to other parts of the central nervous system (CNS) by numerous efferent and afferent fibers that are grouped together on each side into three large bundles, or peduncles (Fig. 6-9). The superior cerebellar peduncles connect the cerebellum to the midbrain, the middle cerebellar peduncles connect the cerebellum to the pons, and the inferior cerebellar peduncles connect the cerebellum to the medulla oblongata.

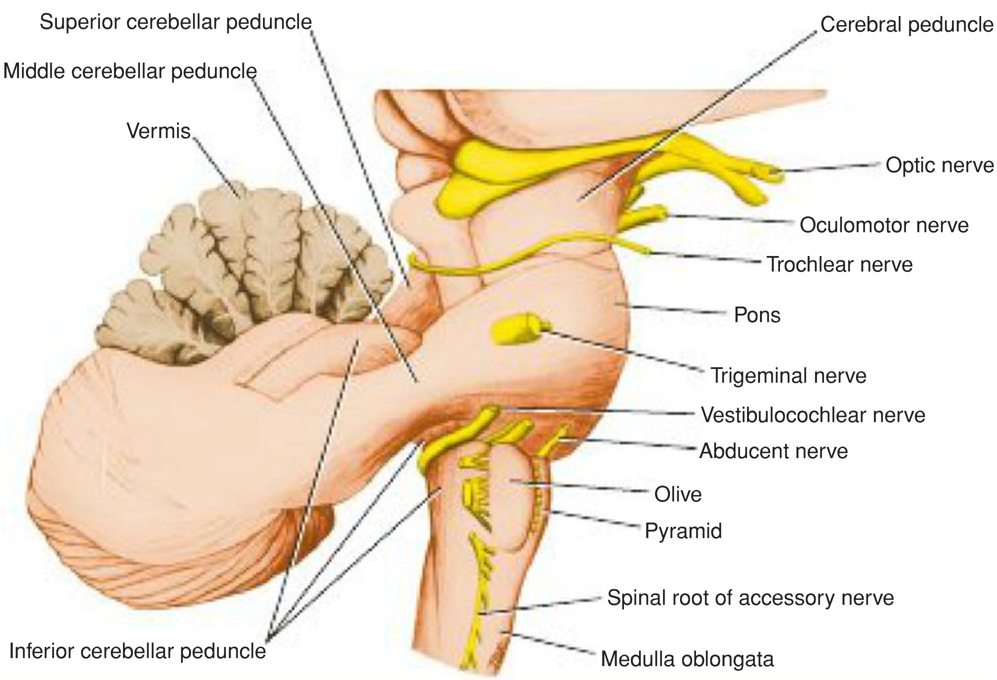


Figure 6-9 Three cerebellar peduncles connecting the cerebellum to the rest of the central nervous system.

CEREBELLAR AFFERENT FIBERS

The cerebellum receives major afferent tracts from the cerebral cortex, pons, medulla oblongata, and the spinal cord.

Cerebellar Afferent Fibers From the Cerebral Cortex

The cerebral cortex sends information to the cerebellum by three pathways: (1) the corticopontocerebellar pathway, (2) the cerebro-olivocerebellar pathway, and (3) the cerebroreticulocerebellar pathway.

Corticopontocerebellar Pathway

The corticopontine fibers arise from nerve cells in the frontal, parietal, temporal, and occipital lobes of the cerebral cortex and descend through the corona radiata and internal capsule and terminate on the pontine nuclei (Fig. 6-10). The pontine nuclei give rise to the **transverse fibers of the pons**, which cross the midline and enter the opposite cerebellar hemisphere as the middle cerebellar peduncle (see Figs. 5-18, 5-19).

Cerebro-Olivocerebellar Pathway

The cortico-olivary fibers arise from nerve cells in the frontal, parietal, temporal, and occipital lobes of the cerebral cortex and descend through the corona radiata and internal capsule to terminate bilaterally on the inferior olivary nuclei. The inferior olivary nuclei give rise to fibers that cross the midline and enter the opposite cerebellar hemisphere through the inferior cerebellar peduncle. These fibers terminate as the climbing fibers in the cerebellar cortex.

Cerebroreticulocerebellar Pathway

The corticoreticular fibers arise from nerve cells from many areas of the cerebral cortex, particularly the sensorimotor areas. They descend to terminate in the

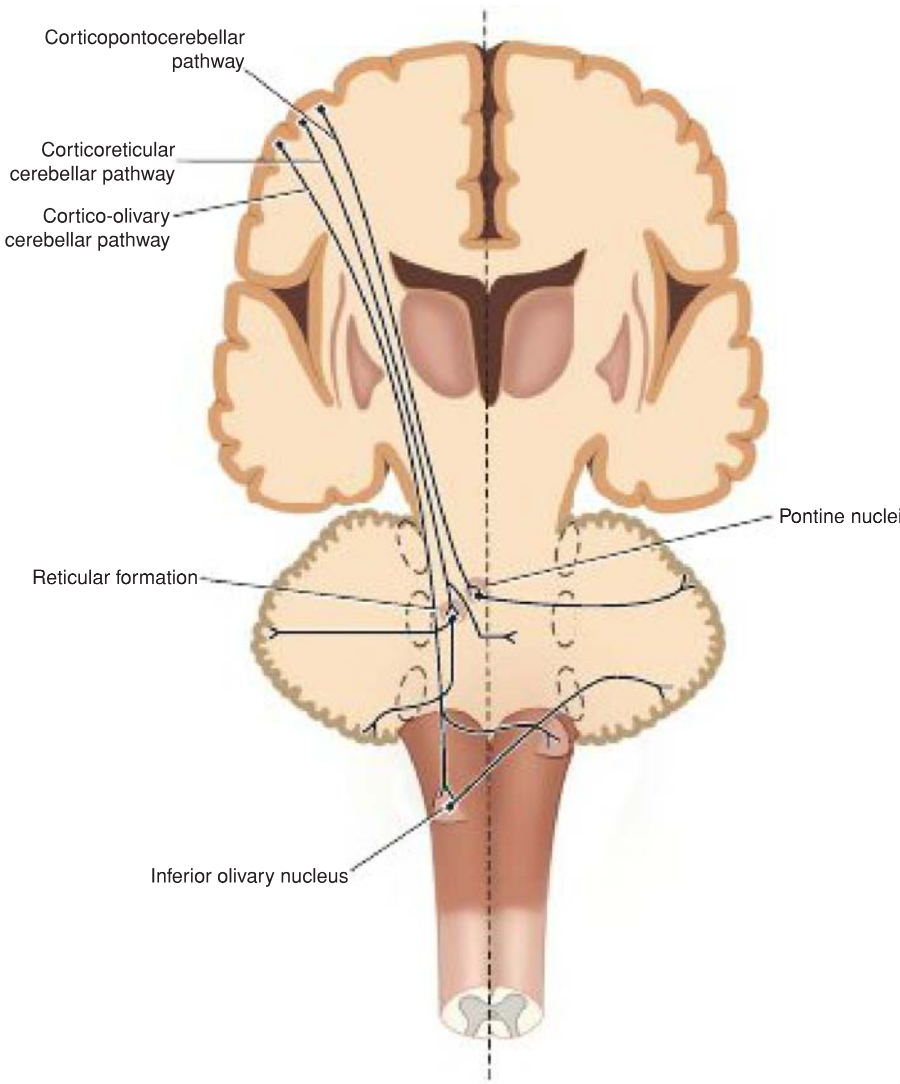


Figure 6-10 Cerebellar afferent fibers from the cerebral cortex. The cerebellar peduncles are shown as *ovoid dotted lines*.

reticular formation on the same side and on the opposite side in the pons and medulla. The cells in the reticular formation give rise to the reticulocerebellar fibers that enter the cerebellar hemisphere on the same side through the inferior and middle cerebellar peduncles.

This connection between the cerebrum and the cerebellum is important in the control of voluntary movement. Information regarding the initiation of movement in the cerebral cortex is probably transmitted to the cerebellum so that the movement can be monitored and appropriate adjustments in the muscle activity can be made.

Cerebellar Afferent Fibers From the Spinal Cord

The spinal cord sends information to the cerebellum from somatosensory receptors by three pathways: (1) the anterior spinocerebellar tract, (2) the posterior spinocerebellar tract, and (3) the cuneocerebellar tract.

Anterior Spinocerebellar Tract

The axons entering the spinal cord from the posterior root ganglion terminate by synapsing with the neurons in the **nucleus dorsalis** (Clarke column) at the base of the posterior gray column. Most of the axons of these neurons cross to the opposite side and ascend as the **anterior spinocerebellar tract** in the contralateral white column; some of the axons ascend as the anterior spinocerebellar tract in the lateral white column on the same side (Fig. 6-11). The fibers enter the cerebellum through the superior cerebellar peduncle and terminate as mossy fibers in the cerebellar cortex. Collateral

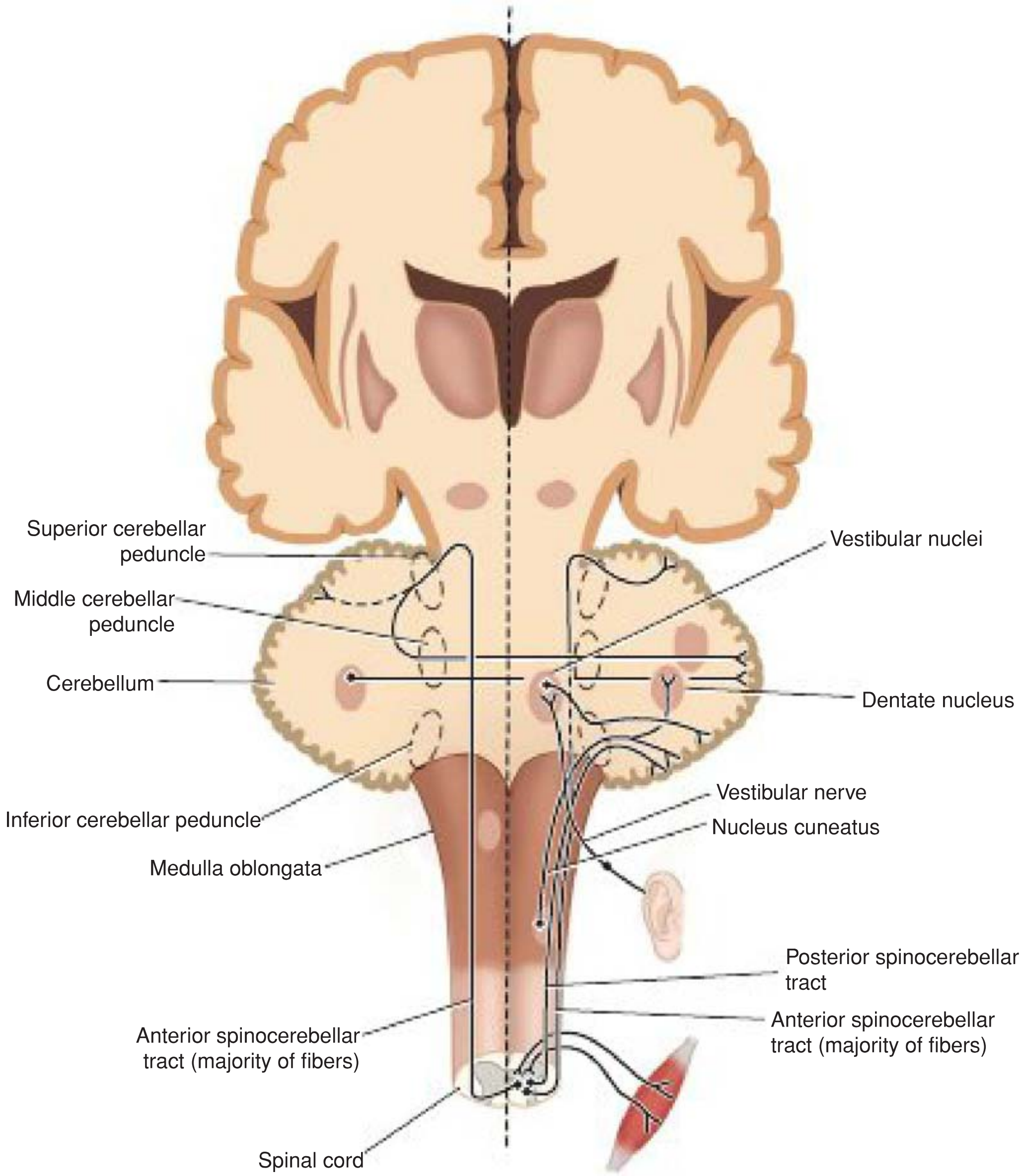


Figure 6-11 Cerebellar afferent fibers from the spinal cord and internal ear. The cerebellar peduncles are shown as *ovoid dotted lines.*

branches that end in the deep cerebellar nuclei are also given off. Those fibers that cross over to the opposite side in the spinal cord are thought to cross back within the cerebellum.

The anterior spinocerebellar tract is found at all segments of the spinal cord, and its fibers convey muscle joint information from the muscle spindles, tendon organs, and joint receptors of the upper and lower limbs. The cerebellum likely receives information from the skin and superficial fascia by this tract.

Posterior Spinocerebellar Tract

The axons entering the spinal cord from the posterior root ganglion enter the posterior gray column and terminate by synapsing on the neurons at the base of the posterior gray column. These neurons are known collectively as the nucleus dorsalis (Clarke column). The axons of these neurons enter the posterolateral part of the lateral white column on the same side and ascend as the **posterior spinocerebellar tract** to the medulla oblongata. Here, the tract enters the cerebellum through the inferior cerebellar peduncle and terminates as mossy fibers in the cerebellar cortex. Collateral branches that end in the deep cerebellar nuclei are also given off. The posterior spinocerebellar tract receives muscle joint information from the muscle spindles, tendon organs, and joint receptors of the trunk and lower limbs.

Cuneocerebellar Tract

These fibers originate in the nucleus cuneatus of the medulla oblongata and enter the cerebellar hemisphere on the same side through the inferior cerebellar peduncle (see Fig. 6-10). The fibers terminate as mossy fibers in the cerebellar cortex. Collateral branches that end in the deep cerebellar nuclei are also given off. The cuneocerebellar tract receives muscle joint information from the muscle spindles, tendon organs, and joint receptors of the upper limb and upper part of the thorax.

Cerebellar Afferent Fibers From the Vestibular Nerve

The vestibular nerve receives information from the inner ear concerning motion from the semicircular canals and position relative to gravity from the utricle and saccule. The vestibular nerve sends many afferent fibers directly to the cerebellum through the inferior cerebellar peduncle on the same side. Other vestibular afferent fibers pass first to the vestibular nuclei in the brainstem, where they synapse and are relayed to the cerebellum (see Fig. 6-11). They enter the cerebellum through the inferior cerebellar peduncle on the same side. All the afferent fibers from the inner ear terminate as mossy fibers in the flocculonodular lobe of the cerebellum.

Other Afferent Fibers

In addition, the cerebellum receives small bundles of afferent fibers from the red nucleus and the tectum.

The afferent cerebellar pathways are summarized in Table 6-1.

Table 6-1 Afferent Cerebellar Pathways

Pathway	Function	Origin	Destination
Corticopontocerebellar	Conveys control from cerebral cortex	Frontal, parietal, temporal, and occipital lobes	Via pontine nuclei and mossy fibers to cerebellar cortex
Cerebro-olivocerebellar	Conveys control from cerebral cortex	Frontal, parietal, temporal, and occipital lobes	Via inferior olivary nuclei and climbing fibers to cerebellar cortex
Cerebroreticulocerebellar	Conveys control from cerebral cortex	Sensorimotor areas	Via reticular formation
Anterior spinocerebellar	Conveys information from muscles and joints	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Posterior spinocerebellar	Conveys information from muscles and joints	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Cuneocerebellar	Conveys information from muscles and joints of upper limb	Muscle spindles, tendon organs, and joint receptors	Via mossy fibers to cerebellar cortex
Vestibular nerve	Conveys information of head position and movement	Utricle, saccule, and semicircular canals	Via mossy fibers to cortex of flocculonodular lobe
Other afferents	Conveys information from midbrain	Red nucleus, tectum	Cerebellar cortex

CEREBELLAR EFFERENT FIBERS

The entire output of the cerebellar cortex is through the axons of the Purkinje cells. Most of the axons of the Purkinje cells end by synapsing on the neurons of the deep cerebellar nuclei (see Fig. 6-4). The axons of the neurons that form the cerebellar nuclei constitute the efferent outflow from the cerebellum. A few Purkinje cell axons pass directly out of the cerebellum to the lateral vestibular nucleus. The efferent fibers from the cerebellum connect with the red nucleus, thalamus, vestibular complex, and reticular formation.

Globose-Emboliform-Rubral Pathway

Axons of neurons in the globose and emboliform nuclei travel through the superior cerebellar peduncle and cross the midline to the opposite side in the **decussation of the superior cerebellar peduncles** (Fig. 6-12). The fibers end by synapsing with cells of the contralateral red nucleus, which give rise to axons of the **rubrospinal tract**. Thus, this pathway crosses twice, once in the decussation of the superior cerebellar peduncle and again in the rubrospinal tract close to its origin. By this means, the globose and emboliform nuclei influence motor activity on the same side of the body.

Dentatothalamic Pathway

Axons of neurons in the dentate nucleus travel through the superior cerebellar peduncle and cross the midline to the opposite side in the **decussation of the superior cerebellar peduncle**. The fibers end by synapsing with cells in the contralateral **ventrolateral nucleus**

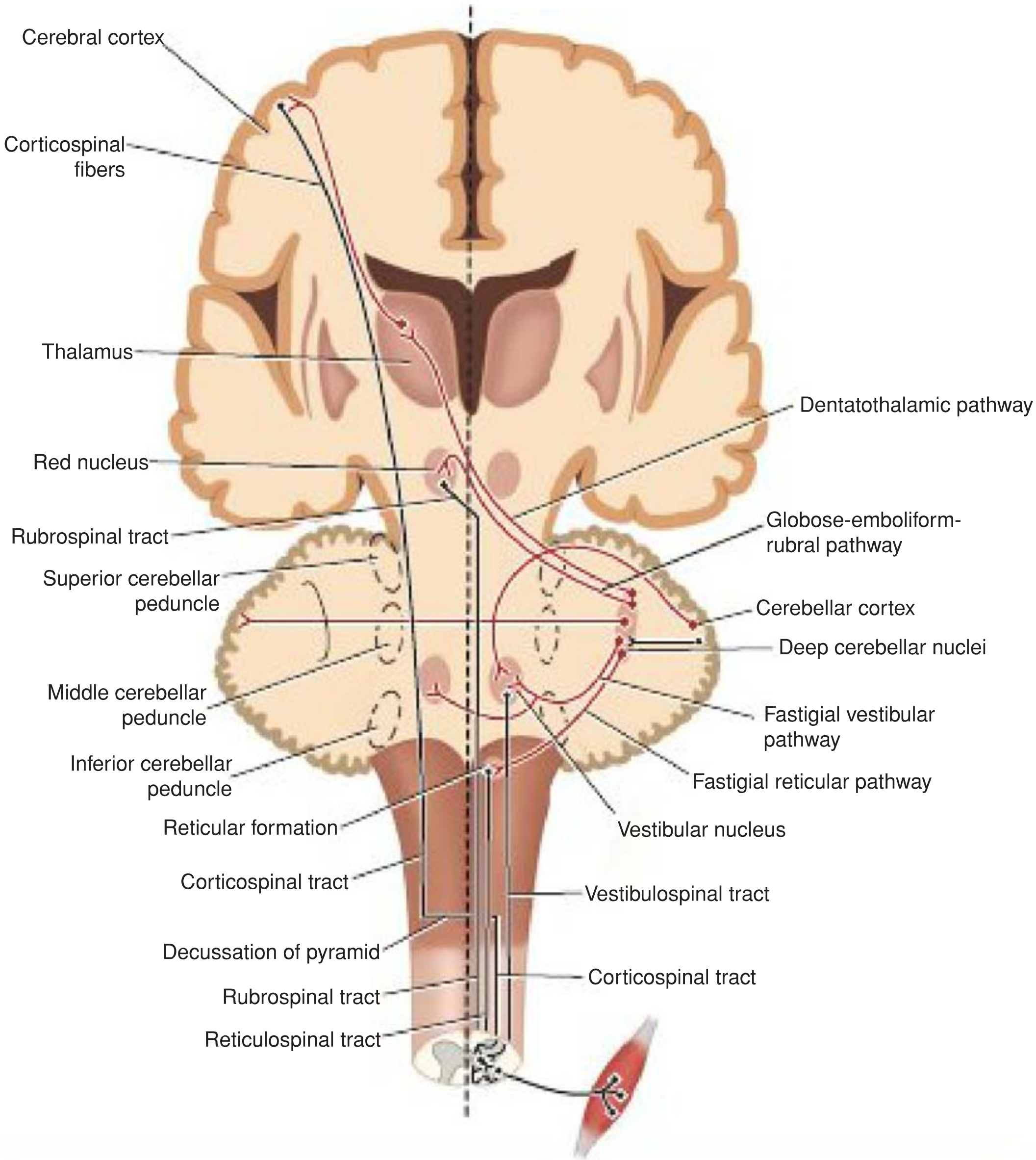


Figure 6-12 Cerebellar efferent fibers. The cerebellar peduncles are shown as *ovoid dotted lines*.

Table 6-2 Efferent Cerebellar Pathways[a]

Pathway	Function	Origin	Destination
Globose-emboliform-rubral	Influences ipsilateral motor activity	Globose and emboliform nuclei	To contralateral red nucleus, then via crossed rubrospinal tract to ipsilateral motor neurons in the spinal cord
Dentatothalamic	Influences ipsilateral motor activity	Dentate nucleus	To contralateral ventrolateral nucleus of the thalamus, then to contralateral motor cerebral cortex; corticospinal tract crosses midline and controls ipsilateral motor neurons in the spinal cord
Fastigial vestibular	Influences ipsilateral extensor muscle tone	Fastigial nucleus	Mainly to ipsilateral and to contralateral lateral vestibular nuclei; vestibulospinal tract to ipsilateral motor neurons in the spinal cord
Fastigial reticular	Influences ipsilateral muscle tone	Fastigial nucleus	To neurons of reticular formation; reticulospinal tract to ipsilateral motor neurons to the spinal cord

[a]Note that each cerebellar hemisphere influences the voluntary muscle tone on the same side of the body.

of the thalamus. The axons of the thalamic neurons ascend through the internal capsule and corona radiata and terminate in the primary motor area of the cerebral cortex. By this pathway, the dentate nucleus can influence motor activity by acting on the motor neurons of the opposite cerebral cortex; impulses from the motor cortex are transmitted to spinal segmental levels through the corticospinal tract. Remember that most of the fibers of the corticospinal tract cross to the opposite side in the decussation of the pyramids or later at the spinal segmental levels. Thus, the dentate nucleus is able to coordinate muscle activity on the same side of the body.

Fastigial Vestibular Pathway

The axons of neurons in the fastigial nucleus travel through the inferior cerebellar peduncle and end by projecting on the neurons of the **lateral vestibular nucleus** on both sides. Remember that some Purkinje cell axons project directly to the lateral vestibular nucleus. The neurons of the lateral vestibular nucleus form the **vestibulospinal tract**. The fastigial nucleus exerts a facilitatory influence mainly on the ipsilateral extensor muscle tone.

Fastigial Reticular Pathway

The axons of neurons in the fastigial nucleus travel through the inferior cerebellar peduncle and end by synapsing with neurons of the reticular formation. Axons of these neurons influence spinal segmental motor activity through the reticulospinal tract. The efferent cerebellar pathways are summarized in Table 6-2.

FUNCTIONS OF THE CEREBELLUM

The cerebellum receives afferent information concerning voluntary movement from the cerebral cortex and from the muscles, tendons, and joints. It also receives information concerning balance from the vestibular nerve and possibly concerning sight through the tectocerebellar tract. All this information is fed into the cerebellar cortical circuitry by the mossy fibers and the climbing fibers and converges on the Purkinje cells (see Fig. 6-8). The axons of the Purkinje cells project with few exceptions on the deep cerebellar nuclei. The output of the vermis projects to the fastigial nucleus, the intermediate regions of the cortex project to the globose and emboliform nuclei, and the output of the lateral part of the cerebellar hemisphere projects to the dentate nucleus. A few Purkinje cell axons pass directly out of the cerebellum and end on the lateral vestibular nucleus in the brainstem. Purkinje axons are generally believed to exert an inhibitory influence on the neurons of the cerebellar nuclei and the lateral vestibular nuclei.

The cerebellar output is conducted to the sites of origin of the descending pathways that influence motor activity at the segmental spinal level. In this respect, the cerebellum has no direct neuronal connections with the lower motor neurons but exerts its influence indirectly through the cerebral cortex and brainstem.

Physiologists have postulated that the cerebellum functions as a coordinator of precise movements by continually comparing the output of the motor area of the cerebral cortex with the proprioceptive information received from the site of muscle action; it is then able to bring about the necessary adjustments by influencing the activity of the lower motor neurons (Fig. 6-13). This is accomplished by controlling the timing and sequence of firing of the α and γ motor neurons. The cerebellum can possibly send back information to the motor cerebral cortex to inhibit the agonist muscles and stimulate the antagonist muscles, thus limiting the extent of voluntary movement.

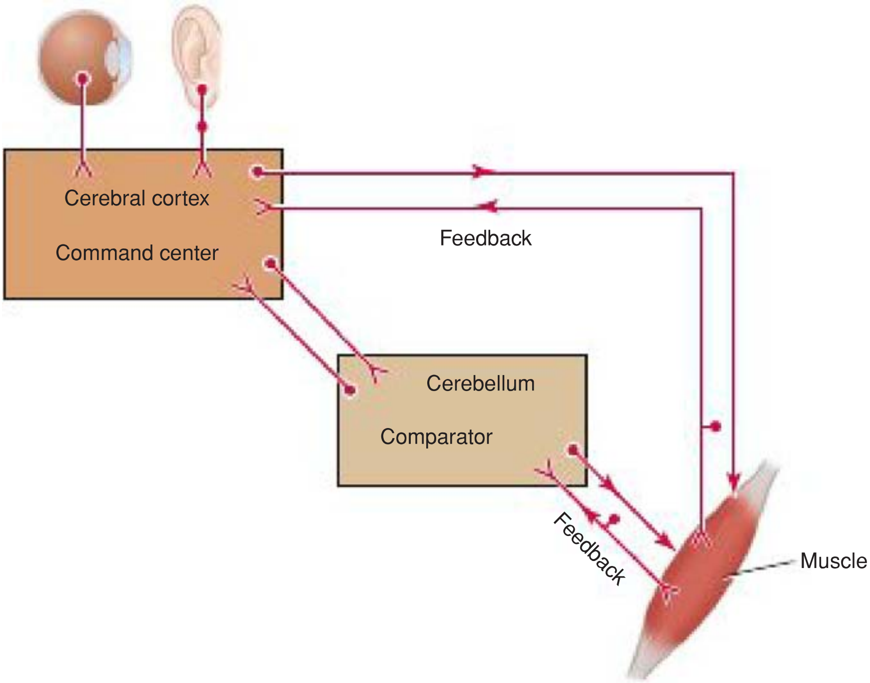


Figure 6-13 Cerebellum serving as a comparator.

Clinical Notes

General Considerations

Each cerebellar hemisphere is connected by nervous pathways principally with the same side of the body; thus, a **lesion in one cerebellar hemisphere gives rise to signs and symptoms that are limited to the same side of the body**. The main connections of the cerebellum are summarized in Figure 6-14.

The essential function of the cerebellum is to coordinate, by synergistic action, all reflex and voluntary muscular activity. Thus, it graduates and harmonizes muscle tone and maintains normal body posture. It permits voluntary movements, such as walking, to take place smoothly with precision and economy of effort. It must be understood that although the cerebellum plays an important role in skeletal muscle activity, it is not able to initiate muscle movement.

Signs and Symptoms of Cerebellar Disease

While the importance of the cerebellum in the maintenance of muscle tone and the coordination of muscle movement has been emphasized, it should be remembered that the symptoms and signs of acute lesions differ from those produced by chronic lesions. Acute lesions produce sudden, severe symptoms and signs, but there is considerable clinical evidence to show that patients can recover completely from large cerebellar injuries. This suggests that other CNS areas can compensate for loss of cerebellar function. Chronic lesions, such as slowly enlarging tumors, produce symptoms and signs that are much less severe than those of acute lesions. The reason for this may be that other CNS areas have time to compensate for loss of cerebellar function. The following symptoms and signs are characteristic of cerebellar dysfunction.

Hypotonia

The muscles lose resilience to palpation. There is diminished resistance to passive movements of joints. Shaking the limb produces excessive movements at the terminal joints. The condition is attributable to loss of cerebellar influence on the simple stretch reflex.

Postural Changes and Alteration of Gait

The head is often rotated and flexed, and the shoulder on the side of the lesion is lower than on the normal side. The patient assumes a wide base when he or she stands and is often stiff legged to compensate for loss of muscle tone. When the individual walks, he or she lurches and staggers toward the affected side.

Disturbances of Voluntary Movement (Ataxia)

The muscles contract irregularly and weakly. **Tremor** occurs when fine movements, such as buttoning clothes, writing, and shaving, are attempted. Muscle groups fail to work harmoniously, and there is **decomposition of movement**. When the patient is asked to touch the tip of the nose with the index finger, the movements are not properly coordinated, and the finger either passes the nose (past-pointing) or hits the nose. A similar test can be performed on the lower limbs by asking the patient to place the heel of one foot on the shin of the opposite leg.

Dysdiadochokinesia

Dysdiadochokinesia is the inability to perform alternating movements regularly and rapidly. Ask the patient to pronate and supinate the forearms rapidly. On the side of

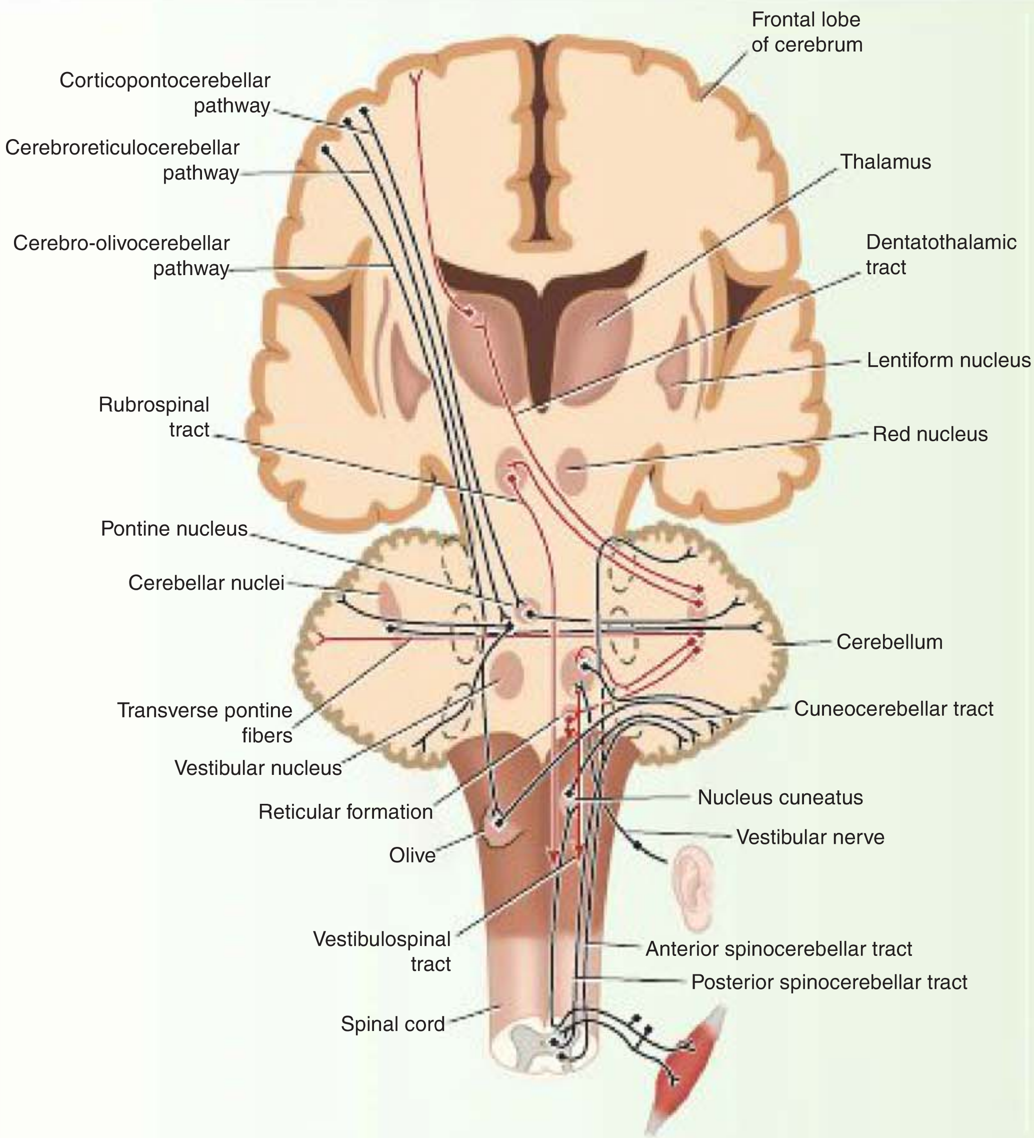


Figure 6-14 Some of the main connections of the cerebellum. The cerebellar peduncles are shown as *ovoid dashed lines*.

the cerebellar lesion, the movements are slow, jerky, and incomplete.

Disturbances of Reflexes

Movement produced by tendon reflexes tends to continue for a longer period of time than normal. The **pendular knee jerk**, for example, occurs following tapping of the patellar tendon. Normally, the movement occurs and is self-limited by the stretch reflexes of the agonists and antagonists. In cerebellar disease, because of loss of influence on the stretch reflexes, the movement continues as a series of flexion and extension movements at the knee joint; that is, the leg moves like a pendulum.

Disturbances of Ocular Movement

Nystagmus, which is essentially an ataxia of the ocular muscles, is a rhythmical oscillation of the eyes. It is more easily demonstrated when the eyes are deviated in a horizontal direction. This rhythmic oscillation of the eyes may be of the same rate in both directions **(pendular nystagmus)** or quicker in one direction than in the other **(jerk nystagmus)**. In the latter situation, the movements are referred to as the slow phase away from the visual object, followed by a quick phase back toward the target. The quick phase is used to describe the form of nystagmus. For example, a patient is said to have a nystagmus to the left if the quick phase is to the left and the slow phase is to the right. The movement of nystagmus may be confined to one plane and may be horizontal or vertical, or it may be in many planes when it is referred to as rotatory nystagmus.

The posture of the eye muscles depends mainly on the normal functioning of two sets of afferent pathways. The first is the visual pathway whereby the eye views the object of interest, and the second pathway is much more complicated and involves the labyrinths, the vestibular nuclei, and the cerebellum.

Disorders of Speech

Dysarthria occurs in cerebellar disease because of ataxia of the muscles of the larynx. Articulation is jerky, and the syllables often are separated from one another. Speech tends to be explosive, and the syllables often are slurred.

In cerebellar lesions, paralysis and sensory changes are not present. Although muscle hypotonia and incoordination may be present, the disorder is not limited to specific muscles or muscle groups; rather, an entire extremity or the entire half of the body is involved. If both cerebellar hemispheres are involved, then the entire body may show disturbances of muscle action. Even though the muscular contractions may be weak and the patient may be easily fatigued, there is no atrophy.

Cerebellar Syndromes

Vermis Syndrome

The most common cause of vermis syndrome is a **medulloblastoma** of the vermis in children. Involvement of the flocculonodular lobe results in signs and symptoms related to the vestibular system. Since the vermis is unpaired and influences midline structures, muscle incoordination involves the head and trunk and not the limbs. There is a tendency to fall forward or backward. There is difficulty in holding the head steady and in an upright position. There also may be difficulty in holding the trunk erect.

Cerebellar Hemisphere Syndrome

Tumors of one cerebellar hemisphere may be the cause of cerebellar hemisphere syndrome. The symptoms and signs are usually unilateral and involve muscles on the side of the diseased cerebellar hemisphere. Movements of the limbs, especially the arms, are disturbed. Swaying and falling to the side of the lesion often occur. Dysarthria and nystagmus are also common findings. Disorders of the lateral part of the cerebellar hemispheres produce delays in initiating movements and inability to move all limb segments together in a coordinated manner but show a tendency to move one joint at a time.

Common Diseases Involving the Cerebellum

One of the most common diseases affecting cerebellar function is acute alcohol poisoning. This occurs as the result of alcohol acting on GABA receptors on the cerebellar neurons.

The following frequently involve the cerebellum: congenital agenesis or hypoplasia, trauma, infections, tumors, multiple sclerosis, vascular disorders such as thrombosis of the cerebellar arteries, and poisoning with heavy metals.

The many manifestations of cerebellar disease can be reduced to two basic defects: hypotonia and loss of influence of the cerebellum on the activities of the cerebral cortex.

Key Concepts

Cerebellum

- The cerebellum is composed of an outer covering of gray matter called the cortex and inner white matter. Embedded in the white matter of each hemisphere are three masses of gray matter forming the four intracerebellar nuclei.
- The gray matter of the cortex is divided into three layers: the external, molecular layer; the middle, Purkinje layer; and the inner, granular layer.
- Basket and stellate cells are found in the molecular layer and are scattered throughout the dendritic arborizations of the Purkinje cells, whose cell bodies are found within the Purkinje layer.
- Granule cells (and Golgi cells) are found throughout the granular layer and have synaptic contact with mossy fiber input (cerebellar afferent tracts). The axon of each granule cell branches and runs parallel to the long axis of the cerebellar folium.
- Climbing fibers are terminal fibers of the olivocerebellar tracts. A single Purkinje neuron makes synaptic contact with only one climbing fiber.
- Mossy fibers are the terminal fibers of all other cerebellar afferent tracts. Each mossy fiber communicates with thousands of Purkinje cells through the granule cells.

Cerebellar Afferent Fibers

- The cerebellum receives three afferent pathways from the cerebrum and is important for monitoring and control of voluntary movements.
- The cerebellum also receives three afferent pathways from the spinal cord, all of which supply the cerebellum with muscle and joint information of the limb and trunk.

Cerebellar Efferent Fibers

- The output of the cerebellum is through Purkinje cell axons, most of which synapse on the neurons of the deep cerebellar nuclei.
- The efferent fibers from the deep nuclei connect with the red nucleus (globose-emboliform-rubral), thalamus (dentatothalamic), vestibular complex (fastigial vestibular), and reticular formation (fastigial reticular).

Cerebellar Functions

- The cerebellum functions as a coordinator of precise movements by continually comparing the output of the motor area of cerebral cortex with the proprioceptive information received from the site of muscle action, and makes necessary adjustments.

Clinical Problem Solving

1. A 10-year-old girl is taken to a neurologist because her parents notice that her gait is becoming awkward. Six months previously, the child had complained that she felt her right arm is clumsy, and she had inadvertently knocked a teapot off the table. More recently, her family notices that her hand movements are becoming jerky and awkward; this is particularly obvious when she is eating with a knife and fork. The mother comments that her daughter has had problems with her right foot since birth and that she had a clubfoot. She also has scoliosis and is attending an orthopedic surgeon for treatment. The mother said she is particularly worried about her daughter because two other members of the family had similar signs and symptoms.

   On physical examination, the child is found to have a lurching gait with a tendency to reel over to the right. Intention tremor is present in the right arm and the right leg. When the strength of the limb muscles is tested, those of the right leg are found to be weaker than those of the left leg. The muscles of the right arm and right lower leg are also hypotonic. She has severe pes cavus of the right foot and a slight pes cavus of the left foot. Kyphoscoliosis of the upper part of the thoracic vertebral column also is present.

   On examination of her sensory system, she is found to have loss of muscle joint sense and vibratory sense of both legs. She also has loss of two-point discrimination of the skin of both legs. Her knee jerks are found to be exaggerated, but her ankle jerks are absent. The biceps and triceps jerks of both arms are normal. She has bilateral Babinski responses. Slight nystagmus is present in both eyes. Using your knowledge of neuroanatomy, explain the symptoms and signs listed for this patient. Did the disease process involve more than one area of the central nervous system? Explain.
2. Two physicians are talking in the street when one turns to the other and says, "Look at that man over there. Look at the way he is walking. He is not swinging his right arm at all; it is just hanging down by his side. I wonder if he has a cerebellar lesion." Does a person with a unilateral cerebellar hemisphere tumor tend to hold the arm limply at the side when he walks?
3. A 37-year-old man visits his physician because he has noticed clumsiness of his right arm. The symptoms started 6 months previously and are getting worse. He also notices that his right hand has a tremor when he attempts fine movements or tries to insert a key in a lock. When he walks, he notices that now and again he tends to reel over to the right, "as if he had too much alcohol to drink." On physical examination, the face is tilted slightly to the left, and the right shoulder is held lower than the left. Passive movements of the arms and legs reveal hypotonia and looseness on the right side. When asked to walk heel to toe along a straight line on the floor, the patient sways over to the right side. When he was asked to touch his nose with his right index finger, the right hand displays tremor, and the finger tends to overshoot the target. Speech is normal, and nystagmus is not present. Using your knowledge of neuroanatomy, explain each sign and symptom. Is the lesion of the cerebellum likely to be in the midline or to one side?
4. A 4½-year-old boy is taken to a neurologist because his mother is concerned about his attacks of vomiting on waking in the morning and his tendency to be unsteady on standing up. The mother also notices that the child walks with an unsteady gait and often falls backward. On physical examination, the child tends to stand with the legs well apart—that is, broad based. The head is larger than normal for his age, and the suture lines of the skull can be easily felt. A retinal examination with an ophthalmoscope shows severe papilledema in both eyes. The muscles of the upper and lower limbs show some degree of hypotonia. Nystagmus is not present, and the child showed no tendency to fall to one side or the other when asked to walk. Using your knowledge of neuroanatomy, explain the symptoms and signs. Is the lesion in the cerebellum likely to be in the midline or to one side?
5. During a ward round, a third-year student is asked to explain the phenomenon of nystagmus. How would you have answered that question? Why do patients with cerebellar disease exhibit nystagmus?
6. What is the essential difference between the symptoms and signs of acute and chronic lesions of the cerebellum? Explain these differences.

Answers and Explanations to Clinical Problem Solving

1. This 10-year-old girl had the symptoms and signs of Friedreich ataxia, an inherited degenerative disease of the cerebellum and posterior and lateral parts of the spinal cord.

   Degeneration of the cerebellum was revealed by the altered gait, clumsy movements of the right arm, tendency to fall to the right, intention tremor of the right arm and leg, hypotonicity of the right arm and right leg, and nystagmus of both eyes.

   Involvement of the fasciculus gracilis was evidenced by loss of vibratory sense, loss of two-point discrimination, and loss of muscle joint sense of the lower limbs.

Corticospinal tract degeneration resulted in weakness of the legs and the presence of the Babinski plantar response. The exaggerated knee jerks were due to the involvement of the upper motor neurons other than the corticospinal tract.

The loss of the ankle jerks was due to the interruption of the reflex arcs at spinal levels S1–S2 by the degenerative process.

The clubfoot and scoliosis can be attributed to altered tone of the muscles of the leg and trunk over a period of many years.

2. Yes. A person who has a unilateral lesion involving one cerebellar hemisphere demonstrates absence of coordination between different groups of muscles on the same side of the body. This disturbance affects not only agonists and antagonists in a single joint movement but also all associated muscle activity. For example, a normal person when walking swings his or her arms at both sides; with cerebellar disease, this activity would be lost on the side of the lesion.
3. This man, at operation, was found to have an astrocytoma of the right cerebellar hemisphere. This fact explains the occurrence of unilateral symptoms and signs. The lesion was on the right side, and the clumsiness, tremor, muscle incoordination, and hypotonia occurred on the right side of the body. The progressive worsening of the clinical condition could be explained on the basis that more and more of the cerebellum was becoming destroyed as the tumor rapidly expanded. The flaccidity of the muscles of the right arm and leg was due to hypotonia, that is, a removal of the influence of the cerebellum on the simple stretch reflex involving the muscle spindles and tendon organs. The clumsiness, tremor, and overshooting on the finger-nose test were caused by the lack of cerebellar influence on the process of coordination between different groups of muscles. The falling to the right side, the tilting of the head, and the drooping of the right shoulder were due to loss of muscle tone and fatigue.
4. The diagnosis was medulloblastoma of the brain in the region of the roof of the fourth ventricle, with involvement of the vermis of the cerebellum. The child died 9 months later after extensive deep x-ray therapy. The sudden onset of vomiting, the increased size of the head beyond normal limits, the sutural separation, and the severe bilateral papilledema could all be accounted for by the rapid rise in intracranial pressure owing to the rapid increase in size of the tumor. The broad-based, unsteady gait and the tendency to fall backward (or forward), and not to one side, indicate a tumor involving the vermis. The presence of bilateral hypotonia, especially during the later stages, was due to involvement of both cerebellar hemispheres. At autopsy, the tumor was found to have invaded the fourth ventricle extensively, and there was evidence of internal hydrocephalus because the cerebrospinal fluid had been unable to escape through the foramina in the roof of the fourth ventricle.
5. Nystagmus, an involuntary oscillation of the eyeball, may occur physiologically, as when a person watches rapidly moving objects, or by rapid rotation of the body. It commonly occurs in diseases of the nervous system, eye, and inner ear. In cerebellar disease, nystagmus is due to ataxia of the muscles moving the eyeball. There is lack of coordination between the agonists and antagonists involved in the eyeball movement. For full understanding of the different forms of nystagmus, a textbook of neurology should be consulted. Also see page 242.
6. Acute lesions, such as those resulting from a thrombosis of a cerebellar artery or a rapidly growing tumor, produce sudden severe symptoms and signs because of the sudden withdrawal of the influence of the cerebellum on muscular activity. Patients can recover quickly from large cerebellar injuries, and this can be explained by the fact that the cerebellum influences muscular activity not directly, but indirectly, through the vestibular nuclei, reticular formation, red nucleus, tectum, and corpus striatum and the cerebral cortex; it may be that these other areas of the central nervous system (CNS) take over this function. In chronic lesions, the symptoms and signs are much less severe, and there is enough time to allow other CNS areas to compensate for loss of cerebellar function.

Review Questions

Directions: Each of the numbered items in this section is followed by answers. Select the ONE lettered answer that is CORRECT.

1. The following statements concern the gross appearance of the cerebellum:
   (a) It is separated from the occipital lobes of the cerebral hemispheres by the tentorium cerebelli.
   (b) It lies anterior to the medulla oblongata and the pons.
   (c) The anterior lobe is separated from the middle (posterior) lobe by the uvulonodular fissure.
   (d) The flocculonodular lobe is separated from the middle (posterior) lobe by the horizontal fissure.
   (e) The third ventricle lies anterior to the cerebellum.

2. The following general statements concern the cerebellum:
   (a) The cerebellum greatly influences the activity of smooth muscle.
   (b) The cerebellum has no influence on the skeletal muscles supplied by the cranial nerves.
   (c) Each cerebellar hemisphere controls the tone of skeletal muscles supplied by spinal nerves on the same side of the body.
   (d) The important Purkinje cells are Golgi type II neurons.
   (e) The Purkinje cells exert a stimulatory influence on the intracerebellar nuclei.
3. The following statements concern the structure of the cerebellum:
   (a) The cerebellum consists of two cerebellar hemispheres joined by a narrow median vermis.
   (b) The inferior surface of the cerebellum shows a deep groove formed by the superior surface of the vermis.
   (c) The inferior cerebellar peduncles join the cerebellum to the pons.
   (d) The gray matter is confined to the cerebellar cortex.
   (e) The gray matter of folia of the dentate nucleus has a branched appearance on the cut surface, called the arbor vitae.
4. The following statements concern the structure of the cerebellar cortex:
   (a) The cortex is folded by many vertical fissures into folia.
   (b) The structure of the cortex differs widely in different parts of the cerebellum.
   (c) The Purkinje cells are found in the most superficial layer of the cortex.
   (d) The Golgi cells are found in the most superficial layer of the cerebellar cortex.
   (e) The axons of the Purkinje cells form the efferent fibers from the cerebellar cortex.
5. The following statements concern the intracerebellar nuclei:
   (a) The nuclei are found within the superficial layers of the white matter.
   (b) The nuclei are located in the walls of the fourth ventricle.
   (c) The nuclei are composed of many small unipolar neurons.
   (d) The axons of the nuclei form the main cerebellar outflow.
   (e) From medial to lateral, the nuclei are named as follows: dentate, emboliform, globose, and fastigial.
6. The following statements concern the cerebellar peduncles:
   (a) In the superior cerebellar peduncle, most of the fibers are afferent and arise from the neurons of the spinal cord.
   (b) The anterior spinocerebellar tract enters the cerebellum through the superior cerebellar peduncle.
   (c) The inferior cerebellar peduncle is made up exclusively of fibers that pass from the inferior olivary nuclei to the middle lobe of the cerebellar hemisphere.
   (d) The middle cerebellar peduncle is formed of fibers that arise from the dentate nuclei.
   (e) The cerebellar peduncles are surface structures that are difficult to see even by brain dissection.
7. The following statements concern the afferent fibers entering the cerebellum:
   (a) The mossy fibers end by making synaptic contacts with the dendrites of the Purkinje cells.
   (b) The fibers enter the cerebellum mainly through the internal and external arcuate fibers.
   (c) The climbing and mossy fibers constitute the two main lines of input to the cerebellar cortex.
   (d) The afferent fibers are inhibitory to the Purkinje cells.
   (e) The afferent fibers to the cerebellum are nonmyelinated.
8. The following statements concern the functions of the cerebellum:
   (a) The cerebellum influences the actions of muscle tendons.
   (b) The cerebellum controls voluntary movement by coordinating the force and extent of contraction of different muscles.
   (c) The cerebellum stimulates the contraction of antagonistic muscles.
   (d) The cerebellum directly influences skeletal muscle activity without the assistance of the cerebral cortex.
   (e) The cerebellum coordinates the peristaltic waves seen in intestinal muscle.
9. The following statements concern the cerebellum:
   (a) The afferent climbing fibers make single synaptic contacts with individual Purkinje cells.
   (b) The afferent mossy fibers may stimulate many Purkinje cells by first stimulating the stellate cells.
   (c) The neurons of the intracerebellar nuclei send axons without interruption to the opposite cerebral hemisphere.
   (d) The output of the cerebellar nuclei influences muscle activity so that movements can progress in an orderly sequence from one movement to the next.
   (e) Past-pointing is caused by the failure of the cerebral cortex to inhibit the cerebellum after the movement has begun.
10. The following statements concern the cerebellum:
   (a) The cerebellar cortex has a different microscopic structure in different individuals.
   (b) The axons of the Purkinje cells exert an inhibitory influence on the neurons of the deep cerebellar nuclei.
   (c) Each cerebellar hemisphere principally influences movement on the opposite hand.
   (d) The part of the cerebellum that lies in the midline is called the flocculus.
   (e) Intention tremor is a sign of cerebellar disease.

Directions: Matching Questions. Following thrombosis of the posterior inferior cerebellar artery, a patient presents the numbered signs and symptoms listed below; match the signs and symptoms with the appropriate lettered structures involved. Each lettered option may be selected once, more than once, or not at all.

11. Loss of pain and temperature on the left side of the body
12. Nystagmus
13. Hypotonicity of the muscles on the right with a tendency to fall to the right
    (a) Right reticulospinal tract
    (b) Right inferior cerebellar peduncle
    (c) None of the above

Directions: Match the numbered nerve tracts listed below with the lettered pathways by which they leave the cerebellum. Each lettered option may be selected once, more than once, or not at all.

14. Corticopontocerebellar
15. Cuneocerebellar
16. Cerebellar reticular
17. Cerebellar rubral

(a) Superior cerebellar peduncle
(b) Corpus callosum
(c) Striae medullaris
(d) Inferior cerebellar peduncle
(e) Middle cerebellar peduncle
(f) None of the above

Directions: Each case history is followed by questions. Read the case history, then select the ONE BEST lettered answer.

A 45-year-old man, who was an alcoholic, started to develop a lurching, staggering gait even when he was not intoxicated. The condition became slowly worse over a period of several weeks and then appeared to stabilize. Friends noticed that he had difficulty in walking in tandem with another person and tended to become unsteady on turning quickly.

18. A thorough physical examination of this patient revealed the following findings **except**:
    (a) The patient exhibited instability of trunk movements and incoordination of leg movements.
    (b) While standing still, the patient stood with his feet together.
    (c) He had no evidence of polyneuropathy.
    (d) The ataxia of the legs was confirmed by performing the heel-to-shin test.
    (e) Magnetic resonance imaging showed evidence of atrophy of the cerebellar vermis.
19. The following additional abnormal signs might have been observed in this patient **except**:
    (a) Nystagmus in both eyes
    (b) Dysarthria
    (c) Tremor of the left hand when reaching for a cup
    (d) Paralysis of the right upper arm muscles
    (e) Dysdiadochokinesia

Answers and Explanations to Review Questions

1. A is correct. The cerebellum is separated from the occipital lobes of the cerebral hemisphere by the tentorium cerebelli. B. The cerebellum lies posterior to the medulla oblongata (see Fig. 6-1). C. The anterior lobe is separated from the middle (posterior) lobe by the primary fissure (see Fig. 6-3). D. The flocculonodular lobe is separated from the middle (posterior) lobe by the uvulonodular fissure (see Fig. 6-3). E. The fourth ventricle lies anterior to the cerebellum (see Fig. 6-1).
2. C is correct. Each cerebellar hemisphere controls the tone of skeletal muscles supplied by spinal nerves on the same side of the body. A. The cerebellum has no effect on the activity of smooth muscle. B. The cerebellum has the same influence on the skeletal muscle supplied by cranial nerves as on that supplied by spinal nerves. D. The important Purkinje cells are Golgi type I neurons. E. The Purkinje cells exert an inhibitory influence on the intracerebellar nuclei.
3. A is correct. The cerebellum consists of two cerebellar hemispheres joined by a narrow median vermis (see Fig. 6-2). B. The inferior surface of the cerebellum shows a deep groove formed by the inferior surface of the vermis (see Fig. 6-2). C. The inferior cerebellar peduncle joins the cerebellum to the medulla oblongata (see Fig. 6-9). D. The gray matter of the cerebellum is found in the cortex and in the three masses forming the intracerebellar nuclei. E. The white matter and folia of the cortex have a branched appearance on the cut surface, called the arbor vitae (see Fig. 6-1).
4. E is correct. The axons of the Purkinje cells form the efferent fibers from the cerebellar cortex. A. The cerebellar cortex is folded by many transverse fissures into folia (see Fig. 6-1). B. The structure of the cortex is identical in different parts of the cerebellum. C. The Purkinje cells are found in the middle layer of the cerebellar cortex (see Fig. 6-4). D. The Golgi cells are found in the deepest (granular) layer of the cerebellar cortex (see Fig. 6-4).
5. D is correct. The axons from the neurons of the intracerebellar nuclei form the main cerebellar outflow. A. The intracerebellar nuclei are deeply embedded in the white matter (see Fig. 6-7). B. The nuclei are located posterior to the roof of the fourth ventricle (see Fig. 6-7). C. The nuclei are composed of large multipolar neurons. E. From medial to lateral, the nuclei are named as follows: fastigial, globose, emboliform, and dentate (see Fig. 6-7).
6. B is correct. The anterior spinocerebellar tract enters the cerebellum through the superior cerebellar

peduncle (see Fig. 6-11). A. In the superior cerebellar peduncle, most of the fibers are efferent and arise from the neurons of the intracerebellar nuclei (see Fig. 6-12). C. The inferior cerebellar peduncle contains afferent fibers of the posterior spinocerebellar tract, the cuneocerebellar tract, the vestibular nucleus, and the olivocerebellar tract (see Figs. 6-10 and 6-11). In addition, efferent fibers come from the cerebellum, including the fastigial vestibular pathway and the fastigial reticular pathway (see Fig. 6-12). D. The middle cerebellar peduncle is formed of fibers that arise from the pontine nuclei (see Fig. 6-10); other fibers connect the cerebellar hemispheres of the two sides together (see Fig. 6-12). E. The cerebellar peduncles are surface structures and are easily seen on dissection.

7. C is correct. The climbing and mossy fibers of the cerebellum constitute the two main lines of input to the cerebellar cortex. A. The mossy fibers end by making synaptic contacts with the dendrites of the granular cells and the Golgi cells (see Fig. 6-8). B. The afferent fibers enter the cerebellum through the superior, inferior, and middle cerebellar peduncles. D. The afferent fibers are excitatory to the Purkinje cells. E. The afferent fibers to the cerebellum are myelinated.
8. B is correct. The cerebellum controls voluntary movement by coordinating the force and extent of contraction of different muscles. A. The cerebellum influences the actions of muscles not tendons. C. The cerebellum inhibits the contraction of antagonistic muscles. D. The cerebellum indirectly influences skeletal muscle activity with the assistance of the cerebral cortex. E. The cerebellum has no effect on the control of smooth muscle in the wall of the intestine.
9. D is correct. The output of the cerebellar nuclei influences muscle activity so that movements can progress in an orderly sequence from one movement to the next. A. The afferent climbing fibers make multiple synaptic contacts with 1 to 10 Purkinje cells. B. The afferent mossy fibers may stimulate many Purkinje cells by first stimulating the granular cells. C. The neurons of the intracerebellar nuclei send axons to the ventrolateral nucleus of the thalamus, where they are relayed to the cerebral cortex (see Fig. 6-12). E. Past-pointing is caused by the failure of the cerebellum to inhibit the cerebral cortex after the movement has begun.
10. E is correct. Intention tremor is a sign of cerebellar disease. A. The cerebellar cortex has the same uniform microscopic structure in different individuals. B. The axons of the Purkinje cells exert a stimulatory influence on the neurons of the deep cerebellar nuclei. C. Each cerebellar hemisphere principally influences movement on the same side of the body. D. The part of the cerebellum that lies in the midline is called the vermis.
11. C is correct.
12. B is correct: right inferior cerebellar peduncle.
13. B is correct: right inferior cerebellar peduncle.
14. E is correct: middle cerebellar peduncle.
15. D is correct: inferior cerebellar peduncle.
16. D is correct: inferior cerebellar peduncle.
17. A is correct: superior cerebellar peduncle.
18. B is correct. Patients with cerebellar disease frequently exhibit poor muscle tone, and to compensate for this, they stand stiff legged with their feet wide apart.
19. D is correct. Although patients with cerebellar disease display disturbances of voluntary movement, none of the muscles are paralyzed or show atrophy.

7 Cerebrum

CHAPTER OBJECTIVES

- To introduce the student to the complexities of the forebrain
- To understand the definition of the diencephalon and accurately localize the thalamus and hypothalamus by studying the sagittal, coronal, and horizontal sections of the brain
- To understand the exact position of the main conduit of the ascending and descending tracts, namely the internal capsule, which is so often the site of pathologic lesions

A 23-year-old man is referred to a neurologist because of intermittent attacks of headaches, dizziness, and weakness and numbness of the left leg. On close questioning, the patient admits that the headache is made worse by changing the position of his head. A computed tomography (CT) scan reveals a small white opaque ball at the anterior end of the third ventricle. A diagnosis of a colloid cyst of the third ventricle is made.

The aggravation of the headache caused by changing the position of the head can be explained by the fact that the cyst is mobile and suspended from the choroid plexus. When the head is moved into certain positions, the ball-like cyst blocks the foramen of Monro on the right side, further raising the intracerebral pressure and increasing the hydrocephalus. The weakness and numbness of the left leg are due to pressure on the right thalamus and the tracts in the right internal capsule, produced by the slowly expanding tumor. The patient makes a complete recovery after surgical excision of the tumor.

The cerebral hemispheres are developed from the telencephalon and form the largest part of the brain. Each hemisphere has a covering of gray matter, the cortex and internal masses of gray matter, the basal nuclei, and a lateral ventricle. The basic anatomical structure of this area is described so that the student can be prepared for the complexities associated with functional localization.

SUBDIVISIONS

The cerebrum is the largest part of the brain, situated in the anterior and middle cranial fossae of the skull and occupying the whole concavity of the vault of the skull. It may be divided into two parts: the **diencephalon**, which forms the central core, and the **telencephalon**, which forms the **cerebral hemispheres**.

DIENCEPHALON

The diencephalon consists of the third ventricle and the structures that form its boundaries (Figs. 7-1 and 7-2). It extends posteriorly to the point where the third ventricle becomes continuous with the cerebral aqueduct and anteriorly as far as the interventricular foramina (Fig. 7-3). Thus, the diencephalon is a midline structure with symmetrical right and left halves. Obviously, these subdivisions of the brain are made for convenience, and from a functional point of view, nerve fibers freely cross the boundaries.

Gross Features

The **inferior surface** of the diencephalon is the only area exposed to the surface in the intact brain (see Fig. 7-2; see also Atlas Plate 1). It is formed by hypothalamic and other structures, which include, from anterior to posterior, the **optic chiasma**, with the **optic tract** on either side; the **infundibulum**, with the **tuber cinereum**; and the **mammillary bodies**.

The **superior surface** of the diencephalon is concealed by the **fornix**, which is a thick bundle of fibers that originates in the **hippocampus** of the temporal lobe and arches posteriorly over the **thalamus** (see Fig. 7-3; see also Atlas Plate 8) to join the **mammillary body**.

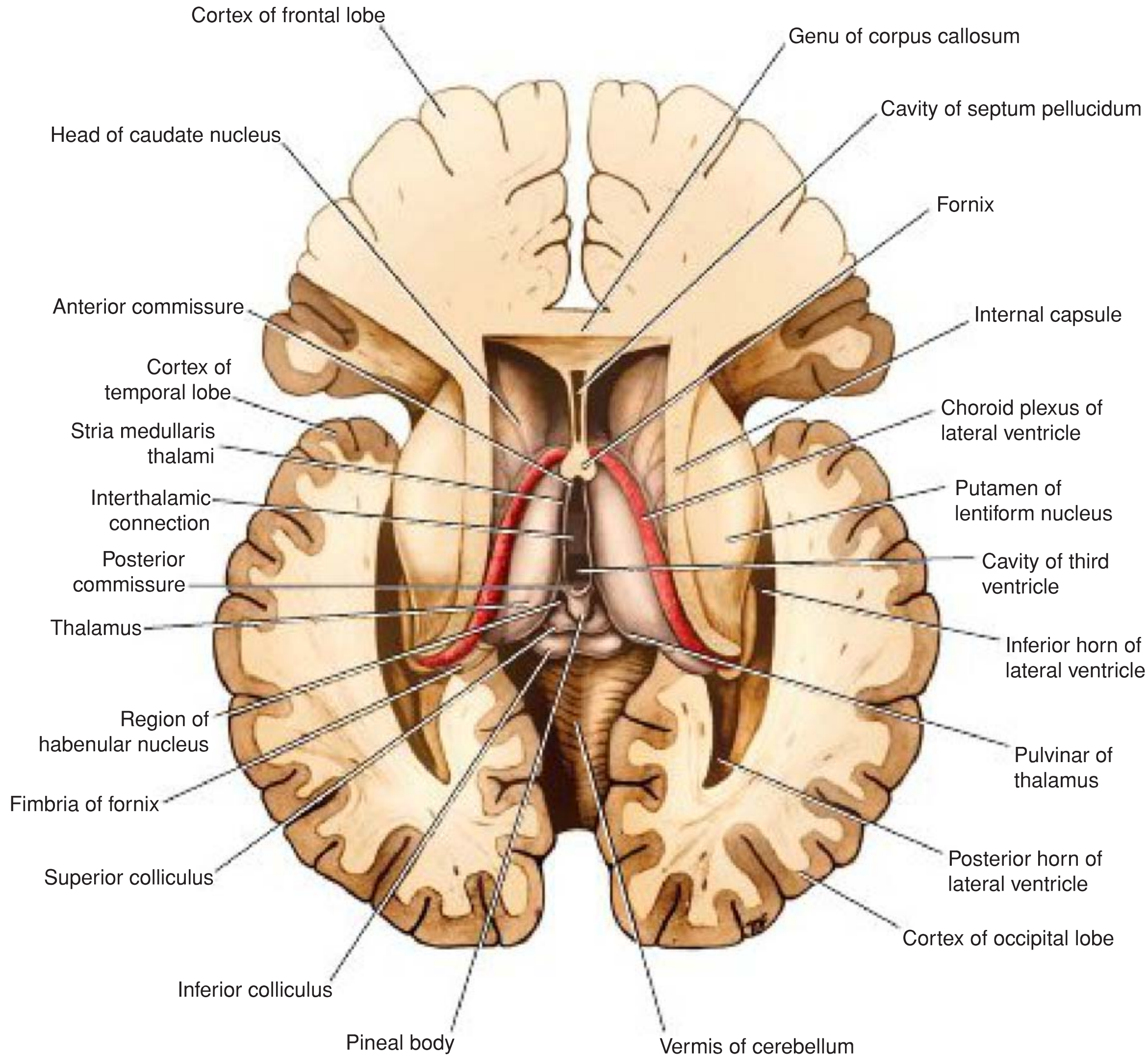


Figure 7-1 Horizontal section of the brain showing the third and lateral ventricles exposed by dissection from above.

The actual superior wall of the diencephalon is formed by the **roof of the third ventricle**. This consists of a layer of ependyma, which is continuous with the rest of the ependymal lining of the third ventricle. It is covered superiorly by a vascular fold of pia mater, called the **tela choroidea of the third ventricle**. From the roof of the third ventricle, a pair of vascular processes, the **choroid plexuses of the third ventricle**, project downward from the midline into the cavity of the third ventricle.

The **lateral surface** of the diencephalon is bounded by the **internal capsule** of white matter and consists of nerve fibers that connect the cerebral cortex with other parts of the brainstem and spinal cord (see Fig. 7-1).

Because the diencephalon is divided into symmetrical halves by the slitlike third ventricle, it also has a **medial surface**. The medial surface of the diencephalon (i.e., the lateral wall of the third ventricle) is formed in its superior part by the medial surface of the **thalamus** and in its inferior part by the **hypothalamus** (see Fig. 7-3; see also Atlas Plate 8). These two areas are separated from one another by a shallow sulcus, the **hypothalamic sulcus**. A bundle of nerve fibers, which are afferent fibers to the habenular nucleus, forms a ridge along the superior margin of the medial surface of the diencephalon and is called the **stria medullaris thalami** (see Fig. 7-1).

The diencephalon can be divided into four major parts: (1) the thalamus, (2) the subthalamus, (3) the epithalamus, and (4) the hypothalamus.

Thalamus

The thalamus is a large ovoid mass of gray matter that forms the major part of the diencephalon. It is a region of great functional importance and serves as a cell station to all the main sensory systems (except the olfactory pathway). The activities of the thalamus are closely related to that of the cerebral cortex and damage to the thalamus causes great loss of cerebral function.

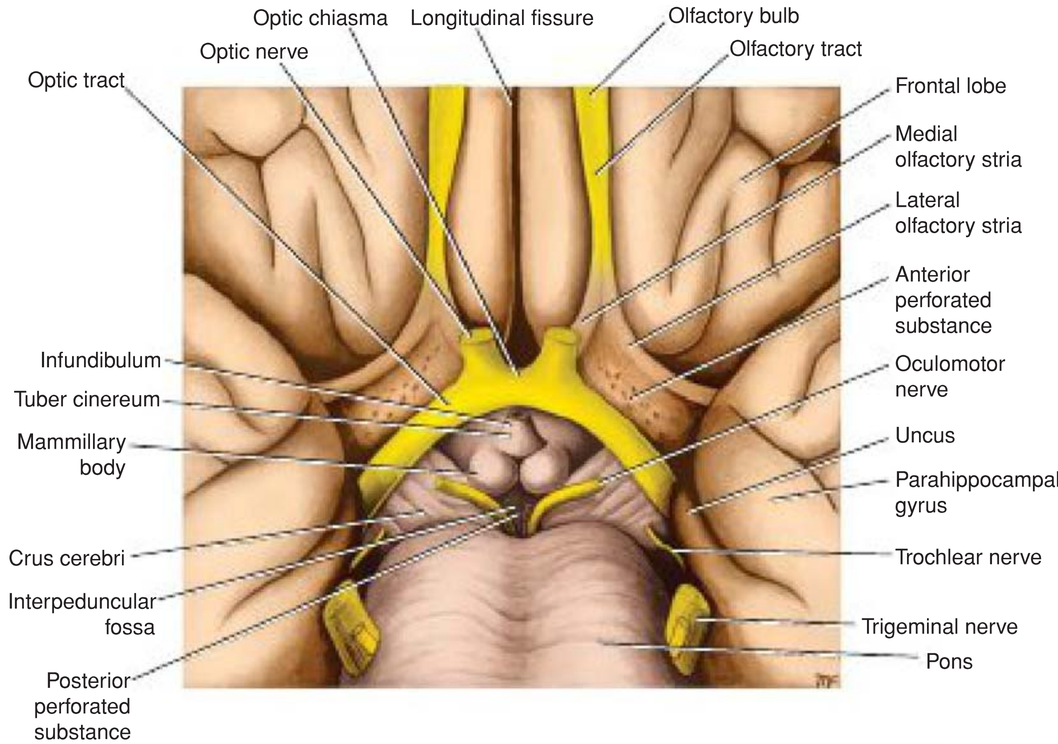


Figure 7-2 Inferior surface of the brain showing parts of the diencephalon.

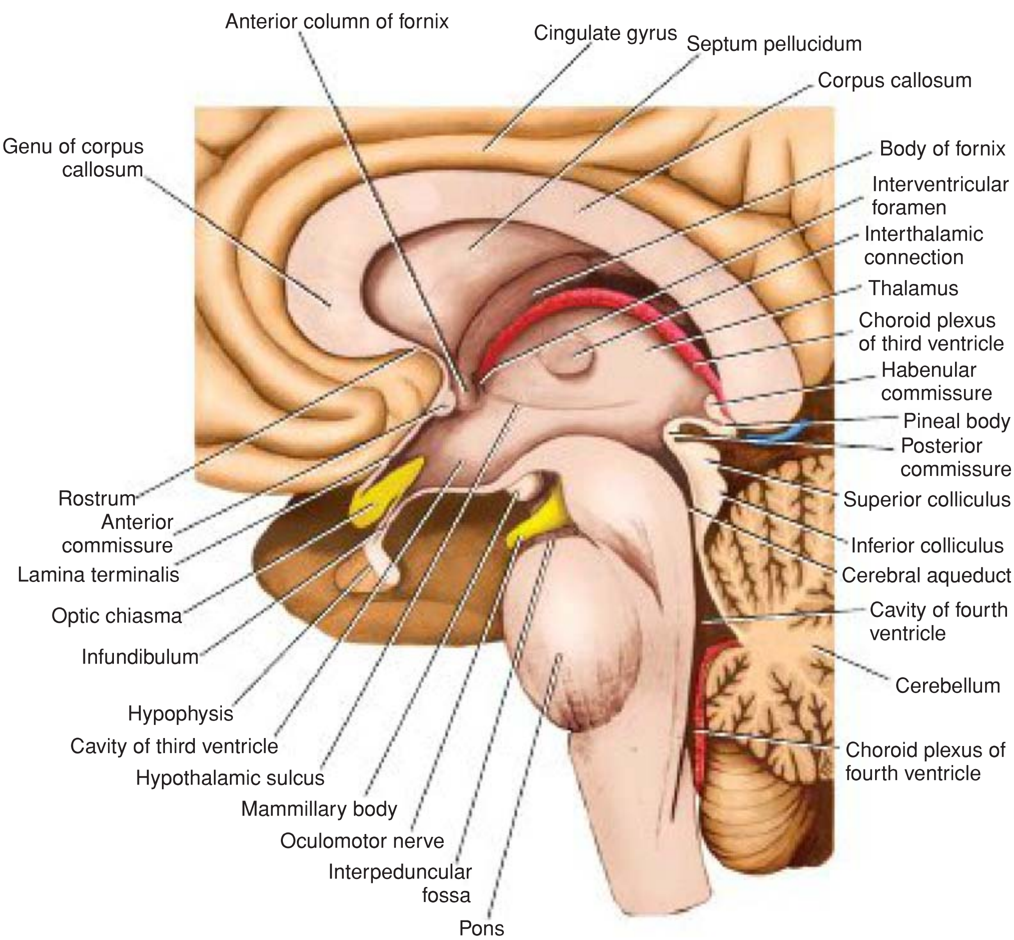


Figure 7-3 Sagittal section of the brain showing the medial surface of the diencephalon.

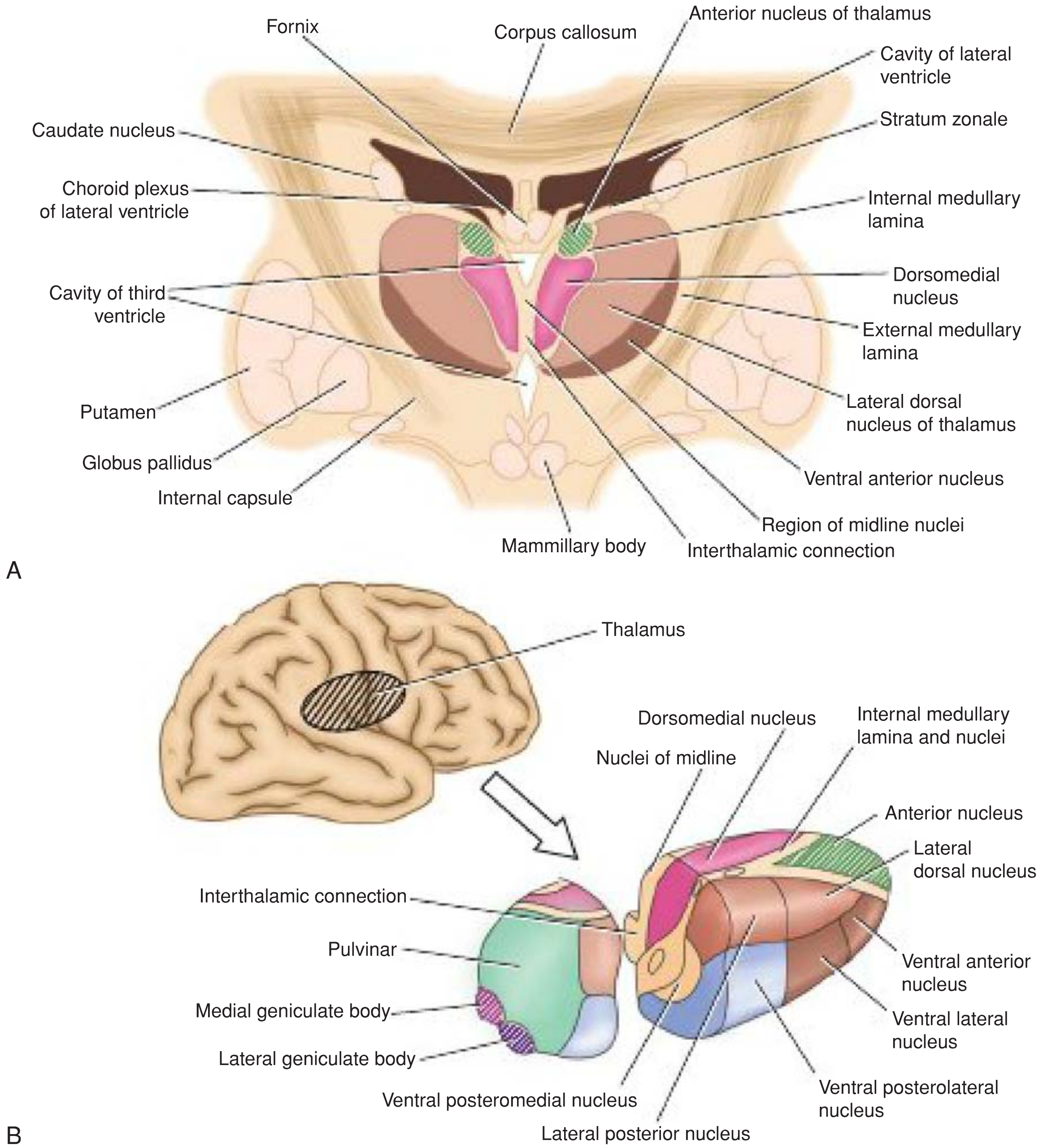


Figure 7-4 Nuclei of the thalamus. **A:** Transverse section through the anterior end of the thalamus. **B:** Diagram showing the position of the thalamus within the right cerebral hemisphere and the relative position of the thalamic nuclei to one another.

The thalamus is situated on each side of the third ventricle (see Fig. 7-3; see also Atlas Plate 5). The anterior end of the thalamus is narrow and rounded and forms the posterior boundary of the interventricular foramen. The posterior end (Fig. 7-4) is expanded to form the **pulvinar**, which overhangs the superior colliculus and the superior brachium. The **lateral geniculate body** forms a small elevation on the under aspect of the lateral portion of the pulvinar.

The superior surface of the thalamus is covered medially by the tela choroidea and the fornix, and laterally, it is covered by ependyma and forms part of the floor of the lateral ventricle; the lateral part is partially hidden by the choroid plexus of the lateral ventricle (see Fig. 7-1). The inferior surface is continuous with the tegmentum of the midbrain (see Fig. 7-3).

The medial surface of the thalamus forms the superior part of the lateral wall of the third ventricle and is usually connected to the opposite thalamus by a band of gray matter, the **interthalamic connection** (interthalamic adhesion) (see Fig. 7-3).

The lateral surface of the thalamus is separated from the lentiform nucleus by the very important band of white matter called the **internal capsule** (see Fig. 7-1).

The subdivisions of the thalamus (see Fig. 7-4) and the detailed description of the thalamic nuclei and their connections are given on first page of Chapter 12.

The thalamus is a very important cell station that receives the main sensory tracts (except the olfactory pathway). It should be regarded as a station where much of the information is integrated and relayed to the cerebral cortex and many other subcortical regions. It also plays a key role in the integration of visceral and somatic functions. For more information on the function of the thalamus, see Chapter 12.

Subthalamus

The subthalamus lies inferior to the thalamus and, therefore, is situated between the thalamus and the tegmentum of the midbrain; craniomedially, it is related to the hypothalamus.

The structure of the subthalamus is extremely complex, and only a brief description is given here. Among the collections of nerve cells found in the subthalamus are the cranial ends of the **red nuclei** and the **substantia nigra**. The **subthalamic nucleus** has the shape of a biconvex lens. The nucleus has important connections with the corpus striatum (see p. 310); as a result, it is involved in the control of muscle activity.

The subthalamus also contains many important tracts that pass up from the tegmentum to the thalamic nuclei; the cranial ends of the medial, spinal, and trigeminal lemnisci are examples.

Epithalamus

The epithalamus consists of the habenular nuclei and their connections and the pineal gland.

Habenular Nucleus

The habenular nucleus is a small group of neurons situated just medial to the posterior surface of the thalamus. Afferent fibers are received from the amygdaloid nucleus in the temporal lobe (see p. 261) through the stria medullaris thalami; other fibers pass from the hippocampal formation through the fornix. Some of the fibers of the stria medullaris thalami cross the midline and reach the habenular nucleus of the opposite side; these latter fibers form the **habenular commissure** (see Fig. 7-3). Axons from the habenular nucleus pass to the interpeduncular nucleus in the roof of the interpeduncular fossa, the tectum of the midbrain, the thalamus, and the reticular formation of the midbrain. The habenular nucleus is believed to be a center for integration of olfactory, visceral, and somatic afferent pathways.

Pineal Gland (Body)

The pineal gland is a small, conical structure that is attached by the pineal stalk to the diencephalon. It projects backward so that it lies posterior to the midbrain (see Fig. 7-3; see also Atlas Plate 8). The base of the pineal stalk possesses a recess that is continuous with the cavity of the third ventricle. The superior part of the base of the stalk contains the **habenular commissure**; the inferior part of the base of the stalk contains the **posterior commissure**.

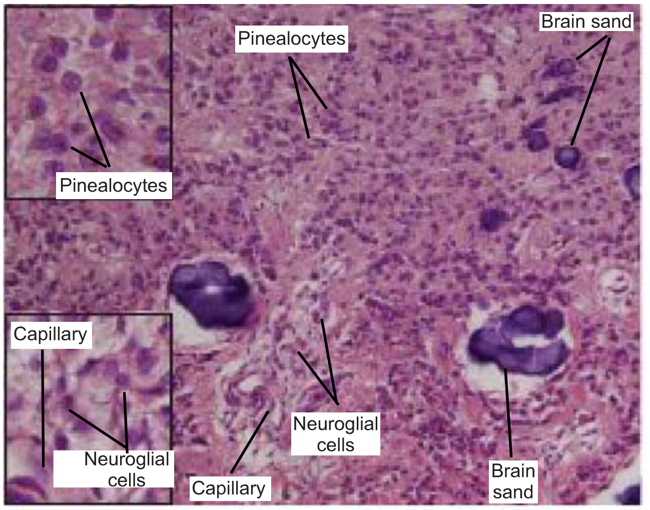


Figure 7-5 Photomicrograph of a section of the pineal gland stained with hematoxylin and eosin. (From Cui, D., Daley, W., Fratkin, J. D., Haines, D. E., Lynch, J. C., Naftel, J. P., Yang, G. Atlas of Histology with Functional and Clinical Correlations. Baltimore, MD: Wolters Kluwer, 2011.)

On microscopic section, the pineal gland is seen to be incompletely divided into lobules by connective tissue septa that extend into the substance of the gland from the capsule. Two types of cells are found in the gland, the **pinealocytes** and the **glial cells**. Concretions of calcified material called **brain sand** progressively accumulate within the pineal gland with age (Fig. 7-5).

The pineal gland possesses no nerve cells, but adrenergic sympathetic fibers derived from the superior cervical sympathetic ganglia enter the gland and run in association with the blood vessels and the pinealocytes.

Pineal Gland Functions

The pineal gland, once thought to be of little significance, is now recognized as an important endocrine gland capable of influencing the activities of the pituitary gland, the islets of Langerhans of the pancreas, the parathyroids, the adrenal cortex and the adrenal medulla, and the gonads. The pineal secretions, produced by the pinealocytes, reach their target organs via the bloodstream or through the cerebrospinal fluid (CSF). Their actions are mainly inhibitory and either directly inhibit the production of hormones or indirectly inhibit the secretion of releasing factors by the hypothalamus. Notably, the pineal gland does not possess a blood–brain barrier.

Animal experiments have shown that pineal activity exhibits a circadian rhythm that is influenced by light. The gland has been found to be most active during darkness. The probable nervous pathway from the retina runs to the suprachiasmatic nucleus of the hypothalamus, then to the tegmentum of the midbrain, and then to the pineal gland to stimulate its secretions. The latter part of this pathway may include the reticulospinal tract, the sympathetic outflow of the thoracic part of the spinal cord, and the superior cervical sympathetic ganglion and postganglionic nerve fibers that travel to the pineal gland on blood vessels.

Melatonin and the enzymes needed for its production are present in high concentrations within the pineal gland. Melatonin and other substances are released into the blood or into the CSF of the third ventricle where they pass to the anterior lobe of the pituitary gland and inhibit the release of the gonadotrophic hormone. In humans, as in animals, the plasma melatonin level rises in darkness and falls during the day. The pineal gland apparently plays an important role in the regulation of reproductive function.

Hypothalamus

The **hypothalamus** is that part of the diencephalon that extends from the region of the optic chiasma to the caudal border of the mammillary bodies (see Fig. 7-2; see also Atlas Plate 8). It lies below the hypothalamic sulcus on the lateral wall of the third ventricle. Thus, anatomically, the hypothalamus is a relatively small area of the brain that is strategically well placed close to the limbic system, the thalamus, the ascending and descending tracts, and the hypophysis. Microscopically, the hypothalamus is composed of small nerve cells that are arranged in groups or nuclei. The arrangement of these nuclei and their connections are fully described in Chapter 13.

Physiologically, nearly all the activities in the body are influenced by the hypothalamus. The hypothalamus controls and integrates the functions of the autonomic nervous system and the endocrine systems and plays a vital role in maintaining body homeostasis. It is involved in such activities as regulation of body temperature, body fluids, drives to eat and drink, sexual behavior, and emotion.

Hypothalamic Relations

Anterior to the hypothalamus is an area that extends forward from the optic chiasma to the lamina terminalis and the anterior commissure; it is referred to as the **preoptic area**. Caudally, the hypothalamus merges into the tegmentum of the midbrain. The thalamus lies superior to the hypothalamus, and the subthalamic region lies inferolaterally to the hypothalamus.

When observed from below, the hypothalamus is seen to be related to the following structures, from anterior to posterior: (1) the optic chiasma, (2) the tuber cinereum and the infundibulum, and (3) the mammillary bodies.

Optic Chiasma

The optic chiasma is a flattened bundle of nerve fibers situated at the junction of the anterior wall and floor of the third ventricle (see Figs. 7-2 and 7-3; see also Atlas Plate 8). The superior surface is attached to the **lamina terminalis**, and inferiorly, it is related to the **hypophysis cerebri**, from which it is separated by the **diaphragma sellae**. The anterolateral corners of the chiasma are continuous with the **optic nerves**, and the posterolateral corners are continuous with the **optic tracts**. A small recess, the **optic recess of the third ventricle**, lies on its superior surface.

Importantly, remember that the fibers originating from the nasal half of each retina cross the median plane at the chiasma to enter the optic tract of the opposite side.

Tuber Cinereum

The tuber cinereum is a convex mass of gray matter, as seen from the inferior surface (see Figs. 7-2 and 7-3; see also Atlas Plate 8). It is continuous inferiorly with the **infundibulum**. The infundibulum is hollow and becomes continuous with the posterior lobe of the **hypophysis cerebri**. The **median eminence** is a raised part of the tuber cinereum to which is attached the infundibulum. The median eminence, the infundibulum, and the posterior lobe (pars nervosa) of the hypophysis cerebri together form the **neurohypophysis**.

Mammillary Bodies

The mammillary bodies are two small hemispherical bodies situated side by side posterior to the tuber cinereum (see Figs. 7-2 and 7-3; see also Atlas Plate 8). They possess a central core of gray matter invested by a capsule of myelinated nerve fibers. Posterior to the mammillary bodies lies an area of the brain that is pierced by a number of small apertures and is called the posterior perforated substance. These apertures transmit the central branches of the posterior cerebral arteries.

Third Ventricle

The third ventricle, which is derived from the forebrain vesicle, is a slitlike cleft between the two thalami (see Figs. 7-1 and 7-3; see also Atlas Plates 5 and 8). It communicates anteriorly with the **lateral ventricles** through the **interventricular foramina** (foramina of Monro), and it communicates posteriorly with the **fourth ventricle** through the **cerebral aqueduct**. The third ventricle has anterior, posterior, lateral, superior, and inferior walls and is lined with ependyma.

The **anterior wall** is formed by a thin sheet of gray matter, the **lamina terminalis**, across which runs the **anterior commissure** (see Fig. 7-3). The anterior commissure is a round bundle of nerve fibers that are situated anterior to the **anterior columns of the fornix**; they connect the right and left temporal lobes.

The **posterior wall** is formed by the opening into the cerebral aqueduct. Superior to this opening is the small **posterior commissure**. Superior to the commissure is the **pineal recess**, which projects into the stalk of the **pineal body**. Superior to the pineal recess is the small **habenular commissure**.

The **lateral wall** is formed by the medial surface of the **thalamus** superiorly and the **hypothalamus** inferiorly. These two structures are separated by the **hypothalamic sulcus**. The lateral wall is limited superiorly by the **stria medullaris thalami**. The lateral walls are joined by the **interthalamic connection**.

The **superior wall** or **roof** is formed by a layer of ependyma that is continuous with the lining of the ventricle. Superior to this layer is a two-layered fold of pia mater called **the tela choroidea of the third ventricle**. The vascular tela choroidea projects downward on each side of the midline, invaginating the ependymal roof to form the **choroid plexuses of the third ventricle**. Within the tela choroidea lie the **internal cerebral veins**. Superiorly, the roof of the ventricle is related to the **fornix** and the **corpus callosum**.

The **inferior wall** or **floor** is formed by the **optic chiasma**, the **tuber cinereum**, the **infundibulum**, with its funnel-shaped recess, and the **mammillary bodies** (see Figs. 7-2 and 7-3). The **hypophysis** is attached to the infundibulum. Posterior to these structures lies the **tegmentum of the cerebral peduncles**.

The ventricular system is fully described in Chapter 16.

GENERAL APPEARANCE OF THE CEREBRAL HEMISPHERES

The cerebral hemispheres are the largest part of the brain; they are separated by a deep midline sagittal fissure, the **longitudinal cerebral fissure** (Fig. 7-6; see also Atlas Plates 1 and 2). The fissure contains the sickle-shaped fold of dura mater, the **falx cerebri**, and the **anterior cerebral arteries**. In the depths of the fissure, the great commissure, the **corpus callosum**, connects the hemispheres across the midline. A second horizontal fold of dura mater separates the cerebral hemispheres

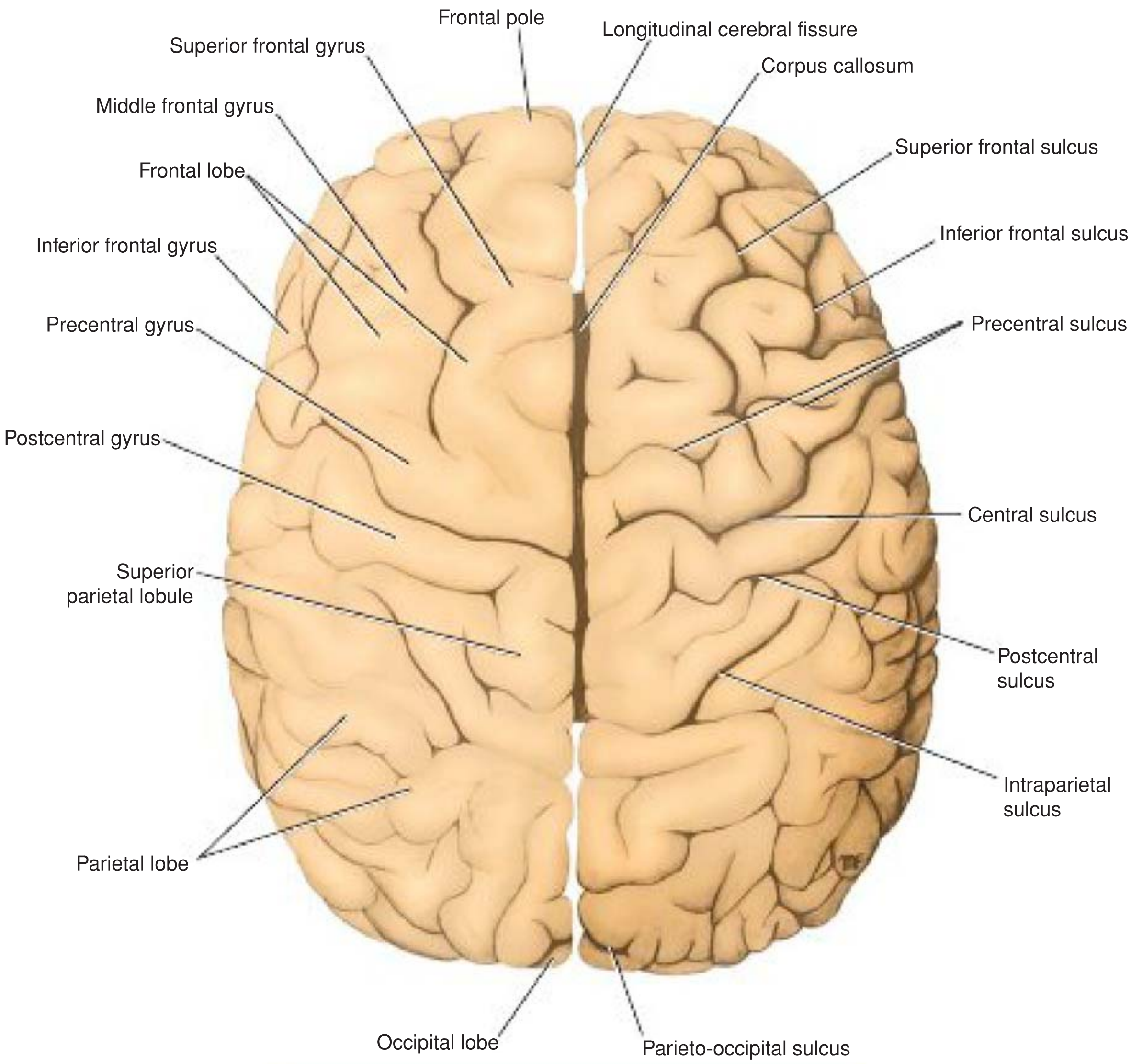


Figure 7-6 Superior view of the cerebral hemispheres.

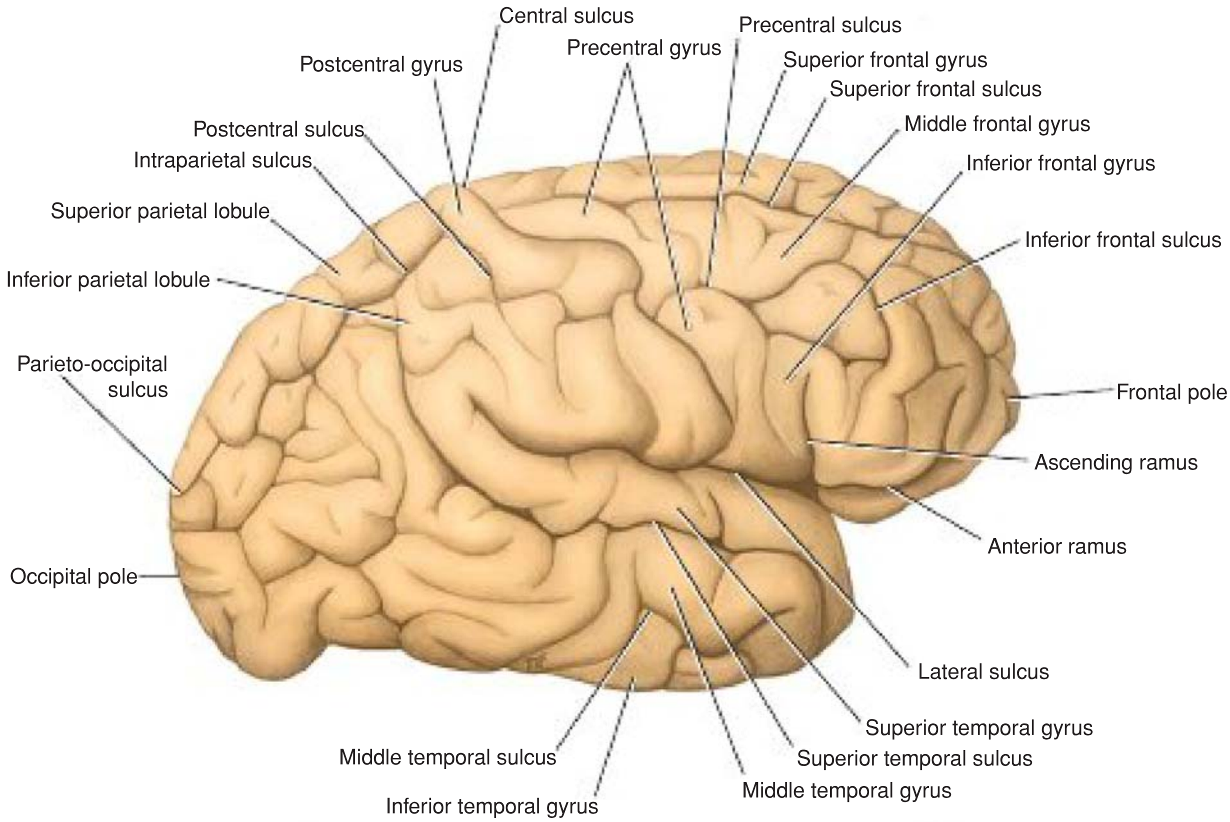


Figure 7-7 Lateral view of the right cerebral hemisphere.

from the cerebellum and is called the **tentorium cerebelli**.

To increase the surface area of the cerebral cortex maximally, the surface of each cerebral hemisphere is thrown into **folds** or **gyri**, which are separated from each other by **sulci** or **fissure**. For ease of description, each hemisphere is divided into **lobes**, which are named according to the cranial bones under which they lie. The **central** and **parieto-occipital sulci** and the **lateral** and **calcarine sulci** are boundaries used for the division of the cerebral hemisphere into **frontal**, **parietal**, **temporal**, and **occipital lobes** (Fig. 7-7; also see Fig. 7-10).

MAIN SULCI

The **central sulcus** (see Fig. 7-7; see also Atlas Plate 3) is of great importance because the gyrus that lies anterior to it contains the motor cells that initiate the movements of the opposite side of the body; posterior to it lies the general sensory cortex that receives sensory information from the opposite side of the body. The central sulcus indents the superior medial border of the hemisphere about 0.4 in (1 cm) behind the midpoint (Fig. 7-8). It runs downward and forward across the lateral aspect of the hemisphere, and its lower end is separated from the posterior ramus of the lateral sulcus by a narrow bridge of cortex. The central sulcus is the only sulcus of any length on this surface of the hemisphere that indents the superomedial border and lies between two parallel gyri.

The **lateral sulcus** (see Fig. 7-7; see also Atlas Plate 3) is a deep cleft found mainly on the inferior and lateral surfaces of the cerebral hemisphere. It consists of a short stem that divides into three rami. The stem arises on the inferior surface, and on reaching the lateral surface, it divides into the **anterior horizontal ramus** and the **anterior ascending ramus** and continues as the **posterior ramus** (see Fig. 7-7). An area of cortex called the **insula** lies at the bottom of the deep lateral sulcus and cannot be seen from the surface unless the lips of the sulcus are separated (Fig. 7-9).

The **parieto-occipital sulcus** begins on the superior medial margin of the hemisphere about 2 in (5 cm) anterior to the occipital pole (see Fig. 7-8; see also Atlas Plate 3). It passes downward and anteriorly on the medial surface to meet the calcarine sulcus (see Fig. 7-8).

The **calcarine sulcus** is found on the medial surface of the hemisphere (see Fig. 7-8; see also Atlas Plate 3). It commences under the posterior end of the corpus callosum and arches upward and backward to reach the occipital pole, where it stops. In some brains, however, it continues for a short distance onto the lateral surface of the hemisphere. The calcarine sulcus is joined at an acute angle by the parieto-occipital sulcus about halfway along its length.

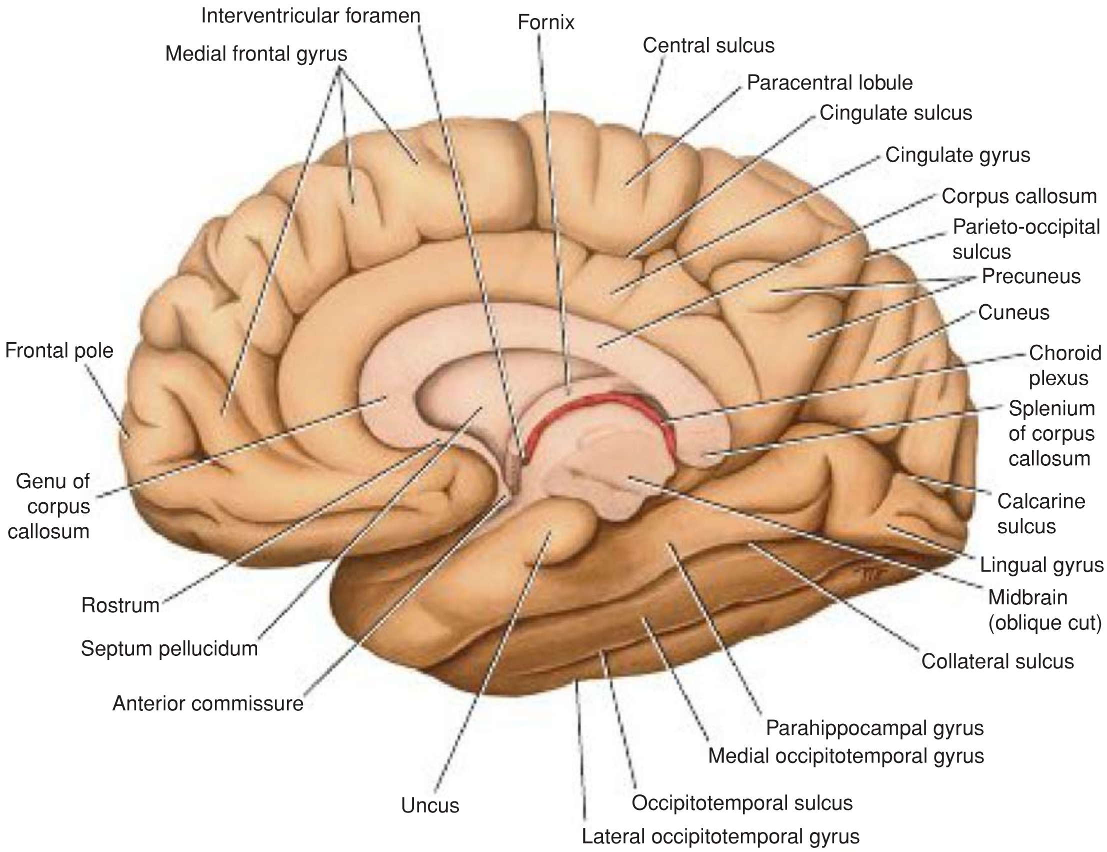


Figure 7-8 Medial view of the right cerebral hemisphere.

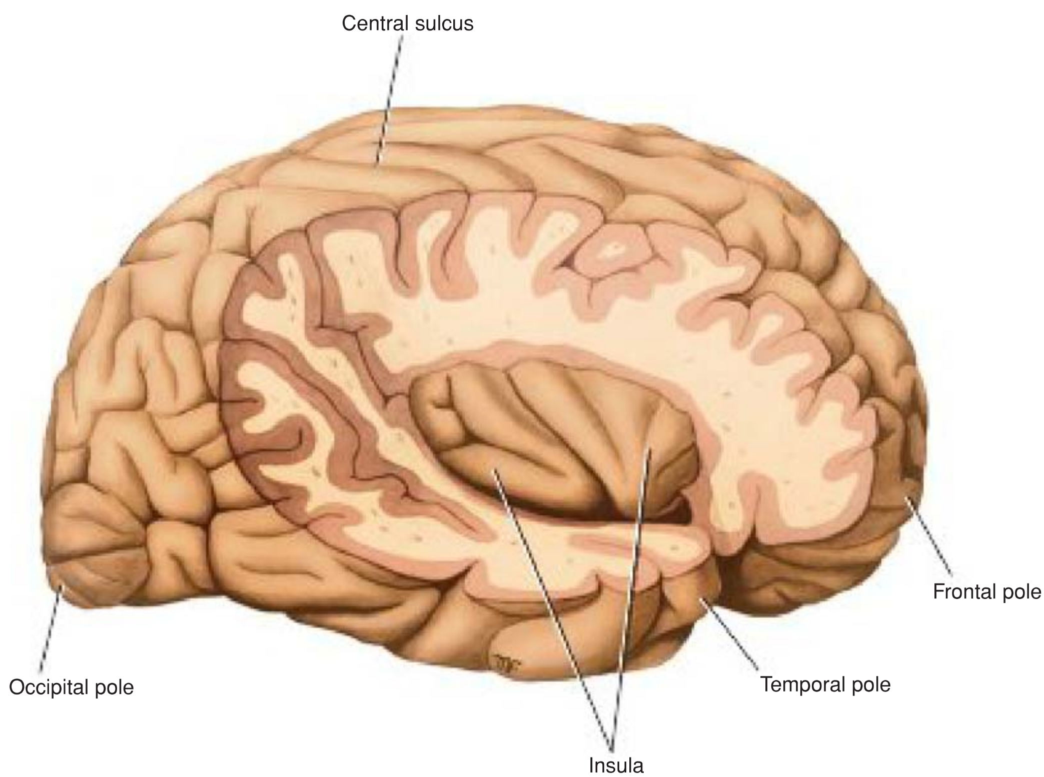
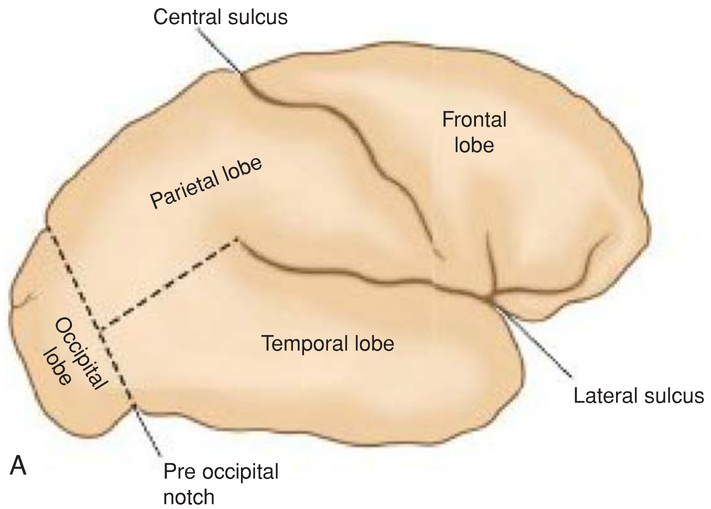


Figure 7-9 Lateral view of the right cerebral hemisphere dissected to reveal the right insula.



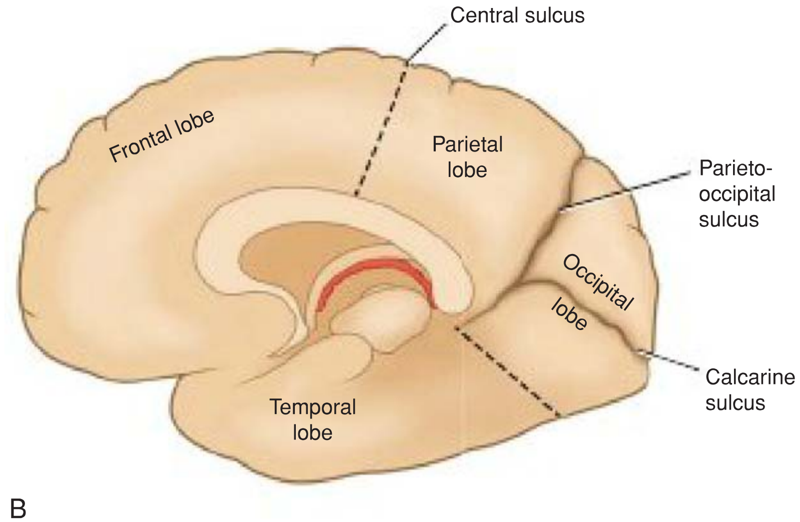


Figure 7-10 **A:** Lateral view of the right cerebral hemisphere showing the lobes. **B:** Medial view of the right cerebral hemisphere showing the lobes. Note that the *dashed lines* indicate the approximate position of the boundaries where no sulci are present.

CEREBRAL HEMISPHERE LOBES

Cerebral hemispheres are functionally divided into lobes, each of which are anatomically identified using specific gyri and sulci.

Superolateral Surface (Atlas Plate 3)

The **frontal lobe** occupies the area anterior to the central sulcus and superior to the lateral sulcus (Fig. 7-10). The superolateral surface of the frontal lobe is divided by three sulci into four gyri. The **precentral sulcus** runs parallel to the central sulcus, and the **precentral gyrus** lies between them (see Fig. 7-7). Extending anteriorly from the precentral sulcus are the **superior** and **inferior frontal sulci**. The **superior frontal gyrus** lies superior to the superior frontal sulcus, the **middle frontal gyrus** lies between the superior and inferior frontal sulci, and the **inferior frontal gyrus** lies inferior to the inferior frontal sulcus. The inferior frontal gyrus is invaded by the anterior and ascending rami of the lateral sulcus.

The **parietal lobe** occupies the area posterior to the central sulcus and superior to the lateral sulcus; it extends posteriorly as far as the parieto-occipital sulcus (see Figs. 7-7 to 7-10). The lateral surface of the parietal lobe is divided by two sulci into three gyri. The postcentral sulcus runs parallel to the central sulcus, and the postcentral gyrus lies between them. Running posteriorly from the middle of the postcentral sulcus is the **intraparietal sulcus** (see Fig. 7-7). Superior to the intraparietal sulcus is the **superior parietal lobule** (gyrus), and inferior to the intraparietal sulcus is the **inferior parietal lobule** (gyrus).

The **temporal lobe** occupies the area inferior to the lateral sulcus (see Figs. 7-7 to 7-10). The lateral surface of the temporal lobe is divided into three gyri by two sulci. The **superior** and **middle temporal sulci** run parallel to the posterior ramus of the lateral sulcus and divide the temporal lobe into the **superior**, **middle**, and **inferior temporal gyri**; the inferior temporal gyrus is continued onto the inferior surface of the hemisphere (see Fig. 7-7).

The **occipital lobe** occupies the small area behind the parieto-occipital sulcus (see Figs. 7-7 to 7-10).

Medial and Inferior Surfaces (Atlas Plates 3, 6, and 8)

The lobes of the cerebral hemisphere are not clearly defined on the medial and inferior surfaces. However, many important areas should be recognized. The **corpus callosum**, which is the largest commissure of the brain, forms a striking feature on this surface (see Fig. 7-8). The **cingulate gyrus** begins beneath the anterior end of the corpus callosum and continues above the corpus callosum until it reaches its posterior end. The gyrus is separated from the corpus callosum by the **callosal sulcus**. The cingulate gyrus is separated from the superior frontal gyrus by the **cingulate sulcus** (see Fig. 7-8).

The **paracentral lobule** is the area of the cerebral cortex that surrounds the indentation produced by the central sulcus on the superior border. The anterior part of this lobule is a continuation of the precentral gyrus on the superior lateral surface, and the posterior part of the lobule is a continuation of the postcentral gyrus.

The **precuneus** is an area of cortex bounded anteriorly by the upturned posterior end of the cingulate sulcus and posteriorly by the parieto-occipital sulcus.

The **cuneus** is a triangular area of cortex bounded above by the parieto-occipital sulcus, inferiorly by the calcarine sulcus, and posteriorly by the superior medial margin.

The **collateral sulcus** is situated on the inferior surface of the hemisphere (Fig. 7-11; also see Fig. 7-8). This runs anteriorly below the calcarine sulcus. Between the collateral sulcus and the **calcarine sulcus** is the

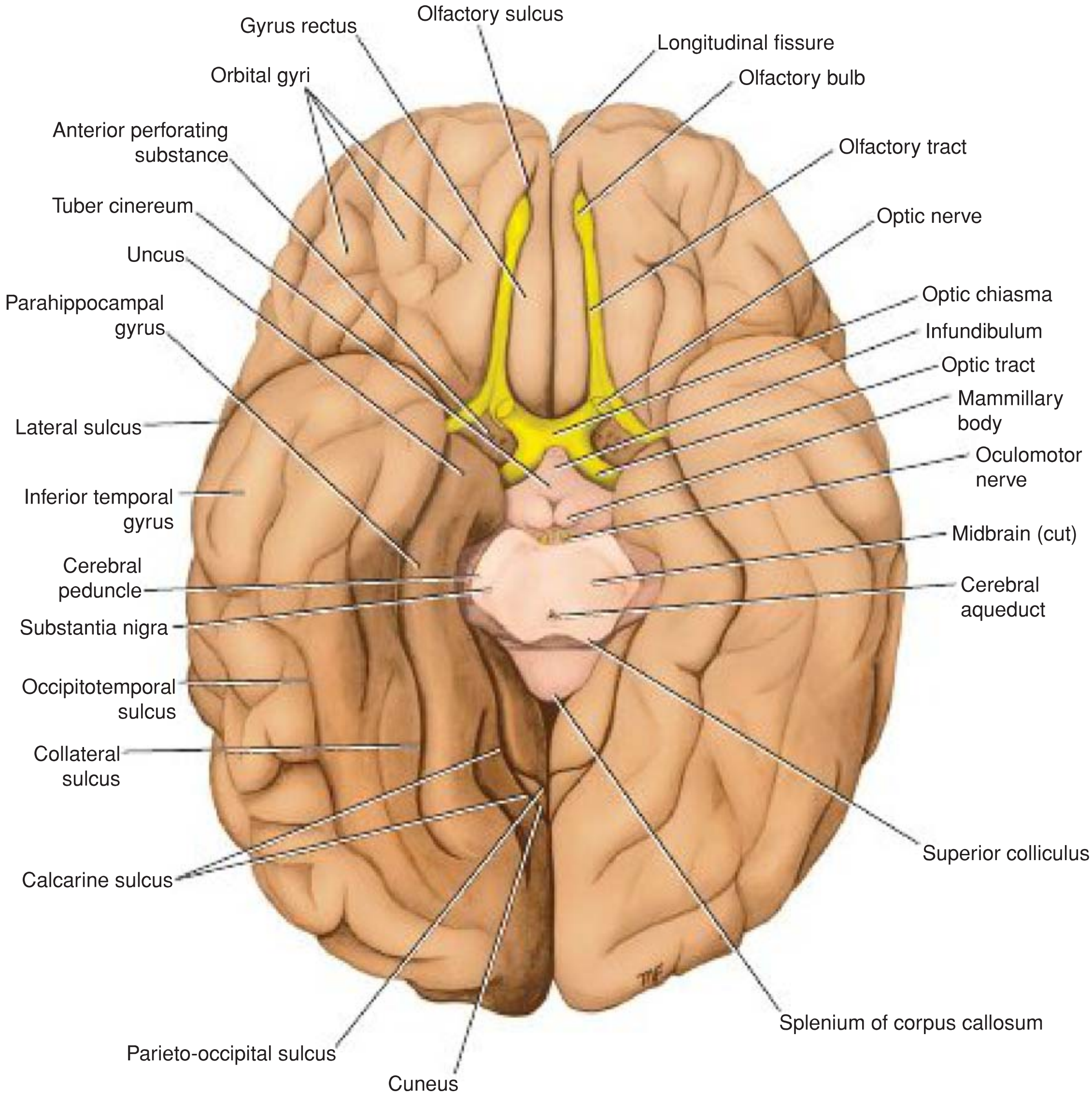


Figure 7-11 Inferior view of the brain; the medulla oblongata, the pons, and the cerebellum have been removed.

lingual gyrus. Anterior to the lingual gyrus is the **parahippocampal gyrus**; the latter terminates in front as the hooklike **uncus** (see Fig. 7-11).

The **medial occipitotemporal gyrus** extends from the occipital pole to the temporal pole. It is bounded medially by the **collateral** and **rhinal sulci** and laterally by the **occipitotemporal sulcus**. The **occipitotemporal gyrus** lies lateral to the sulcus and is continuous with the inferior temporal gyrus.

On the inferior surface of the frontal lobe, the olfactory bulb and tract overlie a sulcus called the **olfactory sulcus**. Medial to the olfactory sulcus is the **gyrus rectus**, and lateral to the sulcus are a number of **orbital gyri**.

INTERNAL STRUCTURE OF THE CEREBRAL HEMISPHERES (ATLAS PLATES 4 AND 5)

The cerebral hemispheres are covered with a layer of gray matter, the cerebral cortex; the structure and function of the cerebral cortex are discussed in Chapter 15. Located in the interior of the cerebral hemispheres are the **lateral ventricles**, masses of gray matter, the **basal nuclei**, and nerve fibers. The nerve fibers are embedded in neuroglia and constitute the **white matter** (Fig. 7-12).

Lateral Ventricles

The two lateral ventricles each occupy one cerebral hemisphere (Fig. 7-13; also see Fig. 7-12). Each ventricle is a roughly C-shaped cavity lined with ependyma and filled with CSF. The lateral ventricle may be divided into a **body**, which occupies the parietal lobe, and from which **anterior**, **posterior**, and **inferior horns** extend into the frontal, occipital, and temporal lobes, respectively. The lateral ventricle communicates with the cavity of the third ventricle through the **interventricular foramen** (see Figs. 7-8 and 7-13). This opening, which lies in the anterior part of the medial wall of the lateral ventricle, is bounded anteriorly by the anterior column of the fornix and posteriorly by the anterior end of the thalamus.

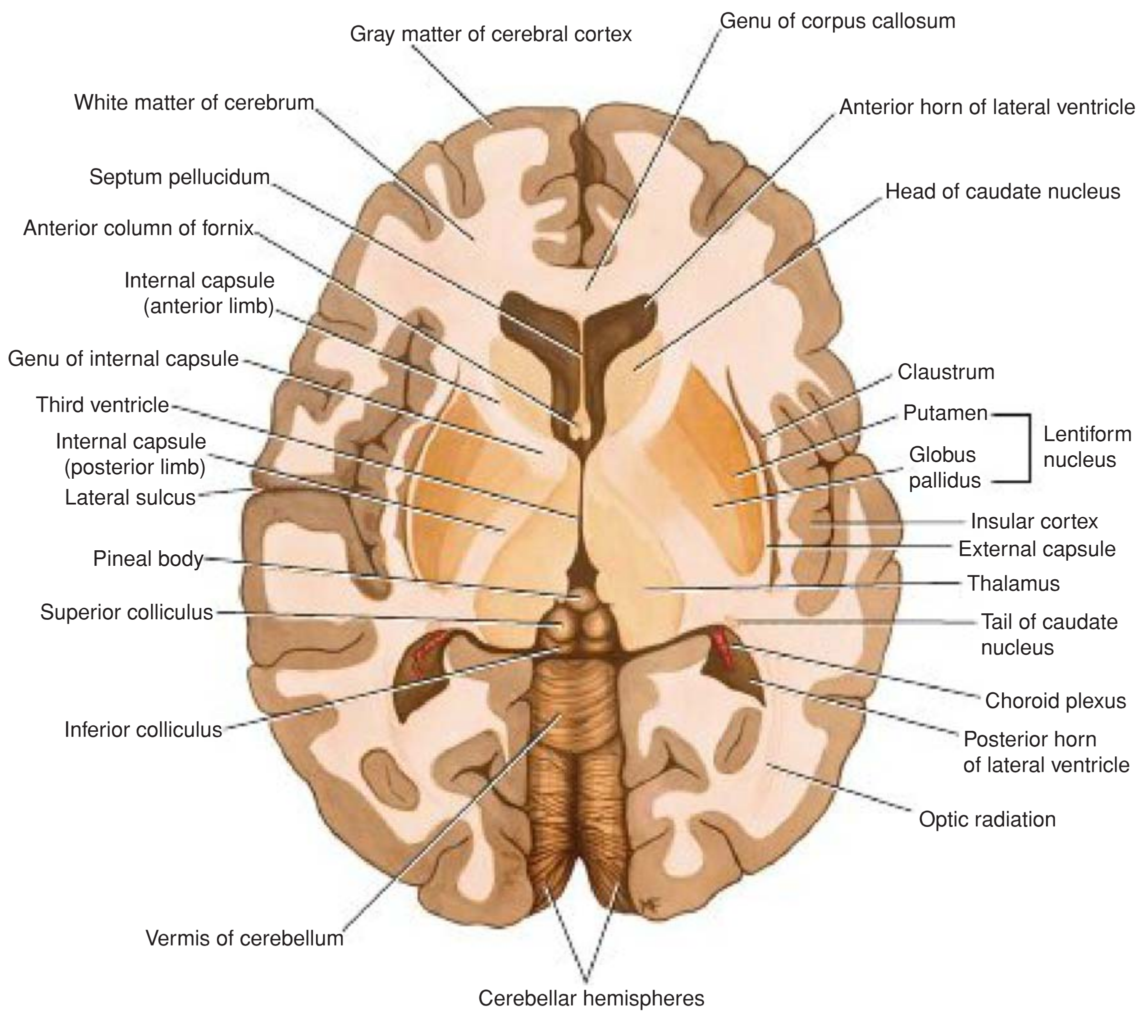


Figure 7-12 Horizontal section of the cerebrum, as seen from above, showing the relationship between the lentiform nucleus, the caudate nucleus, the thalamus, and the internal capsule.

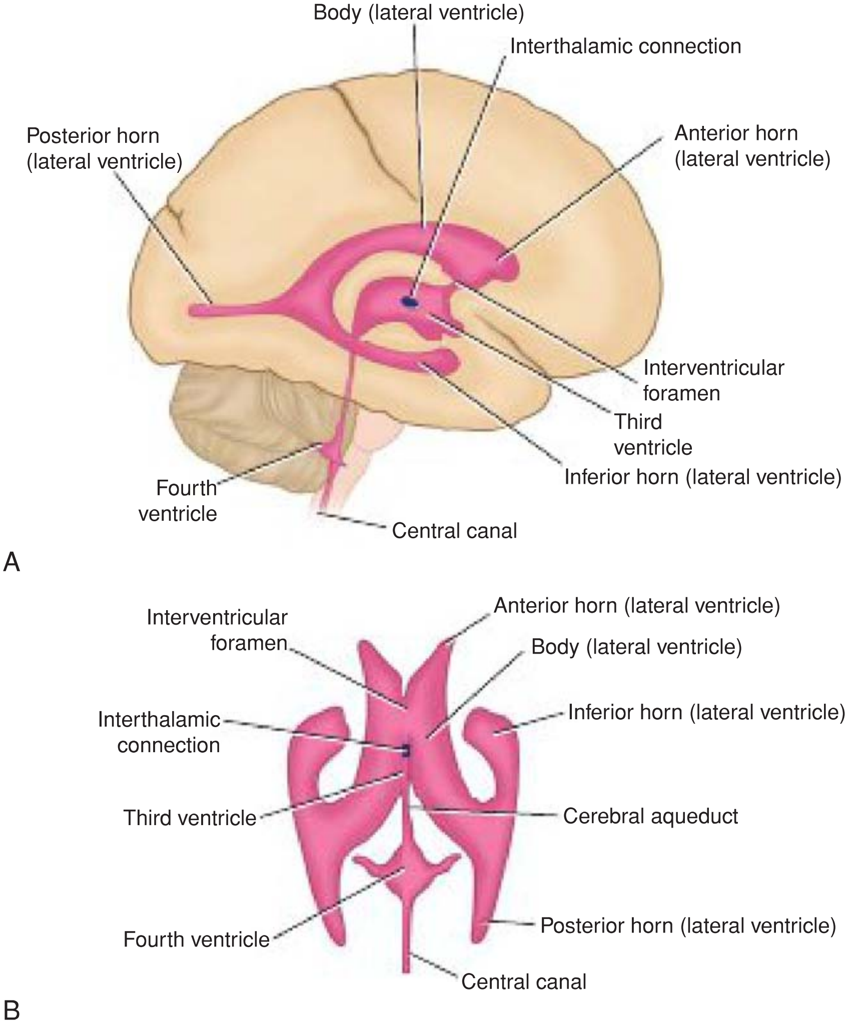


Figure 7-13 Ventricular cavities of the brain. **A:** Lateral view. **B:** Superior view.

Basal Nuclei

The term **basal nuclei** (**basal ganglia**) is applied to a collection of masses of gray matter situated within each cerebral hemisphere. They are the corpus striatum, the amygdaloid nucleus, and the claustrum.

Corpus Striatum

The corpus striatum is situated lateral to the thalamus. It is almost completely divided by a band of nerve fibers, the **internal capsule**, into the caudate nucleus and the lentiform nucleus (see Figs. 7-12 and 7-17).

The **caudate nucleus**, a large C-shaped mass of gray matter that is closely related to the lateral ventricle, lies lateral to the thalamus (Fig. 7-14). The lateral surface of the nucleus is related to the internal capsule, which separates it from the lentiform nucleus.

The **lentiform nucleus** is a wedge-shaped mass of gray matter whose broad convex base is directed laterally and its blade medially (see Figs. 7-12 and 7-14). It is buried deep in the white matter of the cerebral hemisphere and is related medially to the internal capsule, which separates it from the caudate nucleus and the thalamus. The lentiform nucleus is related laterally to a thin sheet of white matter, the **external capsule** (see Fig. 7-12), that separates it from a thin sheet of gray matter, called the **claustrum**. The claustrum, in turn, separates the external capsule from the subcortical white matter of the insula. Inferiorly at its anterior end, the lentiform nucleus is continuous with the caudate nucleus.

The detailed structure and connections of the corpus striatum are considered in Chapter 10. Briefly, it may be stated that the corpus striatum receives afferent fibers from different areas of the cerebral cortex, the thalamus, subthalamus, and brainstem. Efferent fibers then travel back to the same areas of the nervous system. The function of the corpus striatum is concerned with muscular movement, which is accomplished by controlling the cerebral cortex rather than through direct descending pathways to the brainstem and spinal cord.

Amygdaloid Nucleus

The amygdaloid nucleus is situated in the temporal lobe close to the uncus (see Fig. 7-14). The amygdaloid nucleus is considered part of the limbic system and is described in Chapter 9 (see p. 303).

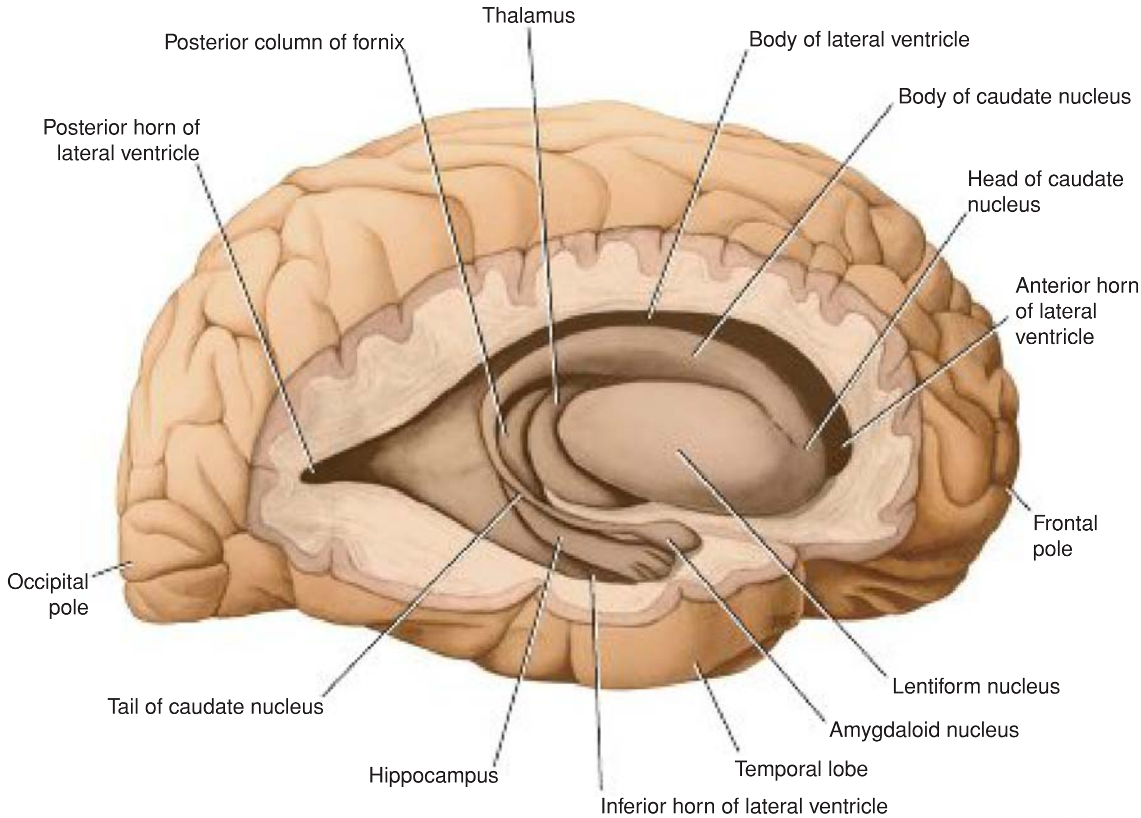


Figure 7-14 Lateral view of the right cerebral hemisphere dissected to show the position of the lentiform nucleus, the caudate nucleus, the thalamus, and the hippocampus.

Claustrum

The claustrum is a thin sheet of gray matter that is separated from the lateral surface of the lentiform nucleus by the **external capsule** (see Fig. 7-12). Lateral to the claustrum is the subcortical white matter of the insula. The function of the claustrum is unknown.

White Matter

The white matter is composed of myelinated nerve fibers of different diameters supported by neuroglia. The nerve fibers may be classified into three groups according to their connections: (1) commissural fibers, (2) association fibers, and (3) projection fibers.

Commissure Fibers

Commissure fibers essentially connect corresponding regions of the two hemispheres. They are as follows: the corpus callosum, the anterior commissure, the posterior commissure, the fornix, and the habenular commissure.

The **corpus callosum**, the largest commissure of the brain, connects the two cerebral hemispheres (Fig. 7-15; see also Fig. 7-8 and Atlas Plate 8). It lies at the bottom of the longitudinal fissure. For purposes of description, it is divided into the rostrum, the genu, the body, and the splenium.

The **rostrum** is the thin part of the anterior end of the corpus callosum, which is prolonged posteriorly to be continuous with the upper end of the lamina terminalis (see Fig. 7-8).

The **genu** is the curved anterior end of the corpus callosum that bends inferiorly in front of the septum pellucidum (see Figs. 7-8 and 7-15).

The **body** of the corpus callosum arches posteriorly and ends as the thickened posterior portion called the **splenium** (see Fig. 7-15).

Traced laterally, the fibers of the genu curve forward into the frontal lobes and form the **forceps minor** (see Fig. 7-15B). The fibers of the body extend laterally as the **radiation of the corpus callosum**. They intersect with bundles of association and projection fibers as they pass to the cerebral cortex. Some of the fibers form the roof and lateral wall of the posterior horn of the lateral ventricle and the lateral wall of the inferior horn of the lateral ventricle; these fibers are referred to as the **tapetum**. Traced laterally, the fibers in the splenium arch backward into the occipital lobe and form the **forceps major**.

The **anterior commissure** is a small bundle of nerve fibers that crosses the midline in the **lamina terminalis** (see Fig. 7-8). When traced laterally, a smaller or anterior bundle curves forward on each side toward the anterior perforated substance and the olfactory tract. A larger bundle curves posteriorly on each side and grooves the inferior surface of the lentiform nucleus to reach the temporal lobes.

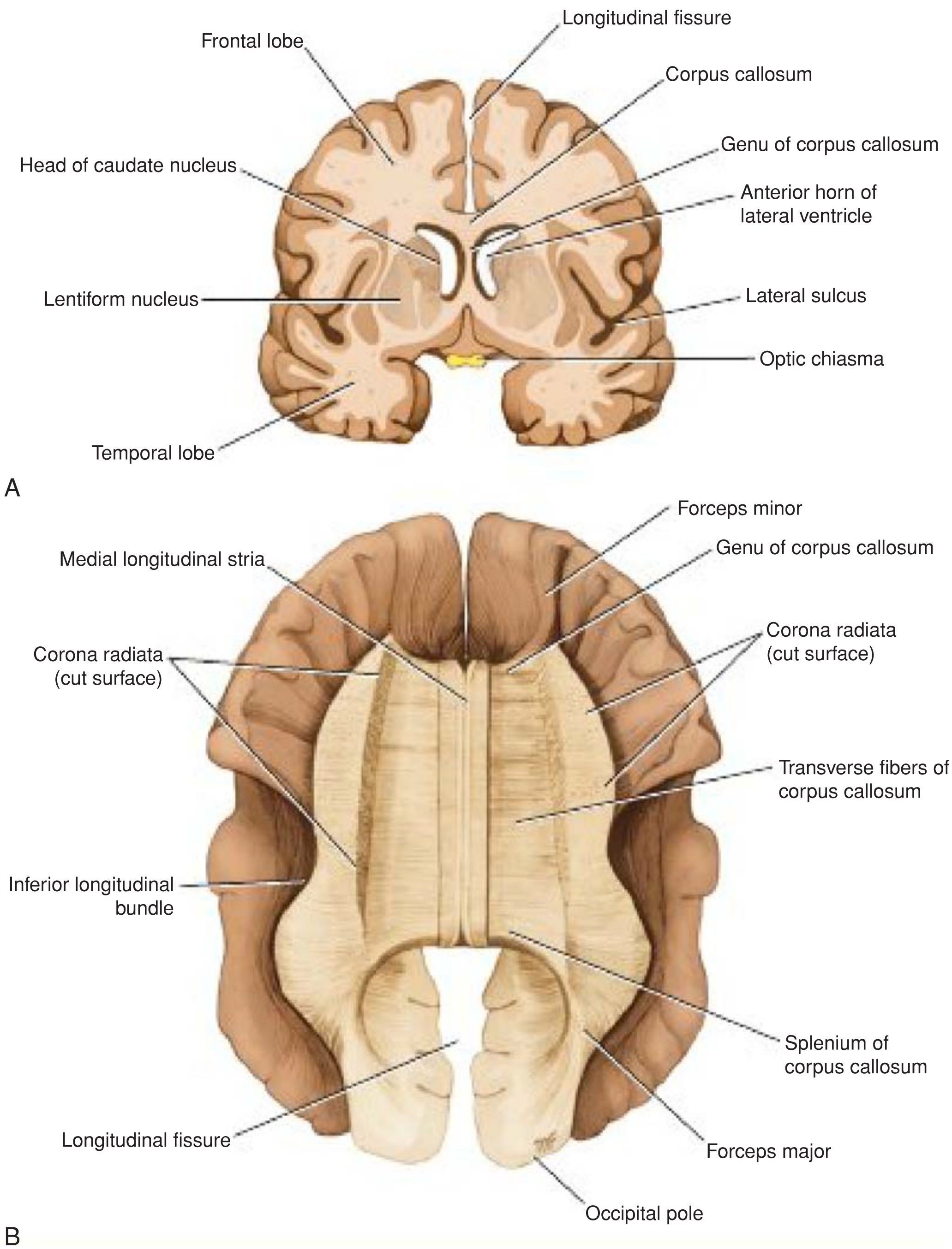


Figure 7-15 **A:** Coronal section of the brain passing through the anterior horn of the lateral ventricle and the optic chiasma. **B:** Superior view of the brain dissected to show the fibers of the corpus callosum and the corona radiata.

The **posterior commissure** is a bundle of nerve fibers that crosses the midline immediately above the opening of the cerebral aqueduct into the third ventricle (see Fig. 7-3); it is related to the inferior part of the stalk of the pineal gland. Various collections of nerve cells are situated along its length. The destinations and functional significance of many of the nerve fibers are not known. However, the fibers from the pretectal nuclei involved in the pupillary light reflex are believed to cross in this commissure on their way to the parasympathetic part of the oculomotor nuclei.

The **fornix** is composed of myelinated nerve fibers and constitutes the efferent system of the hippocampus that passes to the mammillary bodies of the hypothalamus. The nerve fibers first form the **alveus** (see Fig. 9-5), which is a thin layer of white matter covering the ventricular surface of the hippocampus, and then converge to form the **fimbria**. The fimbriae of the two

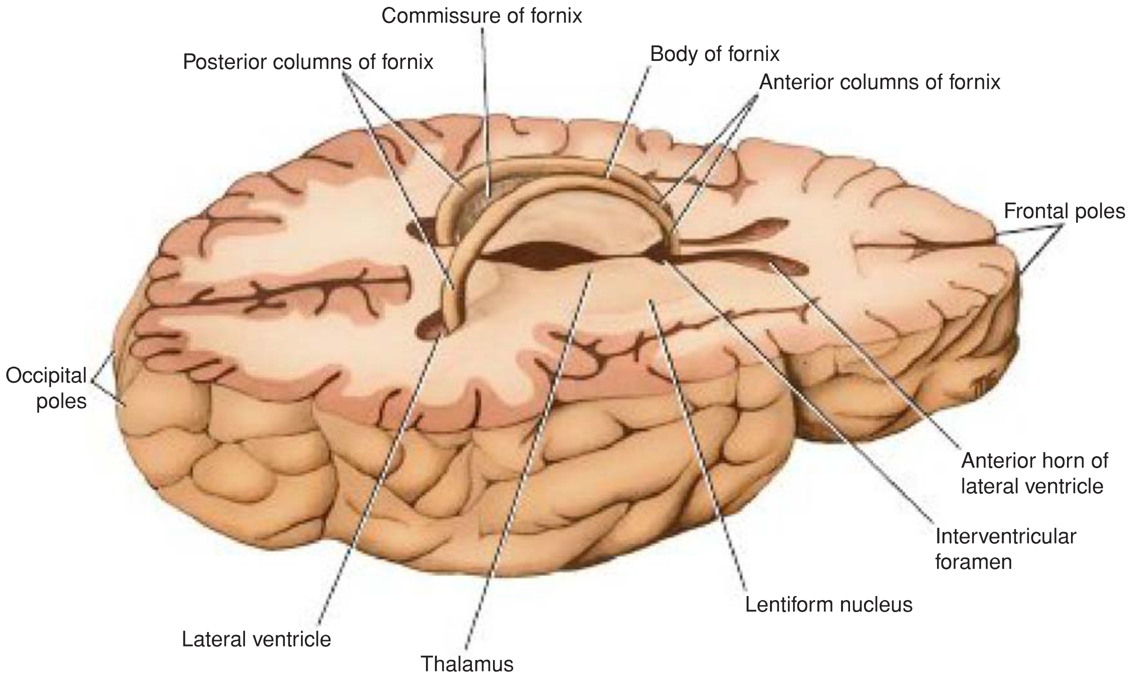


Figure 7-16 Horizontal section of the brain leaving the fornix in position.

sides increase in thickness and, on reaching the posterior end of the hippocampus, arch forward above the thalamus and below the corpus callosum to form the **posterior columns of the fornix**. The two columns then come together in the midline to form the **body of the fornix** (Fig. 7-16). The **commissure of the fornix** consists of transverse fibers that cross the midline from one column to another just before the formation of the body of the fornix. The function of the commissure of the fornix is to connect the hippocampal formations of the two sides.

The **habenular commissure** is a small bundle of nerve fibers that crosses the midline in the superior part of the root of the pineal stalk (see Fig. 7-3). The commissure is associated with the **habenular nuclei**, which are situated on either side of the midline in this region. The habenular nuclei receive many afferents from the amygdaloid nuclei and the hippocampus. These afferent fibers pass to the habenular nuclei in the **stria medullaris thalami**. Some of the fibers cross the midline to reach the contralateral nucleus through the habenular commissure. The function of the habenular nuclei and its connections in humans is unknown.

Association Fibers

Association fibers are nerve fibers that essentially connect various cortical regions within the same hemisphere and may be divided into short and long groups (Fig. 7-17). The **short association fibers** lie immediately beneath the cortex and connect adjacent gyri; these fibers run transversely to the long axis of the sulci. The **long association fibers** are collected into named bundles that can be dissected in a formalin-hardened brain. The **uncinate fasciculus** connects the first motor speech area and the gyri on the inferior surface of the frontal lobe with the cortex of the pole of the temporal lobe. The **cingulum** is a long, curved fasciculus lying within the white matter of the cingulate gyrus (see Fig. 7-8). It connects the frontal and parietal lobes with parahippocampal and adjacent temporal cortical regions. The **superior longitudinal fasciculus** is the largest bundle of nerve fibers. It connects the anterior part of the frontal lobe to the occipital and temporal lobes. The **inferior longitudinal fasciculus** runs anteriorly from the occipital lobe, passing lateral to the optic radiation, and is distributed to the temporal lobe. The **fronto-occipital fasciculus** connects the frontal lobe to the occipital and temporal lobes. It is situated deep within the cerebral hemisphere and is related to the lateral border of the caudate nucleus.

Projection Fibers

Afferent and efferent nerve fibers passing to and from the brainstem to the entire cerebral cortex must travel between large nuclear masses of gray matter within the cerebral hemisphere. At the upper part of the brainstem, these fibers form a compact band known as the **internal capsule**, which is flanked medially by the caudate nucleus and the thalamus and laterally by the lentiform nucleus (see Fig. 7-12). Because of the wedge shape of the lentiform nucleus, as seen on horizontal section, the internal capsule is bent to form an **anterior limb** and a **posterior limb**, which are continuous with each other at the **genu** (Figs. 7-18 and 7-19). Once the nerve fibers have emerged superiorly from between the nuclear masses, they radiate in all directions to the cerebral cortex. These radiating projection fibers are known as the **corona radiata** (Fig. 7-19). Most of the projection fibers lie medial to the association fibers, but they intersect the commissural fibers of the corpus callosum and the anterior commissure. The nerve fibers lying within the most posterior

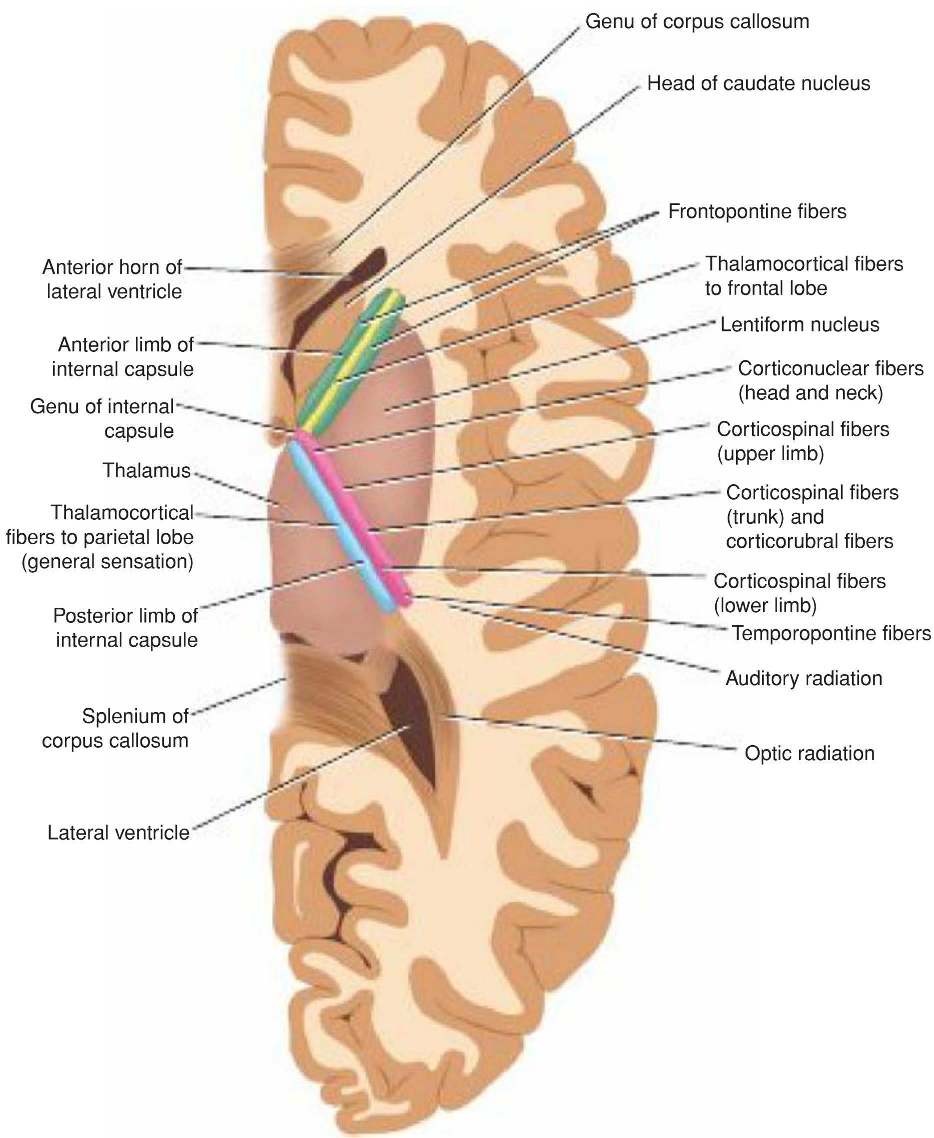


Figure 7-17 Horizontal section of the right cerebral hemisphere showing the relationships and different parts of the internal capsule.

part of the posterior limb of the internal capsule radiate toward the calcarine sulcus and are known as the **optic radiation** (Fig. 7-18). The detailed arrangement of the fibers within the internal capsule is shown in Figure 7-18.

Septum Pellucidum

The septum pellucidum is a thin vertical sheet of nervous tissue consisting of white and gray matter covered on either side by ependyma (see Figs. 7-8 and 7-12; see also Atlas Plate 8). It stretches between the fornix and the corpus callosum. Anteriorly, it occupies the interval between the body of the corpus callosum and the rostrum. It is essentially a double membrane with a closed, slitlike cavity between the membranes. The septum pellucidum forms a partition between the anterior horns of the lateral ventricles.

Tela Choroidea

The tela choroidea is a two-layered fold of pia mater. It is situated between the fornix superiorly and the roof of the third ventricle and the upper surfaces of the two thalami inferiorly. When seen from above, the anterior end is situated at the interventricular foramina (see Fig. 16-6). Its lateral edges are irregular and project laterally into the body of the lateral ventricles. Here, they are covered by ependyma and form the choroid plexuses of the lateral ventricle. Posteriorly, the lateral edges continue into the inferior horn of the lateral ventricle and are covered with ependyma so that the choroid plexus projects through the choroidal fissure.

On either side of the midline, the tela choroidea projects down through the roof of the third ventricle to form the choroid plexuses of the third ventricle.

The blood supply of the tela choroidea and, therefore, also of the choroid plexuses of the third and lateral ventricles is derived from the **choroidal branches of the internal carotid** and **basilar arteries**. The venous blood drains into the **internal cerebral veins**, which unite to form the **great cerebral vein**. The great cerebral vein joins the **inferior sagittal sinus** to form the **straight sinus**.

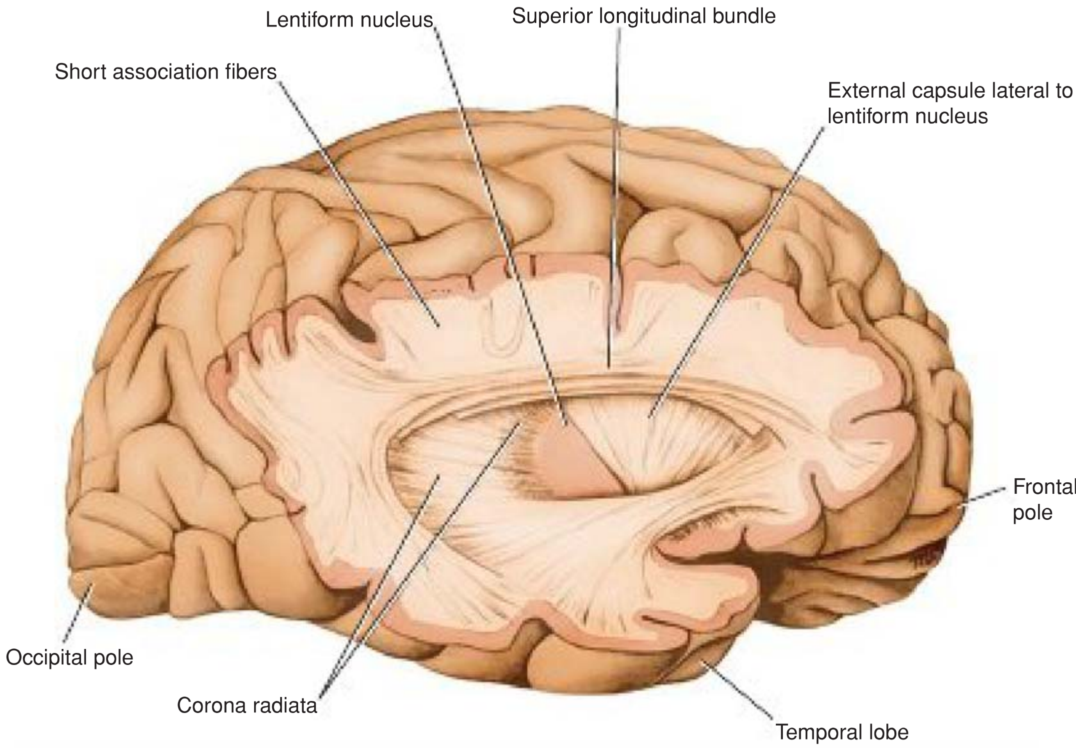


Figure 7-18 Lateral view of the right cerebral hemisphere, which has been dissected to show some of the principal association fibers.

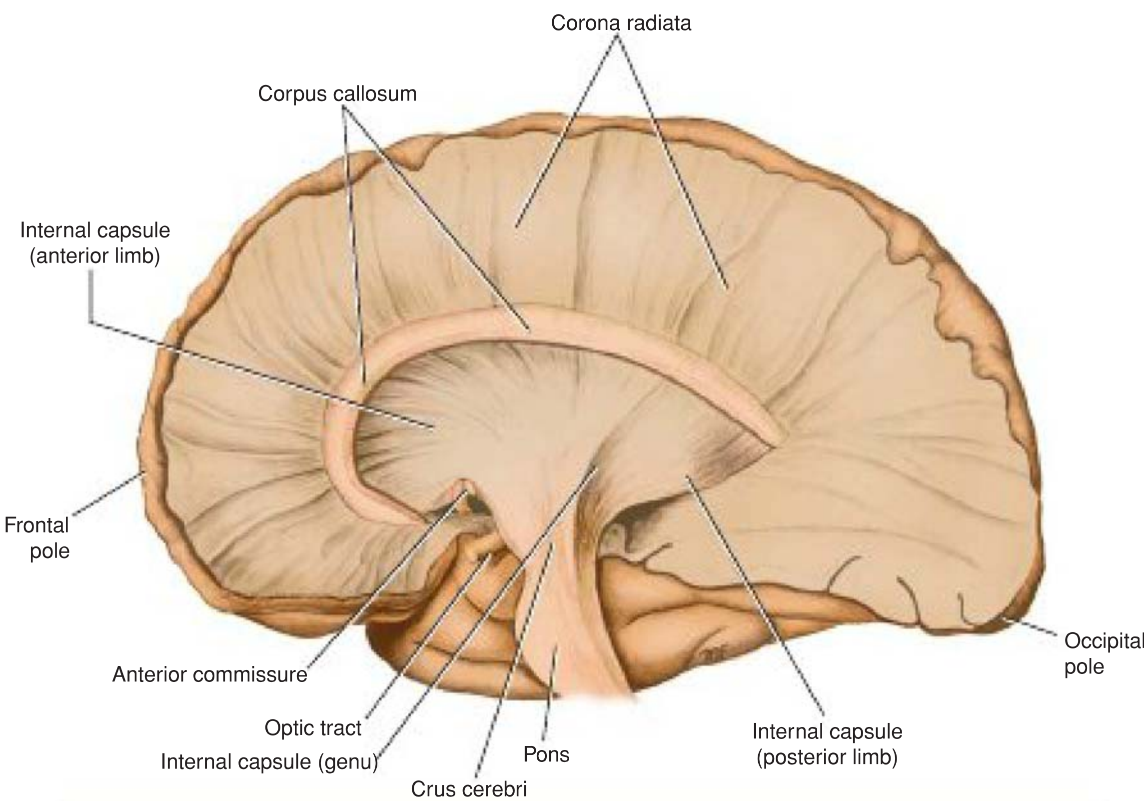


Figure 7-19 Medial view of the right cerebral hemisphere, which has been dissected to show the internal capsule and the corona radiata. The thalamus has been removed. Note the interdigitation of the horizontally running fibers of the corpus callosum and the vertical fibers of the corona radiata.

Clinical Notes

Thalamic Lesions

Lesions of the thalamus usually result from thrombosis or hemorrhage of one of the arteries that supply the thalamus. Because the thalamus is concerned with receiving sensory impulses from the opposite side of the body, the disability resulting from a lesion within it will be confined to the contralateral side of the body. There may be a major impairment of all forms of sensation, which could include light touch, tactile localization and discrimination, and loss of appreciation of joint movements.

Subthalamic Lesions

The subthalamus should be regarded as one of the extrapyramidal motor nuclei and has a large connection with the globus pallidus. Lesions of the subthalamus result in sudden, forceful involuntary movements in a contralateral extremity. The movements may be jerky (choreiform) or violent (ballistic).

Pineal Gland

The pineal gland consists essentially of pinealocytes and glial cells supported by a connective tissue framework. As the result of regressive changes that occur with age, calcareous concretions accumulate within the glial cells and connective tissue of the gland. These deposits are useful to the radiologist, since they serve as a landmark and assist in determining whether the pineal gland has been displaced laterally by a space-occupying lesion within the skull.

The functions of the pineal gland are mainly inhibitory and have been shown to influence the pituitary gland, the islets of Langerhans, the parathyroids, the adrenals, and the gonads.

Clinical observation of patients with pineal tumors or tumors of neighboring areas of nervous tissue that may press on the pineal gland has shown severe alteration of reproductive function.

Hypothalamus

The hypothalamus is an area of the nervous system that is of great functional importance. Not only does it control emotional states, but it also assists in the regulation of fat, carbohydrate, and water metabolism. Among its many other activities, it influences body temperature, genital functions, sleep, and food intake. The pituitary and the hypothalamus constitute a closely integrated unit, and the hypothalamus plays a role in the release of pituitary hormones.

Hypothalamic Syndromes

Lesions of the hypothalamus may result from infection, trauma, or vascular disorders. Tumors, such as a **craniopharyngioma** or **chromophobe adenoma of the pituitary** and **pineal tumors**, may interfere with the function of the hypothalamus. The most common abnormalities include **genital hypoplasia** or **atrophy**, **diabetes insipidus**, **obesity**, **disturbances of sleep**, **irregular pyrexia**, and **emaciation**. Some of these disorders may occur together, such as in the **adiposogenital dystrophy syndrome**.

Cerebral Cortex, Sulci, and Cerebral Hemisphere Lobes

The cerebral cortex is composed of gray matter. Only about a third lies on the exposed convexity of the gyri; the remaining two thirds form the walls of the sulci. Moreover, different areas of the cortex have different functions, and the anatomical division of the cortex into lobes and gyri by sulci enables the physician to localize loss of function or accurately place a brain lesion. For example, focal lesions of the precentral gyrus will produce contralateral hemiparesis, while lesions of the postcentral gyrus will result in contralateral hemisensory loss. More widespread lesions of the frontal lobe might cause symptoms and signs indicative of loss of attention span or change in social behavior. Widespread degeneration of the cerebral cortex gives rise to symptoms of dementia.

Lateral Ventricles

Each lateral ventricle contains about 7 to 10 mL of cerebrospinal fluid (CSF). This fluid is produced in the choroid plexus of the lateral ventricle and normally drains into the third ventricle through the interventricular foramen (foramen of Monro). Blockage of the foramen by a cerebral tumor would result in distention of the ventricle, thus producing a type of **hydrocephalus**.

The choroid plexus of the lateral ventricle is continuous with that of the third ventricle through the interventricular foramen. The choroid plexus is largest where the body and posterior and inferior horns join, where it may become calcified with age. Do not confuse this **calcification of the choroid plexus**, as seen on radiographs, with that of the pineal gland.

In the past, the size and shape of the lateral ventricle were investigated clinically by **pneumoencephalography** (Figs. 7-20 to 7-23). In this procedure, small amounts of air were introduced into the subarachnoid space by lumbar puncture with the patient in the sitting position. If the patient already had a raised intracranial pressure, this method was dangerous, and air or radiopaque fluid was injected directly into the lateral ventricles through a burr hole in the skull (this procedure was referred to as **ventriculography**). This procedure has now been replaced by CT and magnetic resonance imaging (MRI) (Figs. 7-24 to 7-27).

Basal Nuclei

The **basal nuclei**, in this discussion, refers to the masses of gray matter that are deeply placed within the cerebrum. They include the caudate nucleus, the lentiform nucleus, the amygdaloid nucleus, and the claustrum.

Because of the close relationship that exists between these nuclei and the internal capsule, tumors of the caudate or lentiform nuclei may cause severe motor or sensory symptoms on the opposite side of the body. Tumors pressing on the anterior two thirds of the posterior limb of the internal capsule will cause progressive spastic hemiplegia, while more posteriorly situated tumors will produce impairment of sensation on the opposite side.

Disorders of function of the basal nuclei are considered after the connections of these nuclei are discussed in Chapter 10.

Cerebral Commissures

The major commissure is the large corpus callosum. Most fibers within the corpus callosum interconnect symmetrical areas of the cerebral cortex. Because it transfers

Figure 7-20 Anteroposterior pneumoencephalogram of a 28-year-old man.

information from one hemisphere to another, the corpus callosum is essential for learned discrimination, sensory experience, and memory.

Occasionally, the corpus callosum fails to develop, and in these individuals, no definite signs or symptoms appear. Should the corpus callosum be destroyed by disease in later life, however, each hemisphere becomes isolated, and the patient responds as if he or she has two separate brains. The patient's general intelligence and behavior appear normal, since over the years both hemispheres have been trained to respond to different situations. If a pencil is placed in the patient's right hand (with the eyes closed), he or she will recognize the object by touch and be able to describe it. If the pencil is placed in the left hand, the tactile information will pass to the right postcentral gyrus. This information will not be able to travel through the corpus callosum to the speech area in the left hemisphere; therefore, the patient will be unable to describe the object in his or her left hand.

Section of the corpus callosum has been attempted surgically, with some success, in order to prevent the spread of seizures from one hemisphere to the other.

Internal Capsule Lesions

The internal capsule is an important compact band of white matter. It is composed of ascending and descending nerve fibers that connect the cerebral cortex to the brainstem and spinal cord. The internal capsule is flanked medially

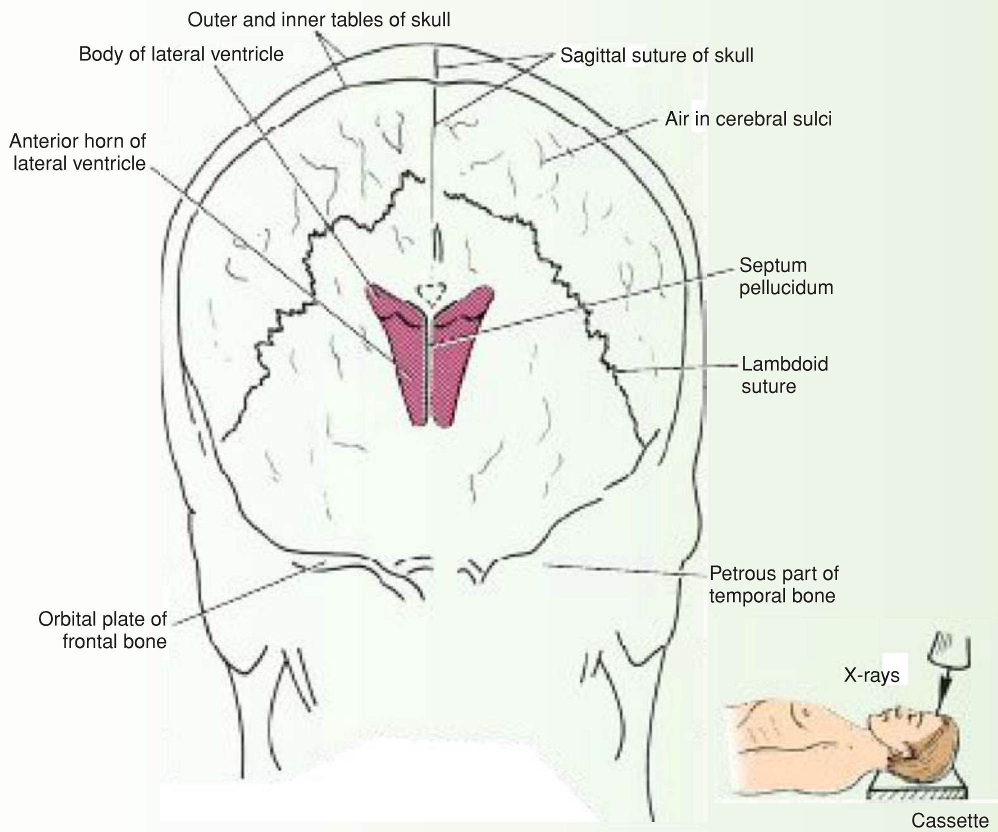


Figure 7-21 Explanation of the radiograph seen in Figure 7-20. Note the position of the x-ray gun relative to the head and the film cassette.

Figure 7-22 Lateral pneumoencephalogram of a 28-year-old man.

by the caudate nucleus and thalamus and laterally by the lentiform nucleus. The arrangement of the nerve fibers within the internal capsule is shown in Figure 7-18.

The internal capsule is frequently involved in vascular disorders of the brain. The most common cause of arterial hemorrhage is atheromatous degeneration in an artery in a patient with high blood pressure. Because of the high concentration of important nerve fibers within the internal capsule, even a small hemorrhage can cause widespread effects on the contralateral side of the body. Not only is the immediate neural tissue destroyed by the blood, which later clots, but also neighboring nerve fibers may be compressed or be edematous.

Alzheimer Disease

Alzheimer disease is a degenerative disease of the brain occurring in middle to late life, but an early form of the disease is now well recognized. The disease affects more than 4 million people in the United States, resulting in

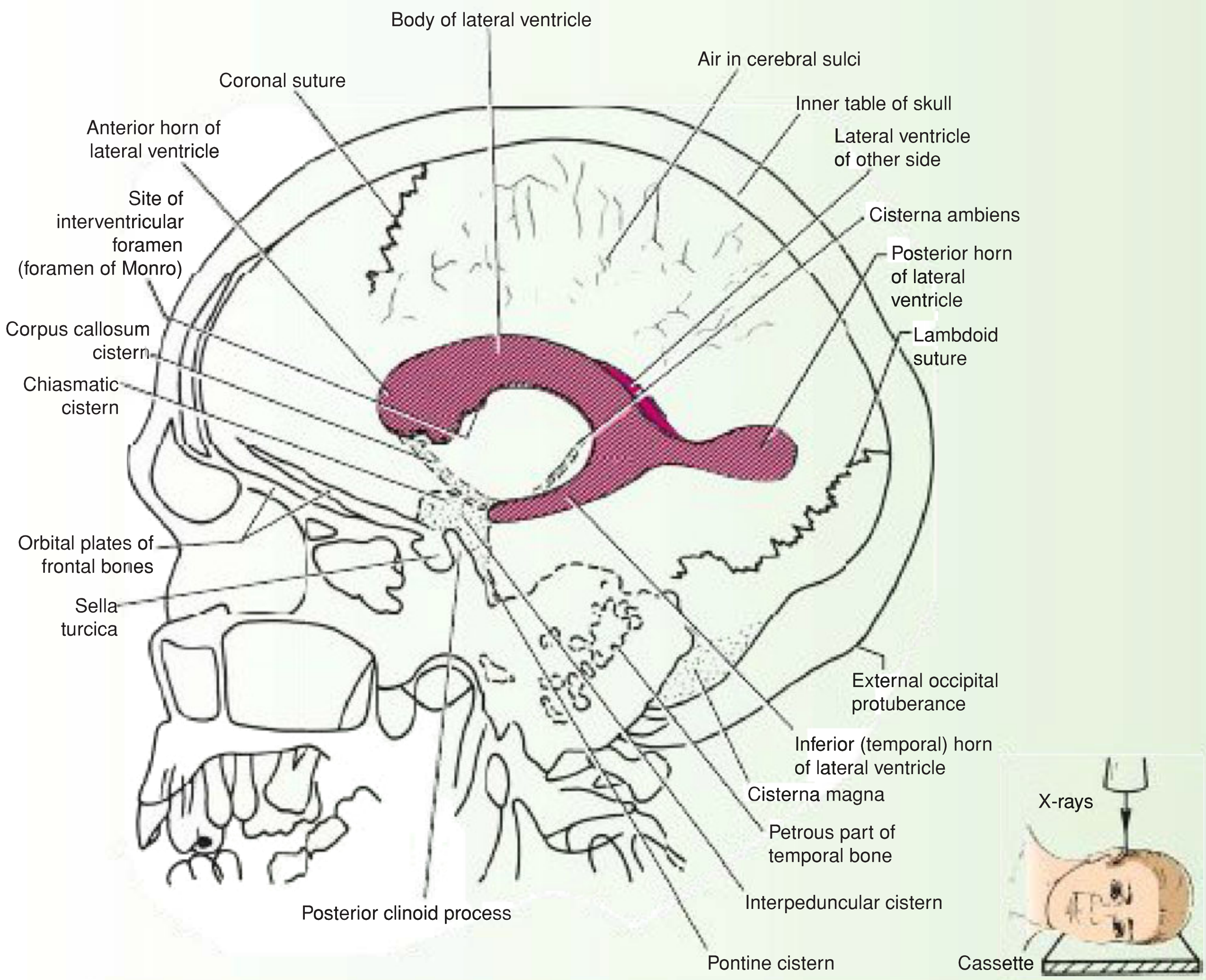


Figure 7-23 Explanation of the radiograph seen in Figure 7-22. Note the position of the x-ray gun relative to the head and the film cassette.

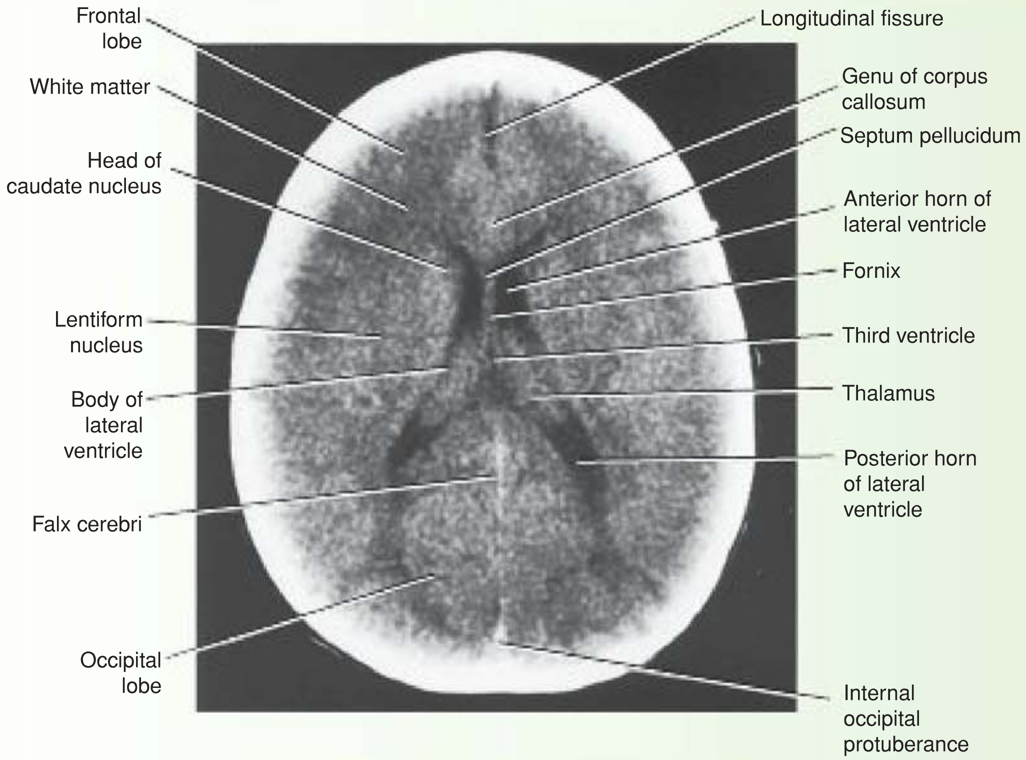


Figure 7-24 Horizontal (axial) CT scan of the brain.

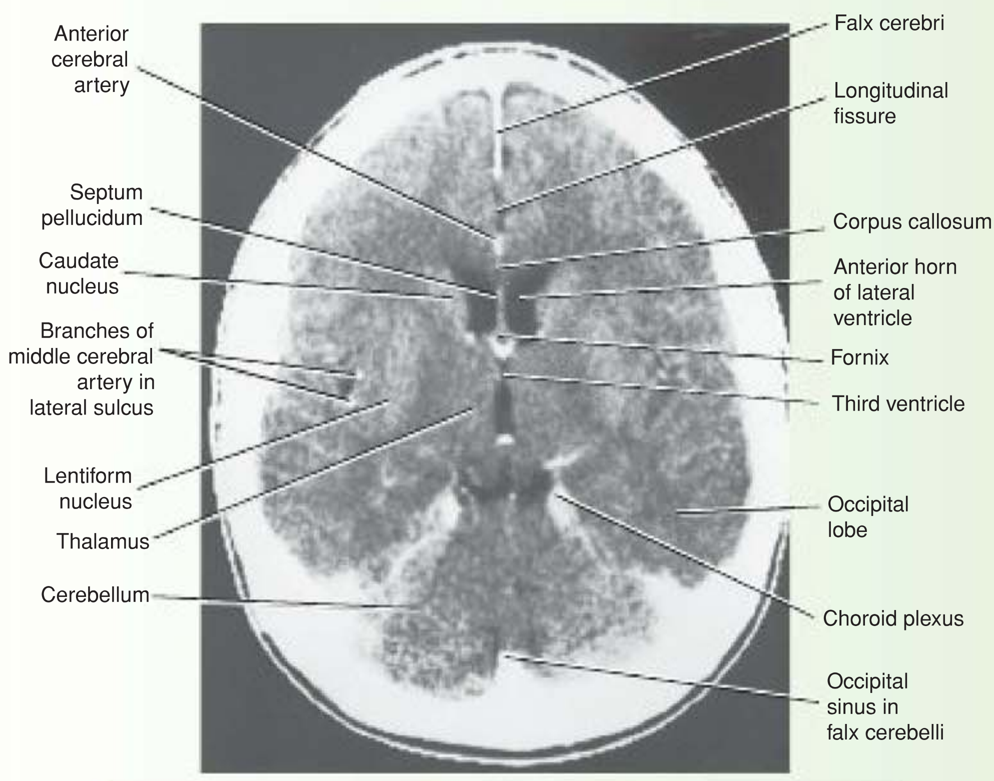


Figure 7-25 Horizontal (axial) CT scan of the brain (contrast enhanced).

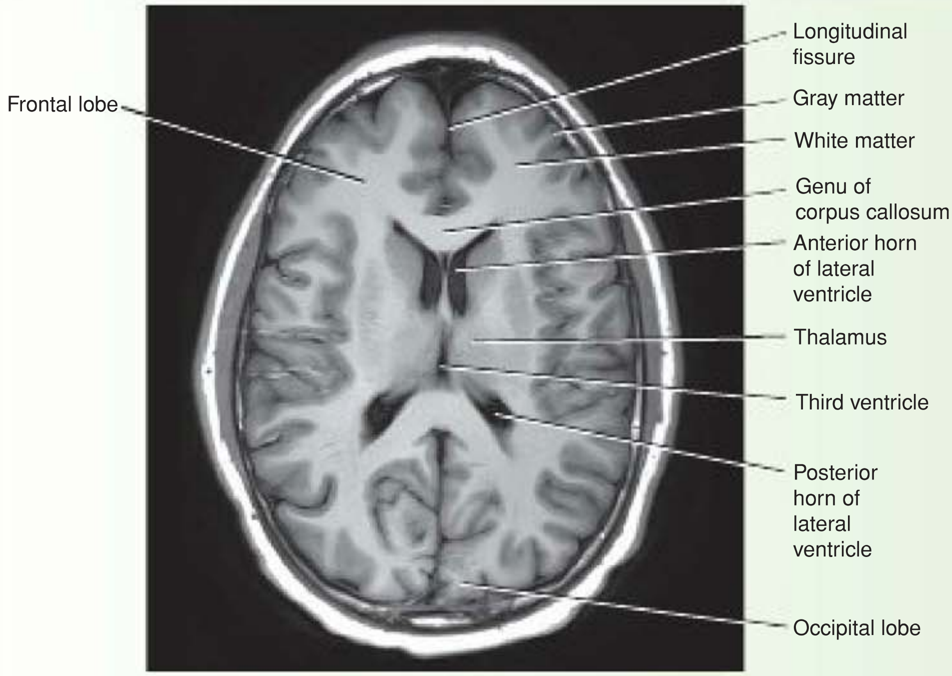


Figure 7-26 Horizontal (axial) MRI of the brain.

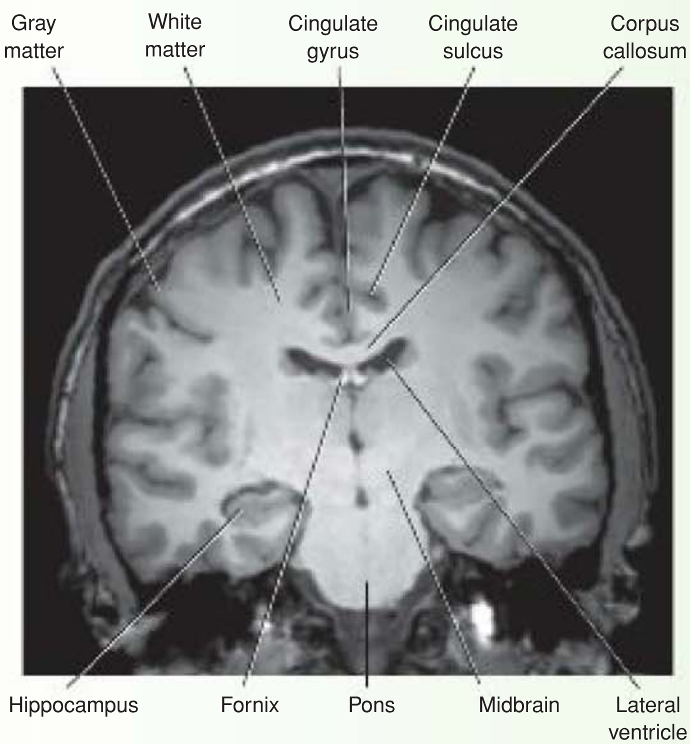


Figure 7-27 Coronal MRI of the brain.

over 100,000 deaths per year. The risk of the disease rises sharply with advancing years.

The cause of Alzheimer disease is unknown, but evidence suggests a genetic predisposition. Several abnormal genes have been found, each of which leads to a similar clinical and pathologic syndrome, with only variations in the age of onset and the rate of progression to suggest that the pathogenetic mechanisms differ. Some cases of familial Alzheimer disease, for example, have been shown to have mutations in several genes (*App*, *presenilin 1*, and *presenilin 2*).

Early memory loss, a disintegration of personality, complete disorientation, deterioration in speech, and restlessness are common signs. In the late stages, the patient may become mute, incontinent, and bedridden and usually dies of some other disease.

Microscopically, changes eventually occur throughout the cerebral cortex, but to begin with, certain regions of the brain are selectively involved. The early sites include the hippocampus, the entorhinal cortex, and the associated areas of the cerebral cortex. Many so-called senile plaques are found in the atrophic cortex. The plaques result from the accumulation of several proteins around deposits of beta amyloid. In the center of each plaque is an extracellular collection of degenerating nervous tissue; surrounding the core is a rim of large abnormal neuronal processes, probably presynaptic terminals, filled with an excess of intracellular neurofibrils that are tangled and twisted, forming neurofibrillary tangles. The neurofibrillary tangles are aggregations of the microtubular protein tau, which is hyperphosphorylated. There is a marked loss of choline acetyltransferase, the biosynthetic enzyme for acetylcholine, in the areas of the cortex in which the senile plaques occur. This is thought to be due to loss of the ascending projection fibers rather than a loss of cortical cells. As these cellular changes occur, the affected neurons die.

At this time, there is no clinical test for making the definite diagnosis of Alzheimer disease. Reliance is placed on taking a careful history and carrying out numerous neurologic and psychiatric examinations spaced out over time. In this way, other causes of dementia can be excluded. Alterations in the levels of amyloid peptides or tau in the serum or CSF may be helpful. CT scans or MRIs are also used, and abnormalities in the medial part of the temporal lobe occur in this disease. In advanced cases, a thin, atrophied cerebral cortex and dilated lateral ventricles may be found. The recent use of positron emission tomography (PET) shows evidence of diminished cortical metabolism (Fig. 7-28).

The use of cholinesterase inhibitors for the treatment of Alzheimer disease has been found to be helpful. These drugs probably act by increasing the presence of acetylcholine at the sites of the disease where there is a deficiency of this neurotransmitter.

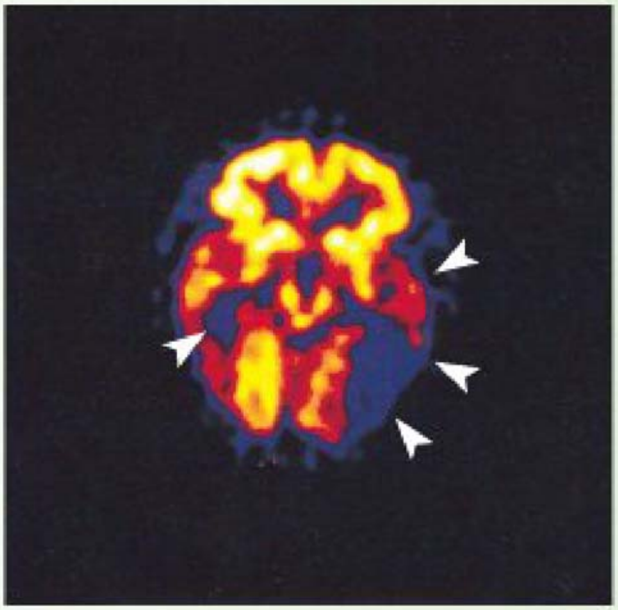


Figure 7-28 Axial (horizontal) PET scan of a male patient with Alzheimer disease, showing defects (*arrowheads*) in metabolism in the bitemporoparietal regions of the cerebral cortex, following the injection of 18-fluorodeoxyglucose. The yellow areas indicate regions of high metabolic activity. (*Courtesy Dr. Holley Dey.*)

Key Concepts

Cerebral Subdivisions

- The cerebrum is subdivided into the diencephalon (central core) and the telencephalon (cerebral hemispheres).

Diencephalon

- The diencephalon consists of the third ventricle and the structures that form its boundaries, including the thalamus, subthalamus, epithalamus, and hypothalamus.

Thalamus

- The thalamus is a very important cell station that receives the main sensory tracts. Sensory information is integrated and relayed to the cerebral cortex and other subcortical regions.