Subthalamus

- The subthalamus consists of nerve cells associated with the red nuclei and substantia nigra and is involved in control of muscle activity.

Epithalamus

- The epithalamus consists of the habenular nuclei (integration of visceral and somatic pathways) and the pineal gland (endocrine gland and melatonin).

Hypothalamus

- The hypothalamus controls and integrates the functions of the autonomic nervous system and endocrine systems and plays a vital role in maintaining body homeostasis.
- Physiologically, hardly any activity in the body is not influenced by the hypothalamus.

Main Sulci

- The central sulcus separates the frontal and parietal lobes. The gyrus anterior to it contains motor cells that initiate the movements of the contralateral side of the body; the gyrus posterior to it contains general sensory cortex that receives sensory information from the contralateral side of the body.
- The lateral sulcus is a deep cleft on the inferior lateral cerebral hemisphere, between frontal and temporal lobes. The insula lies deep to the lateral sulcus.
- The parieto-occipital sulcus is located on the medial side of the hemisphere, running inferiorly to intersect the calcarine sulcus.
- The calcarine sulcus is found on the medial surface of the hemispheres, in the occipital lobe. Primary visual cortex is located here.

Cerebral Hemisphere Lobes

- The frontal lobe occupies the area anterior to the central sulcus and is divided by three sulci into three gyri.
- The temporal lobe occupies the area inferior to the lateral sulcus and is divided into three gyri by two sulci.
- The occipital lobe occupies the area behind the parieto-occipital sulcus.

Internal Structures

- The two lateral ventricles are located one in each hemisphere. The lateral ventricles are large cavities that house CSF. Each are in communication with the third ventricle through the interventricular foramen.
- Basal nuclei are a collection of gray matter masses including the corpus striatum, amygdaloid nucleus, and the claustrum.
  - The corpus striatum is composed of the caudate nucleus and the lentiform nucleus, both separated by the internal capsule. These structures are involved in muscular movement control through communications with the cortex.
  - The claustrum is separated from the lentiform nucleus by the external capsule. The function of the claustrum is unknown.
  - The amygdaloid nucleus is located in the temporal lobe adjacent to the anterior horn of the lateral ventricle.
- Commissure fibers in the cerebrum are myelinated fibers connecting two corresponding regions of the two hemispheres.
- The largest commissure is the corpus callosum, which connects the two hemispheres. Other commissures include the fornix and the anterior and posterior commissures.

Clinical Problem Solving

1. A 53-year-old woman is admitted to an emergency department after she collapses in the street. Apart from being confused and disoriented, she exhibits violent, uncoordinated movements of her right arm and right leg and slight spontaneous movements on the right side of her face. The physician is able to ascertain from a friend that the patient had been perfectly fit that morning and has no previous history of this condition. On examination, the involuntary movements of the right limbs are mainly confined to the muscles of the proximal part of the limbs. One week later, the patient dies of cardiac failure. What is the medical term used to describe this condition? Which area of the brain is likely to be involved in the production of this condition?
2. A 64-year-old man is admitted to a hospital on the suspicion that he has a cerebral tumor. One of the investigations asked for by the physician is a simple anteroposterior radiograph and lateral radiograph of the head. Using your knowledge of

neuroanatomy, name the structure that would assist the radiologist in this case in determining whether lateral displacement of the brain had occurred within the skull.

3. A 12-year-old boy is seen by a pediatrician because his parents are concerned about his excessive weight and lack of development of the external genitalia. On examination, the child is seen to be tall for his age and very obese. The excessive fat is concentrated especially in the lower part of the anterior abdominal wall and the proximal parts of the limbs. His penis and testes are small. Is it possible that disease of the diencephalon might account for this condition?
4. A neurosurgeon explains to her residents that she will attempt to remove a glioma located in the right middle frontal gyrus by turning back a flap of the scalp and removing a rectangular piece of the overlying skull. Where exactly is the right middle frontal gyrus in the brain? What are the names of the sulci that lie above and below this gyrus? Which skull bone overlays this gyrus?
5. While performing an autopsy, a pathologist has great difficulty in finding the central sulcus in each cerebral hemisphere. Because finding this sulcus is the key to localizing many other sulci and gyri, what landmarks would you use to identify the central sulcus? Are the sulci and gyri in the two hemispheres similar in size and shape? Do they exhibit individual variations in their arrangement?
6. A fourth-year medical student is shown coronal and horizontal MRIs of the brain and is asked to comment on his observations. The patient is a 55-year-old man. The student responds by saying that the left lateral ventricle is larger than normal and that there is an area of low signal intensity close to the left interventricular foramen suggesting the presence of a brain tumor. On looking at a standard lateral radiograph of the skull and brain, he notes a small area of "calcification" situated in the region of the posterior part of the left ventricle. Using your knowledge of neuroanatomy, describe the location of the lateral ventricle in the brain. What are the different parts of the lateral ventricle? Where is the cerebrospinal fluid in the lateral ventricle produced, and what does it normally drain into? What is responsible for the calcification seen in the left lateral ventricle in this patient?
7. A medical student, while performing an autopsy, finds that the patient has no corpus callosum. On consulting the patient's clinical notes, she is surprised to find no reference to a neurologic disorder. Are you surprised that this patient had no recorded neurologic signs and symptoms?

Answers and Explanations to Clinical Problem Solving

1. This woman exhibited continuous uncoordinated activity of the proximal musculature of the right arm and right leg, resulting in the limbs being flung violently about. The muscles of the right side of the face were also slightly affected. This condition is known as hemiballismus. It was caused by hemorrhage into the left subthalamic nucleus.
2. During the third decade of life, calcareous concretions appear in the neuroglia and connective tissue of the pineal gland. This provides a useful midline landmark to the radiologist. A lateral displacement of such a landmark would indicate the presence of an intracranial mass. In this patient, the pineal gland shadow was in the midline, and all the other investigations, including CT, showed no evidence of a cerebral tumor.
3. Yes. Adiposity alone or associated with genital dystrophy can occur with disease of the hypothalamus.
4. The right middle frontal gyrus is located on the lateral surface of the frontal lobe of the right cerebral hemisphere. It is bounded superiorly and inferiorly by the superior and inferior frontal sulci, respectively. The right middle frontal gyrus is overlaid by the frontal bone of the skull.
5. The important central sulcus is large and runs downward and forward across the lateral aspect of each hemisphere. Superiorly, it indents the superior medial border of the hemisphere about 1 cm behind the midpoint; it lies between two parallel gyri. It is the only sulcus of any length that indents the superior medial border. The arrangement of the sulci and gyri is very similar on both sides of the brain. However, individual details of their arrangement vary greatly.
6. The lateral ventricle is a C-shaped cavity situated within each cerebral hemisphere. The lateral ventricle wraps itself around the thalamus, the lentiform nucleus, and the caudate nucleus. It is divided into a body that occupies the parietal lobe, an anterior horn that extends into the frontal lobe, a posterior horn that extends into the occipital lobe, and an inferior horn that runs forward and inferiorly into the temporal lobe. The cerebrospinal fluid is produced in the choroid plexus of the lateral ventricle and drains through the small interventricular foramen into the third ventricle. In later life, the choroid plexus, especially in its posterior part, sometimes shows calcified deposits, which are occasionally revealed on radiographs, as in this case. This patient later was found to have a cerebral tumor that was compressing the left interventricular foramen, hence the enlarged left ventricle.
7. No. The corpus callosum occasionally fails to develop, and in those patients, no definite neurologic signs and symptoms appear. If, however, the corpus callosum is divided during a surgical procedure in the adult, the loss of interconnections between the two hemispheres becomes apparent (see pp. 267–268).

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 diencephalon:
   (a) It extends anteriorly as far as the optic chiasma.
   (b) It is bounded laterally by the internal capsule.
   (c) The thalamus is located in the medial wall of the third ventricle.
   (d) The epithalamus is formed by the cranial end of the substantia nigra and the red nuclei.
   (e) It extends posteriorly as far as the interthalamic connection.
2. The following statements concern the pineal gland:
   (a) It produces a secretion that is opaque to x-rays.
   (b) It contains high concentrations of melatonin.
   (c) Melatonin stimulates the release of the gonadotrophic hormone from the anterior lobe of the pituitary gland.
   (d) Production of secretions of the pineal gland decreases during darkness.
   (e) The pinealocytes are inhibited by the sympathetic nerve endings.
3. The following statements concern the thalamus:
   (a) It is the largest part of the diencephalon and serves as a relay station to all the main sensory tracts (except the olfactory pathway).
   (b) It is separated from the lentiform nucleus by the external capsule.
   (c) It forms the anterior boundary of the interventricular foramen.
   (d) It is completely separate from the thalamus on the opposite side.
   (e) The thalamus is a small rectangular mass of gray matter.
4. The following statements concern the hypothalamus:
   (a) It is formed by the upper part of the lateral wall and roof of the third ventricle.
   (b) Caudally, the hypothalamus merges with the tectum of the midbrain.
   (c) The nuclei are composed of groups of large nerve cells.
   (d) Functionally, it plays a role in the release of pituitary hormones.
   (e) The mammillary bodies are not part of the hypothalamus.
5. The following statements concern the hypothalamus:
   (a) The hypothalamus has no influence on the activities of the autonomic and endocrine systems.
   (b) It receives few afferent visceral and somatic sensory fibers.
   (c) It gives off efferent fibers that pass to the sympathetic and parasympathetic outflows in the brain and spinal cord.
   (d) It does not assist in the regulation of water metabolism.
   (e) The hypothalamus plays no role in controlling emotional states.
6. The following statements concern the third ventricle:
   (a) The posterior wall is formed by the opening into the cerebral aqueduct and the pineal recess.
   (b) It does not communicate directly with the lateral ventricles.
   (c) The vascular tela choroidea projects from the floor to form the choroid plexus.
   (d) Lying in the floor of the ventricle, from posterior to anterior, are the optic chiasma, the tuber cinereum, and the mammillary bodies.
   (e) The wall of the ventricle is not lined with ependyma.

Matching Questions. Directions: The following questions apply to Figure 7-29. 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.

7. Number 1
8. Number 2
9. Number 3
10. Number 4
11. Number 5
12. Number 6
13. Number 7

(a) Genu of corpus callosum
(b) Interventricular foramen
(c) Body of fornix
(d) Anterior commissure
(e) None of the above

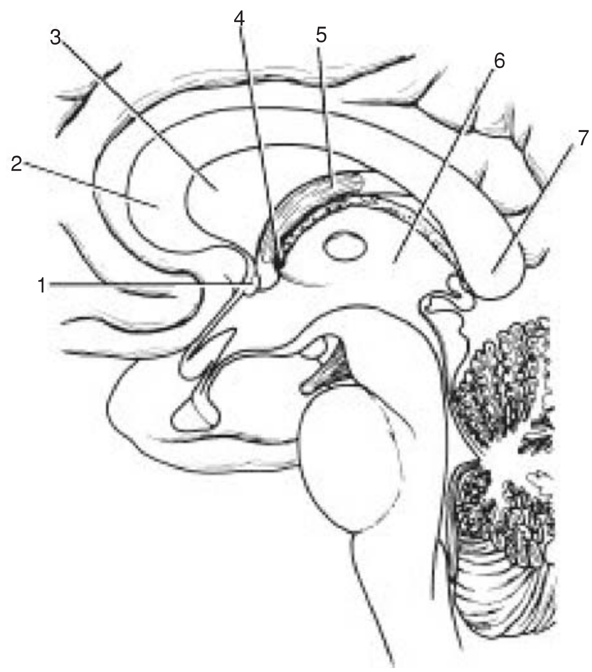


Figure 7-29 Sagittal section of the brain showing the medial surface of the diencephalon.

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 longitudinal cerebral fissure:
    (a) The fissure contains the fold of dura mater, the falx cerebelli.
    (b) The fissure contains the middle cerebral arteries.
    (c) The superior sagittal sinus lies below it.
    (d) In the depths of the fissure, the corpus callosum crosses the midline.
    (e) The inferior sagittal sinus lies above it.
15. The following statements concern the central sulcus:
    (a) The central sulcus extends onto the medial surface of the cerebral hemisphere.
    (b) The frontal lobe lies posterior to it.
    (c) The parietal lobe lies anterior to it.
    (d) The central sulcus is continuous inferiorly with the lateral sulcus.
    (e) The arachnoid mater extends into the central sulcus.
16. The following statements concern the lateral ventricle:
    (a) Each ventricle is J shaped and filled with cerebrospinal fluid.
    (b) It communicates with the third ventricle through the interventricular foramen.
    (c) The body of the ventricle occupies the frontal lobe.
    (d) The lateral ventricle does not possess a choroid plexus.
    (e) The anterior horn occupies the parietal lobe.
17. The following statements concern the corpus callosum:
    (a) It is connected to the fornix by the lamina terminalis.
    (b) The rostrum connects the genu to the septum pellucidum.
    (c) Most of the fibers within the corpus callosum interconnect symmetrical areas of the cerebral cortex.
    (d) The fibers of the genu curve forward into the frontal lobes as the forceps major.
    (e) The corpus callosum is related inferiorly to the falx cerebri.
18. The following statements concern the anterior commissure:
    (a) It is embedded in the superior part of the septum pellucidum.
    (b) When traced laterally, an anterior bundle of fibers curves forward to join the olfactory tract.
    (c) Some of the fibers are concerned with the sensations of taste.
    (d) It forms the anterior boundary of the interventricular foramen.
    (e) It is formed by a large bundle of nerve fibers.
19. The following statements concerning the internal capsule are correct **except**:
    (a) It is continuous below with the tectum of the midbrain.
    (b) It has an anterior limb and a posterior limb, which are in a straight line.

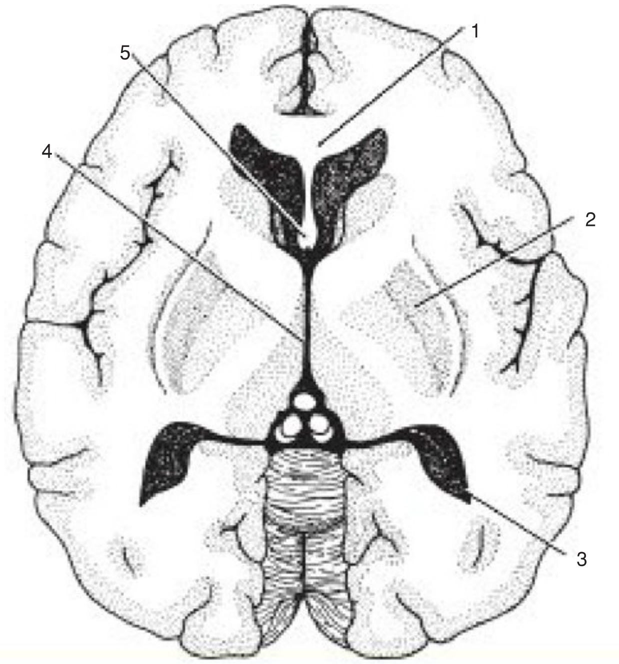


Figure 7-30 Horizontal section of the cerebrum, as seen from above.

    (c) The genu and the anterior part of the posterior limb contain the corticobulbar and corticospinal fibers.
    (d) It is related medially to the lentiform nucleus.
    (e) It is continuous below with the corona radiata.
20. The following statements concern the basal ganglia:
    (a) The caudate nucleus is not attached to the lentiform nucleus.
    (b) The corpus striatum is concerned with muscular movement.
    (c) The lentiform nucleus is related medially to the external capsule.
    (d) The lentiform nucleus is oval shaped, as seen on horizontal section.
    (e) The amygdaloid nucleus does not form one of the basal ganglia.

Matching Questions. Directions: The following questions apply to Figure 7-30. 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.

21. Number 1 (a) Optic radiation
22. Number 2 (b) Lateral sulcus
23. Number 3 (c) Lentiform nucleus
24. Number 4 (d) Anterior horn of lateral ventricle
25. Number 5 (e) None of the above

The following questions apply to Figure 7-31. 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.

26. Number 1 (a) Central sulcus
27. Number 2 (b) Postcentral gyrus

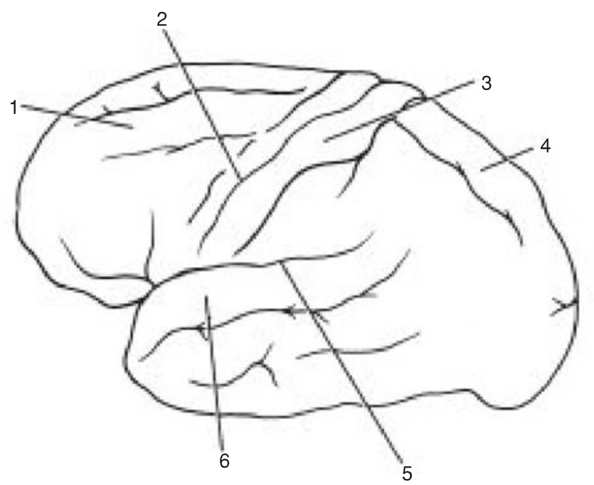


Figure 7-31 Lateral view of the left cerebral hemisphere.

28. Number 3
29. Number 4
30. Number 5
31. Number 6

(c) Superior temporal gyrus
(d) Superior parietal lobule
(e) None of the above

Directions: The case histories below are followed by questions. Select the ONE BEST lettered answer.

A 70-year-old man with hypertension was admitted to an emergency department, having suddenly developed hemiparesis on the right side and numbness of the right leg. Axial CT and MRI were undertaken. MRI revealed a small hemorrhage in the left thalamus, which passed horizontally through the lateral ventricles. After careful observation, 2 days later, the paresis was much improved, and the patient reported that his numbness had disappeared. The patient was discharged from the hospital 1 week later and made an uneventful recovery. His hypertension was brought under control with suitable medication.

32. Using your knowledge of the relationships of the left thalamus, select the statement that explains the transient right hemiparesis and numbness.
    (a) The hemorrhage occurred into the third ventricle.
    (b) The hemorrhage into the thalamus extended laterally into the posterior limb of the left internal capsule.
    (c) The hemorrhage was small and confined to the thalamus on the left side.
    (d) The hemorrhage was small and occurred in the lateral part of the left thalamus, producing transient edema in the left internal capsule.
    (e) The hemorrhage extended laterally into the left lateral ventricle.
33. This hypertensive patient had a small thalamic hemorrhage. Select the **most likely** cause for the hemorrhage:
    (a) One of the small diseased thalamic arteries may have ruptured.
    (b) One of the small veins draining the thalamus may have ruptured.
    (c) Vasoconstriction of the thalamic arteries could have occurred.
    (d) Softening of the neuronal tissue around the thalamic arteries might have taken place.
    (e) No relation exists between hypertension and the thalamic hemorrhage in this patient.

An 8-year-old boy with a severe earache on the right side was taken to a pediatrician. The symptoms had started 7 days ago, and the pain had progressively worsened. On examination, the boy was found to have severe right-sided otitis media with acute mastoiditis. On being questioned, the boy admitted that his head hurt badly all over and that he felt sick. While he was being examined, he vomited. His body temperature was slightly elevated. In view of the severity of the headache and the presence of nausea and vomiting, the pediatrician decided to have an MRI performed. The result showed a small, well-defined, right cerebral abscess.

34. The cerebral abscess in this patient was most likely located at which site in the right cerebral hemisphere:
    (a) Frontal lobe
    (b) Thalamus
    (c) Occipital lobe
    (d) Temporal lobe
    (e) Cuneus

Answers and Explanations to Review Questions

1. B is correct. The diencephalon is bounded laterally by the internal capsule (see Fig. 7-1). A. The diencephalon extends anteriorly as far as the interventricular foramen (see Fig. 7-3). C. The thalamus is situated on the lateral wall of the third ventricle (see Fig. 7-3). D. The epithalamus consists of the habenular nuclei and their connections and the pineal gland. E. The diencephalon extends posteriorly as far as the cerebral aqueduct (see Fig. 7-3).
2. B is correct. The pineal gland contains high concentrations of melatonin. A. The pineal secretions are translucent to x-rays. C. Melatonin inhibits the release of the gonadotrophic hormone from the anterior lobe of the pituitary gland. D. There is an increased production of the secretions of the pineal gland during darkness. E. The pinealocytes are stimulated by the sympathetic nerve endings.
3. A is correct. The thalamus is the largest part of the diencephalon and serves as a relay station to all the main sensory tracts, except the olfactory pathway. B. The thalamus is separated from the lentiform nucleus by the internal capsule (see Fig. 7-1). C. The thalamus forms the posterior boundary of the interventricular foramen (see Fig. 7-3). D. The

thalamus may be joined to the thalamus of the opposite side by the interthalamic connection. E. The thalamus is a large ovoid mass of gray matter (see Fig. 7-4).

4. D is correct. The hypothalamus plays an important role in the release of pituitary hormones. A. The hypothalamus is formed by the lower part of the lateral wall and floor of the third ventricle, below the hypothalamic sulcus (see Fig. 7-3). B. Caudally, the hypothalamus merges with the tegmentum of the midbrain. C. The nuclei of the hypothalamus are composed of groups of small nerve cells. E. The mammillary bodies are part of the hypothalamus.
5. C is correct. The hypothalamus gives off efferent fibers that pass to the sympathetic and parasympathetic outflows in the brain and spinal cord. A. The hypothalamus has influence on the activities of the autonomic and endocrine systems. B. The hypothalamus receives many afferent visceral and somatic sensory nerve fibers. D. The hypothalamus assists in the regulation of water metabolism. E. The hypothalamus plays a role in controlling emotional states.
6. A is correct. The posterior wall of the third ventricle is formed by the opening into the cerebral aqueduct and the pineal recess (see Fig. 7-3). B. The third ventricle does communicate directly with the lateral ventricles through the interventricular foramina (see Fig. 7-13). C. The vascular tela choroidea projects from the roof of the third ventricle to form the choroid plexus (see Fig. 7-3). D. Lying in the floor of the third ventricle, from anterior to posterior, are the optic chiasma, the tuber cinereum, and the mammillary bodies. E. The wall of the third ventricle is lined with ependyma.
7. D is correct.
8. A is correct.
9. E is correct. The structure is the septum pellucidum.
10. B is correct.
11. C is correct.
12. E is correct. The structure is the thalamus.
13. E is correct. The structure is the splenium of the corpus callosum.
14. D is correct. In the depths of the longitudinal cerebral fissure, the corpus callosum crosses the midline (see Fig. 7-6). A. The longitudinal cerebral fissure contains a fold of dura mater, the falx cerebri. B. The longitudinal cerebral fissure does not contain the middle cerebral arteries; they are located in the lateral cerebral fissures. C. The superior sagittal venous sinus lies above the longitudinal cerebral fissure. E. The inferior sagittal venous sinus lies in the lower border of the falx cerebri in the longitudinal cerebral fissure.
15. A is correct. The central sulcus extends onto the medial surface of the cerebral hemisphere (see Fig. 7-8). B. The frontal lobe lies anterior to the central sulcus (see Fig. 7-10). C. The parietal lobe lies posterior to the central sulcus (see Fig. 7-10). D. The central sulcus is not continuous inferiorly with the lateral sulcus (see Fig. 7-10). E. The arachnoid mater does not extend into the central sulcus.
16. B is correct. The lateral ventricle communicates with the third ventricle through the interventricular foramen (see Fig. 7-3). A. Each lateral ventricle is C shaped and filled with cerebrospinal fluid (see Fig. 7-13). C. The body of the lateral ventricle occupies the parietal lobe. D. The lateral ventricle does possess a choroid plexus (see Fig. 7-1). E. The anterior horn of the lateral ventricle occupies the frontal lobe (see Fig. 7-13).
17. C is correct. Most of the fibers within the corpus callosum interconnect symmetrical areas of the cerebral cortex. A. The corpus callosum is connected to the fornix by the septum pellucidum (see Fig. 7-3). B. The rostrum of the corpus callosum connects the genu to the lamina terminalis (see Fig. 7-3). D. The fibers of the genu of the corpus callosum curve forward into the frontal lobes of the cerebral hemisphere as the forceps minor (see Fig. 7-15). E. The corpus callosum is related superiorly to the falx cerebri.
18. B is correct. When the anterior commissure is traced laterally, an anterior bundle of nerve fibers is seen to curve forward to join the olfactory tract. A. The anterior commissure is embedded in the superior part of the lamina terminalis (see Fig. 7-3). C. Some of the fibers of the anterior commissure are concerned with the sensation of smell. D. The anterior boundary of the interventricular foramen is formed by the anterior pillar of the fornix and not the anterior commissure (see Fig. 7-3). E. The anterior commissure is formed by a small bundle of nerve fibers.
19. C is correct. The internal capsule contains the corticobulbar and corticospinal fibers in the genu and the anterior part of the posterior limb (see Fig. 7-18). A. The internal capsule is continuous below with the crus cerebri of the midbrain (see Fig. 7-19). B. The internal capsule is bent around the lentiform nucleus and has an anterior limb, the genu, and a posterior limb (see Fig. 7-18). D. The internal capsule is related laterally to the lentiform nucleus (see Fig. 7-18). E. The internal capsule is continuous above with the coronal radiata (see Fig. 7-19).
20. B is correct. The corpus striatum is concerned with the control of muscular movement. A. The head of the caudate nucleus is attached to the lentiform nucleus (see Fig. 7-14). C. The lentiform nucleus is related laterally to the external capsule (see Fig. 7-12). D. The lentiform nucleus is wedge shaped, as seen on horizontal section (see Fig. 7-12). E. The amygdaloid nucleus forms one of the basal ganglia.
21. E is correct. The structure is the genu of the corpus callosum.
22. C is correct.
23. E is correct. The structure is the posterior horn of the lateral ventricle.
24. E is correct. The structure is the third ventricle.
25. E is correct. The structure is the anterior column of the fornix.
26. E is correct. The structure is the middle frontal gyrus.
27. A is correct.
28. B is correct.
29. D is correct.
30. E is correct. The structure is the lateral sulcus.
31. C is correct.
32. D is correct.
33. A is correct.
34. D is correct.

8 The Structure and Functional Localization of the Cerebral Cortex

CHAPTER OBJECTIVES

- To describe the basic structure and functional localization of the highly complex cerebral cortex
- To describe behavioral consequences from regional damage of the different cortical regions

A 19-year-old woman is involved in an automobile accident. She is not wearing a seat belt and is thrown from the car and suffers severe head injuries. During examination by the emergency medical technicians, she is found to be unconscious and is admitted to the emergency department. After 5 hours, she recovers consciousness and makes a remarkable recovery over the next 2 weeks. She leaves the hospital 1 month after the accident, with very slight weakness of her right leg. Nothing else abnormal is noted. Four months later, she is seen by a neurologist because she is experiencing sudden attacks of jerking movements of her right leg and foot. The attacks last only a few minutes. One week later, the patient has a very severe attack, which involves her right leg and then spreads to her right arm. On this occasion, she loses consciousness during the attack. The neurologist diagnoses Jacksonian epileptic seizures, caused by cerebral scarring secondary to the automobile injury. The weakness of the right leg immediately after the accident is due to damage to the superior part of the left precentral gyrus. Her initial attacks of epilepsy are of the partial variety and are caused by irritation of the area of the left precentral gyrus corresponding to the leg. In her last attack, the epileptiform seizure spreads to other areas of the left precentral gyrus, thus involving most of the right side of her body, and she loses consciousness. Knowledge of the functional localization of the cerebral cortex enables the physician to make an accurate diagnosis and advise suitable treatment. The cerebral scar tissue is cleanly excised by a neurosurgeon, and, apart from a small residual weakness of the right leg, the patient has no further epileptiform seizures. The cerebral cortex is the highest level of the central nervous system and always functions in association with the lower centers. The cerebral cortex receives vast amounts of information and responds in a precise manner by bringing about appropriate changes. Many of the responses are influenced by inherited programs, whereas others are colored by programs learned during an individual's life and stored in the cerebral cortex. The clinician can use this information to locate hemispheric lesions based on clinical symptoms and signs.

STRUCTURE

The cerebral cortex forms a complete covering of the cerebral hemisphere. It is composed of gray matter and has been estimated to contain approximately 10 billion neurons. The surface area of the cortex has been increased by throwing it into convolutions, or gyri, which are separated by fissures or sulci. The thickness of the cortex varies from 1.5 to 4.5 mm. The cortex is thickest over the crest of a gyrus and thinnest in the depth of a sulcus. The cerebral cortex, like gray matter elsewhere in the central nervous system, consists of a mixture of nerve cells, nerve fibers, neuroglia, and blood vessels. The following types of nerve cells are present in the cerebral cortex: (1) pyramidal cells, (2) stellate cells, (3) fusiform cells, (4) horizontal cells of Cajal, and (5) cells of Martinotti (Fig. 8-1).

Nerve Cells

The **pyramidal cells** are named from the shape of their cell bodies. Most of the cell bodies measure 10 to 50 μm long. However, giant pyramidal cells, also known as **Betz cells**, whose cell bodies measure as much as 120 μm, are found in the motor precentral gyrus of the frontal lobe.

The apices of the pyramidal cells are oriented toward the pial surface of the cortex. From the apex of each cell, a thick apical dendrite extends upward toward the pia, giving off collateral branches. From

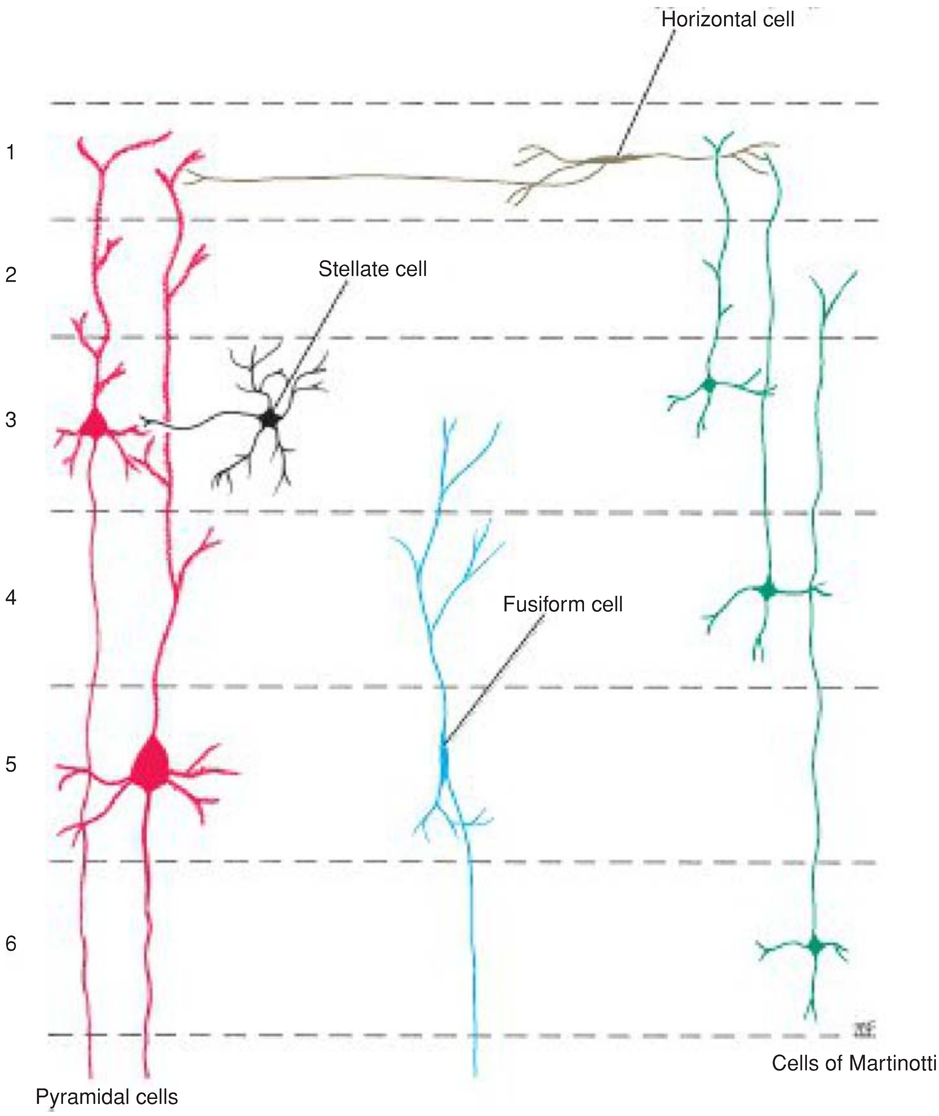


Figure 8-1 Main types of neurons found in the cerebral cortex.

the basal angles, several basal dendrites pass laterally into the surrounding neuropil. Each dendrite possesses numerous **dendritic spines** for synaptic junctions with axons of other neurons. The axon arises from the base of the cell body and either terminates in the deeper cortical layers or, more commonly, enters the white matter of the cerebral hemisphere as a projection, association, or commissural fiber.

The **stellate cells**, sometimes called granule cells because of their small size, are polygonal in shape, and their cell bodies measure about 8 µm in diameter. These cells have multiple branching dendrites and a relatively short axon, which terminates on a nearby neuron.

The **fusiform cells** have their long axis vertical to the surface and are concentrated mainly in the deepest cortical layers. Dendrites arise from each pole of the cell body. The inferior dendrite branches within the same cellular layer, while the superficial dendrite ascends toward the surface of the cortex and branches in the superficial layers. The axon arises from the inferior part of the cell body and enters the white matter as a projection, association, or commissural fiber.

The **horizontal cells of Cajal** are small, fusiform, horizontally oriented cells found in the most superficial layers of the cortex. A dendrite emerges from each end of the cell, and an axon runs parallel to the surface of the cortex, making contact with the dendrites of pyramidal cells.

The **cells of Martinotti** are small, multipolar cells that are present throughout the levels of the cortex. The cell has short dendrites, but the axon is directed toward the pial surface of the cortex, where it ends in a more superficial layer, commonly the most superficial layer. The axon gives origin to a few short collateral branches en route.

Nerve Fibers

The nerve fibers of the cerebral cortex are arranged both radially and tangentially (Figs. 8-2 and 8-3). The **radial fibers** run at right angles to the cortical surface.

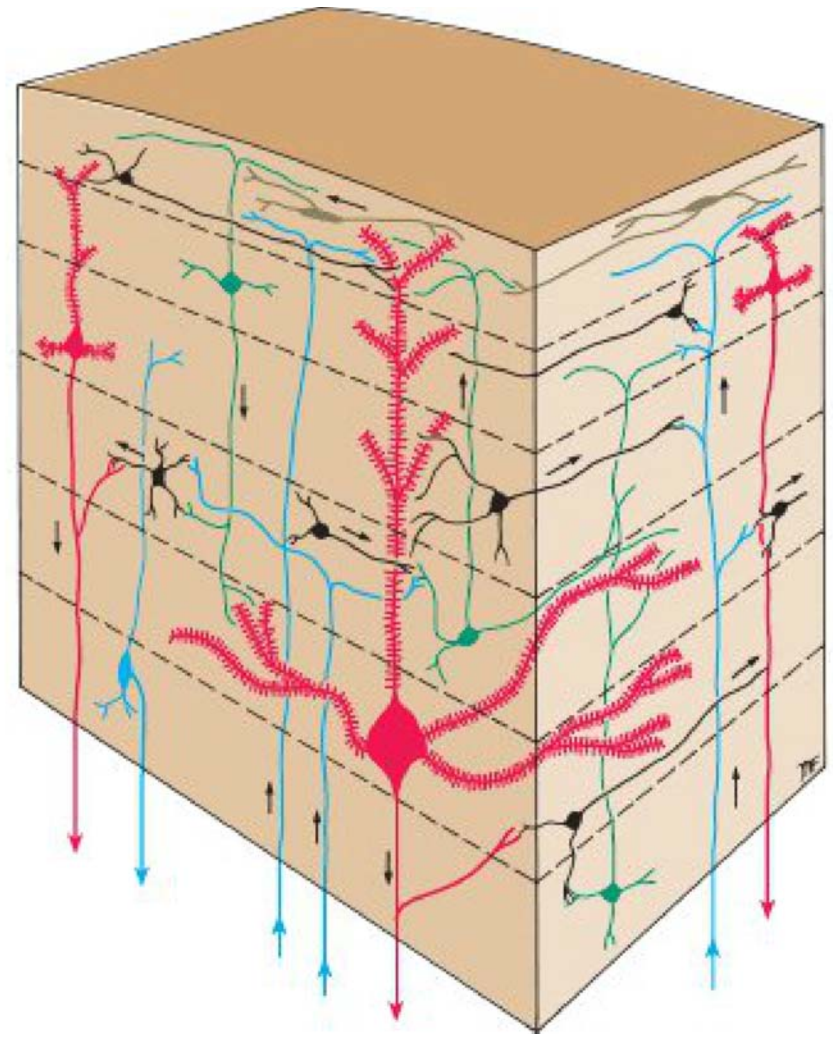


Figure 8-2 Neuronal connections of the cerebral cortex. Note the presence of the afferent and efferent fibers.

They include the afferent entering projection, association, and commissural fibers, which terminate within the cortex, and the axons of pyramidal, stellate, and fusiform cells, which leave the cortex to become projection, association, and commissural fibers of the white matter of the cerebral hemisphere.

The **tangential fibers** run parallel to the cortical surface and are, for the most part, collateral and terminal branches of afferent fibers. They also include the axons of horizontal and stellate cells and collateral branches of pyramidal and fusiform cells. The tangential fibers are most concentrated in layers 4 and 5, where they are referred to as the outer and inner **bands of Baillarger**, respectively. The bands of Baillarger are particularly well developed in the sensory areas due to the high concentration of the terminal parts of the thalamocortical fibers. In the visual cortex, the outer **band of Baillarger**, which is so thick that it can be seen with the naked eye, is known as the **stria of Gennari**. Because of this obvious band, or stria, the visual cortex in the walls of the calcarine sulcus is sometimes called the **striate cortex**.

Layers

Dividing the cerebral cortex into layers that may be distinguished by the type, density, and arrangement of their cells is convenient for descriptive purposes (see Figs. 8-1 and 8-3). The names and characteristic features of the layers are described here; regional differences are discussed later.

1. **Molecular layer (plexiform layer).** This is the most superficial layer; it consists mainly of a dense network of tangentially oriented nerve fibers. These fibers are derived from the apical dendrites of the pyramidal cells and fusiform cells, the axons of the stellate cells, and the cells of Martinotti. Afferent fibers originating in the thalamus and in association with commissural fibers also are present. Scattered among these nerve fibers are occasional horizontal cells of Cajal. This most superficial layer of the cortex clearly is where large numbers of synapses between different neurons occur.
2. **External granular layer.** This layer contains large numbers of small pyramidal cells and stellate cells.

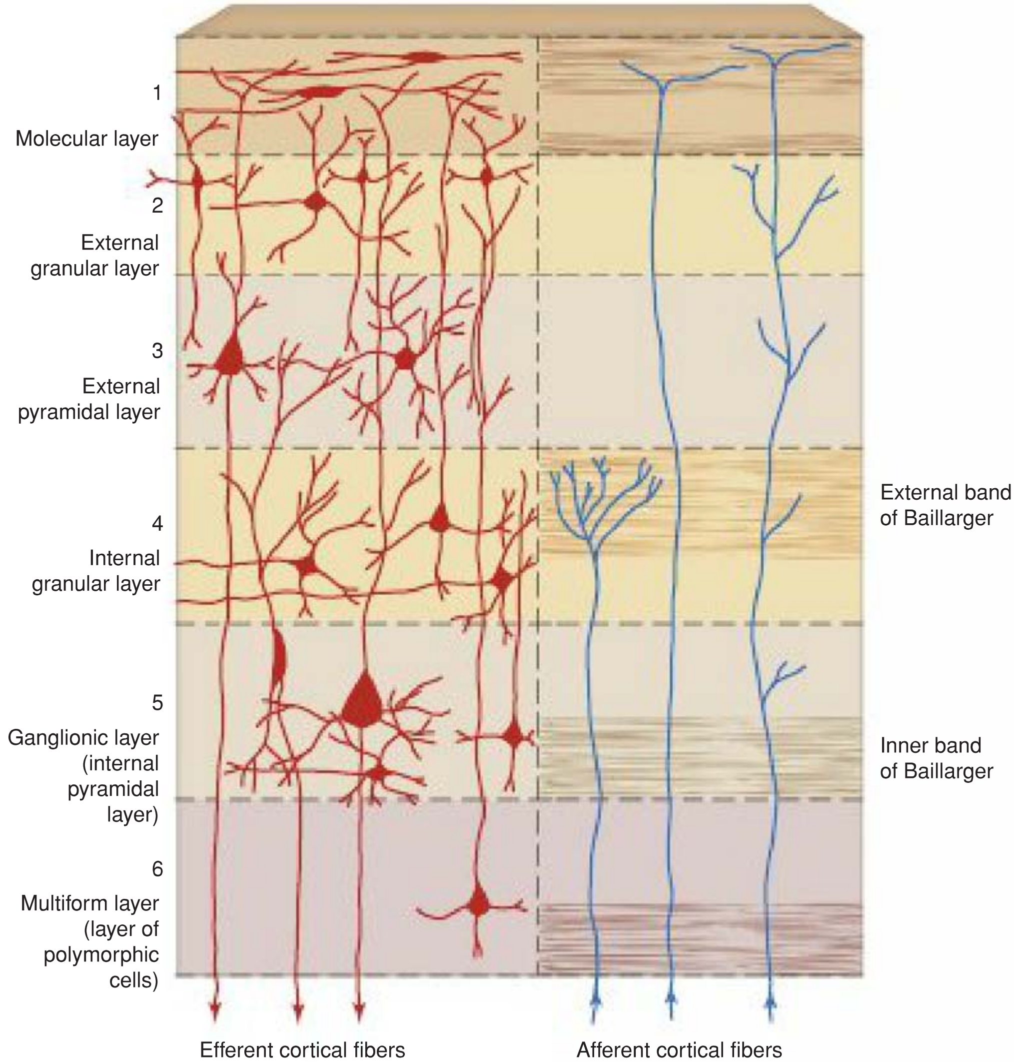


Figure 8-3 Layers of the cerebral cortex showing the neurons on the left and the nerve fibers on the right.

The dendrites of these cells terminate in the molecular layer, and the axons enter deeper layers, where they terminate or pass on to enter the white matter of the cerebral hemisphere.

3. **External pyramidal layer.** This layer is composed of pyramidal cells, whose cell body size increases from the superficial to the deeper borders of the layer. The apical dendrites pass into the molecular layer, and the axons enter the white matter as projection, association, or commissural fibers.
4. **Internal granular layer.** This layer is composed of closely packed stellate cells with a high concentration of horizontally arranged fibers known collectively as the **external band of Baillarger**.
5. **Ganglionic layer (internal pyramidal layer).** This layer contains very large and medium-size pyramidal cells. Scattered among the pyramidal cells are stellate cells and cells of Martinotti. In addition, a large number of horizontally arranged fibers form the **inner band of Baillarger** (see Fig. 8-3). In the motor cortex of the precentral gyrus, the pyramidal cells of this layer are very large and are known as Betz cells. These cells account for about 3% of the projection fibers of the **corticospinal** or **pyramidal tract**.
6. **Multiform layer (layer of polymorphic cells).** Although the majority of the cells are fusiform, many of the cells are modified pyramidal cells, whose cell bodies are triangular or ovoid. The cells of Martinotti also are conspicuous in this layer. Many nerve fibers are present that are entering or are leaving the underlying white matter.

Cortical Structure Variations

The system of numbering and nomenclature of the cortical layers used above is similar to that distinguished by Brodmann (1909). However, recognize that not all areas of the cerebral cortex possess six layers (see Fig. 8-3). Those areas of the cortex in which the basic six layers cannot be recognized are referred to as **heterotypical**, as opposed to the majority, which are **homotypical** and possess six layers. Two heterotypical areas are described: the granular and the agranular type.

In the **granular type**, the granular layers are well developed and contain densely packed stellate cells. Thus, layers 2 and 4 are well developed, and layers 3 and 5 are poorly developed, so layers 2 through 5 merge into a single layer of predominantly granular cells. These cells receive thalamocortical fibers. The granular type of cortex is found in the postcentral gyrus, in the superior temporal gyrus, and in parts of the hippocampal gyrus.

In the **agranular type** of cortex, the granular layers are poorly developed, so layers 2 and 4 are practically absent. The pyramidal cells in layers 3 and 5 are densely packed and are very large. The agranular type of cortex is found in the precentral gyrus and other areas in the frontal lobe. These areas give rise to large numbers of efferent fibers that are associated with motor function.

CORTICAL MECHANISMS

Extensive research in recent years involving electrophysiology, histochemistry, immunocytochemistry, and other microscopic techniques has resulted in a vast increase in our knowledge of the connections of the neurons of the cerebral cortex. This information combined with new methods of studying the functions of the human cerebral cortex in the living using electroencephalograms (EEGs), positron emission tomography (PET), and magnetic resonance imaging (MRI) have led to a new understanding of the functions of the different areas and the different layers of the cerebral cortex. Much of the new information, however, is still merely factual data and cannot be used in the clinical setting.

The cerebral cortex is organized into vertical units or columns of functional activity (see Fig. 8-2) measuring about 300 to 600 μm wide. In the sensory cortex, for example, each column serves a single specific sensory function. Such a functional unit extends through all six layers from the cortical surface to the white matter. Each unit possesses afferent fibers, internuncial neurons, and efferent fibers. An afferent fiber may synapse directly with an efferent neuron or may involve vertical chains of internuncial neurons. A single vertical chain of neurons may be involved in isolation, or the wave of excitation may spread to adjacent vertical chains through short axon granular cells. The horizontal cells of Cajal permit activation of vertical units that lie some distance away from the incoming afferent fiber. The spread of incoming information serving one sensory modality laterally from one column to an adjacent column, or to columns some distance away, may permit the individual to start the process of understanding the nature of the sensory input.

CORTICAL AREAS

Over the past century, clinicopathologic studies in humans and electrophysiologic and ablation studies in animals have produced evidence that different areas of the cerebral cortex are functionally specialized. However, the precise division of the cortex into different areas of specialization, as described by Brodmann, oversimplifies and misleads the reader. The simple division of cortical areas into motor and sensory is erroneous because many of the sensory areas are far more extensive than originally described and because motor responses can be obtained by stimulation of sensory areas. Until a satisfactory terminology has been devised to describe the various cortical areas, the main cortical areas will be named by their anatomical location.

Some of the main anatomical connections of the cerebral cortex are summarized in Table 8-1.

Frontal Lobe

The **precentral area** is situated in the precentral gyrus and includes the anterior wall of the central sulcus and the posterior parts of the superior, middle, and inferior frontal gyri; it extends over the superomedial border of the hemisphere into the paracentral lobule (Fig. 8-4). Histologically, the characteristic feature of this area is the almost complete absence of the granular layers and the prominence of the pyramidal nerve cells. The giant pyramidal cells of Betz, which can measure as much as 120 μm long and 60 μm wide, are concentrated most highly in the superior part of the precentral gyrus and the paracentral lobule; their numbers diminish as one passes anteriorly in the precentral gyrus or inferiorly toward the lateral fissure. The great majority of the corticospinal and corticobulbar fibers originate from the small pyramidal cells in this area. The number of Betz cells present is estimated to be between 25,000 and 30,000 and accounts for only about 3% of the corticospinal fibers. Notably, the postcentral gyrus and the second somatosensory areas, as well as the occipital and temporal lobes, give origin to descending tracts as well; they are involved in controlling the sensory input to the nervous system and are not involved in muscular movement.

The precentral area may be divided into posterior and anterior regions. The posterior region, which is referred to as the **motor area**, **primary motor area**, or Brodmann area 4, occupies the precentral gyrus extending over the superior border into the paracentral lobule. The anterior region is known as the **premotor area**, **secondary motor area**, or Brodmann area 6 and parts of areas 8, 44, and 45. It occupies the anterior part of the precentral gyrus and the posterior parts of the superior, middle, and inferior frontal gyri.

The primary motor area, if electrically stimulated, produces isolated movements on the opposite side of the body as well as contraction of muscle groups concerned with the performance of a specific movement. Although isolated ipsilateral movements do not occur, bilateral movements of the extraocular muscles, the muscles of the upper part of the face, the tongue, and the mandible, and the larynx and the pharynx do occur.

The movement areas of the body are represented in inverted form in the precentral gyrus (Fig. 8-5). Starting from below and passing superiorly are structures

Table 8-1 Main Anatomical Connections of the Cerebral Cortex

Function	Origin	Cortical Area	Destination
Sensory			
Somatosensory (most to contralateral side of body; oral to same side; pharynx, larynx, and perineum bilateral)	Ventral posterior lateral and ventral posterior medial nuclei of thalamus	Primary somesthetic area (B3, 1, and 2), posterior central gyrus	Secondary somesthetic area; primary motor area
Vision	Lateral geniculate body	Primary visual area (B17)	Secondary visual area (B18 and 19)
Auditory	Medial geniculate body	Primary auditory area (B41 and 42)	Secondary auditory area (B22)
Taste	Nucleus solitarius	Posterior central gyrus (B43)	
Smell	Olfactory bulb	Primary olfactory area; periamygdaloid and prepiriform areas	Secondary olfactory area (B28)
Motor			
Fine movements (most to contralateral side of body; extraocular muscles, upper face, tongue, mandible, larynx, bilateral)	Thalamus from cerebellum, basal ganglia; somatosensory area; premotor area	Primary motor area (B4)	Motor nuclei of brainstem and anterior horn cells of spinal cord; corpus striatum

B, Brodmann area.

involved in swallowing and the tongue, jaw, lips, larynx, eyelid, and brow. The next area is an extensive region for movements of the fingers, especially the thumb, hand, wrist, elbow, shoulder, and trunk. The movements of the hip, knee, and ankle are represented in the highest areas of the precentral gyrus; the movements of the toes are situated on the medial surface of the cerebral hemisphere in the paracentral lobule. The movements of the anal and vesical sphincters are also located in the paracentral lobule. The area of cortex controlling a particular movement is proportional to the skill involved in performing the movement and is unrelated to the mass of muscle participating in the movement.

Thus, the function of the primary motor area is to carry out the individual movements of different parts of the body. To assist in this function, it receives numerous afferent fibers from the premotor area, the sensory cortex, the thalamus, the cerebellum, and the basal ganglia. The primary motor cortex is not responsible for the design of the pattern of movement but is the final station for conversion of the design into execution of the movement.

The premotor area, which is wider superiorly than below and narrows down to be confined to the anterior part of the precentral gyrus, has no giant pyramidal cells of Betz. Electrical stimulation of the premotor area produces muscular movements similar to those obtained by stimulation of the primary motor area; however, stronger stimulation is necessary to produce the same degree of movement.

The premotor area receives numerous inputs from the sensory cortex, the thalamus, and the basal ganglia. The function of the premotor area is to store programs of motor activity assembled as the result of past experience. Thus, the premotor area programs the activity of the primary motor area. It is particularly involved in controlling coarse postural movements through its connections with the basal ganglia.

The **supplementary motor area** is situated in the medial frontal gyrus on the medial surface of the hemisphere and anterior to the paracentral lobule. Stimulation of this area results in movements of the contralateral limbs, but a stronger stimulus is necessary than when the primary motor area is stimulated. Removal of the supplementary motor area produces no permanent loss of movement.

The **frontal eye field** (see Fig. 8-4A) extends forward from the facial area of the precentral gyrus into the middle frontal gyrus (parts of Brodmann areas 6, 8, and 9). Electrical stimulation of this region causes conjugate movements of the eyes, especially toward the opposite side. The exact pathway taken by nerve fibers from this area is not known, but they are thought to pass to the superior colliculus of the midbrain. The superior colliculus is connected to the nuclei of the extraocular muscles by the reticular formation. The frontal eye field is considered to control voluntary scanning movements of the eye and is independent of visual stimuli. The involuntary following of moving objects by the eyes involves the visual area of the occipital cortex to which the frontal eye field is connected by association fibers.

The **motor speech area of Broca** is located in the inferior frontal gyrus between the anterior and ascending rami and the ascending and posterior rami of the lateral fissure (Brodmann areas 44 and 45). In the majority of

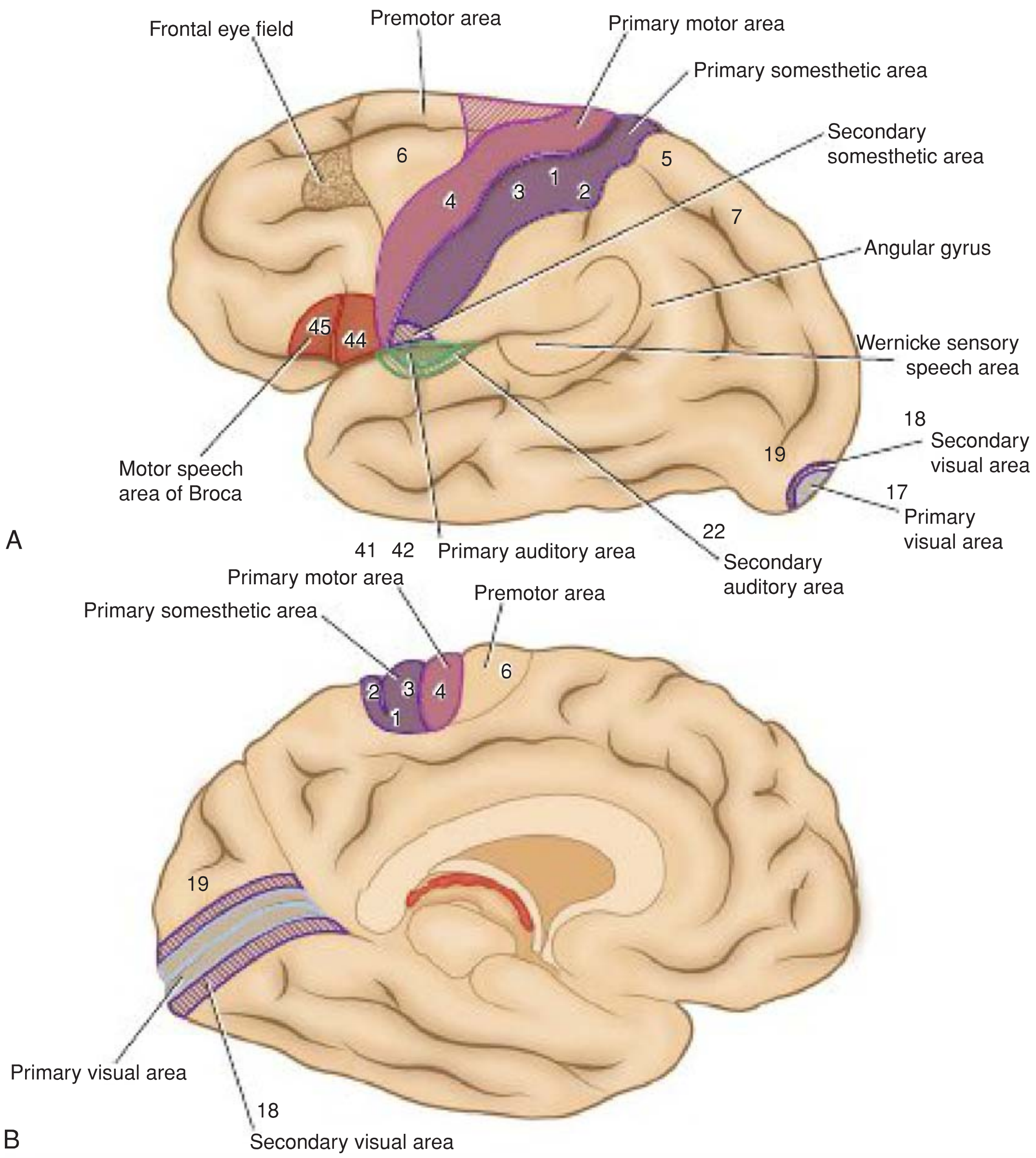


Figure 8-4 Functional localization of the cerebral cortex. **A:** Lateral view of the left cerebral hemisphere. **B:** Medial view of the left cerebral hemisphere.

individuals, this area is important on the left or dominant hemisphere, and ablation will result in paralysis of speech. In those individuals in whom the right hemisphere is dominant, the area on the right side is of importance. The ablation of this region in the nondominant hemisphere has no effect on speech.

The Broca speech area brings about the formation of words by its connections with the adjacent primary motor areas; the muscles of the larynx, mouth, tongue, soft palate, and the respiratory muscles are appropriately stimulated.

The **prefrontal cortex** is an extensive area that lies anterior to the precentral area. It includes the greater parts of the superior, middle, and inferior frontal gyri; the orbital gyri; most of the medial frontal gyrus; and the anterior half of the cingulate gyrus (Brodmann areas 9, 10, 11, and 12). Large numbers of afferent and efferent pathways connect the prefrontal area with other areas of the cerebral cortex, the thalamus, the hypothalamus, and the corpus striatum. The frontopontine fibers also connect this area to the cerebellum through the pontine nuclei. The commissural fibers of the forceps minor and genu of the corpus callosum unite these areas in both cerebral hemispheres.

The prefrontal area is concerned with the makeup of the individual's personality. As the result of the input from many cortical and subcortical sources, this area plays a role as a regulator of the person's depth of feeling. It also exerts its influence in determining the initiative and judgment of an individual.

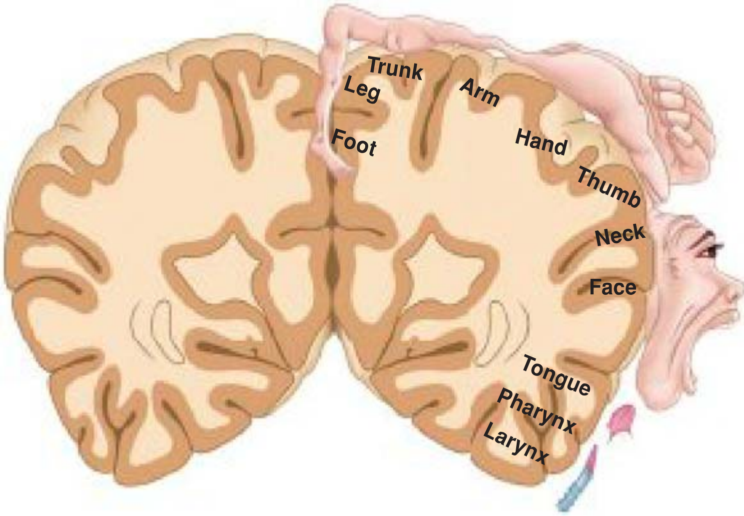


Figure 8-5 Motor homunculus on the precentral gyrus.

Parietal Lobe

The **primary somesthetic area** (primary somatic sensory cortex S1) occupies the postcentral gyrus (see Fig. 8-4) on the lateral surface of the hemisphere and the posterior part of the paracentral lobule on the medial surface (Brodmann areas 3, 1, and 2). Histologically, the anterior part of the postcentral gyrus is the area that borders the central sulcus (area 3), is granular in type, and contains only scattered pyramidal cells. The **outer layer of Baillarger** is broad and very obvious. The posterior part of the postcentral gyrus (areas 1 and 2) possesses fewer granular cells. The primary somesthetic areas of the cerebral cortex receive projection fibers from the ventral posterior lateral and ventral posterior medial nuclei of the thalamus. The opposite half of the body is represented as inverted. The pharyngeal region, tongue, and jaws are represented in the most inferior part of the postcentral gyrus; this is followed by the face, fingers, hand, arm, trunk, and thigh. The leg and the foot areas are found on the medial surface of the hemisphere in the posterior part of the paracentral lobule. The anal and genital regions are also found in this latter area. The apportioning of the cortex for a particular part of the body is related to its functional importance rather than to its size. The face, lips, thumb, and index finger have particularly large areas assigned to them. In fact, the size of the cortical area allocated to each part of the body is directly proportional to the number of sensory receptors present in that part of the body.

Although most sensations reach the cortex from the contralateral side of the body, some from the oral region go to the same side, and those from the pharynx, larynx, and perineum go to both sides. On entering the cortex, the afferent fibers excite the neurons in layer IV, and then the signals spread toward the surface of the cerebral unit and toward the deeper layers. From layer VI, large numbers of axons leave the cortex and pass to lower sensory relay stations of the thalamus, medulla oblongata, and the spinal cord, providing feedback. This sensory feedback is largely inhibitory and serves to modulate the intensity of the sensory input.

The anterior part of the postcentral gyrus situated in the central sulcus receives a large number of afferent fibers from muscle spindles, tendon organs, and joint receptors. This sensory information is analyzed in the vertical columns of the sensory cortex; it is then passed forward beneath the central sulcus to the primary motor cortex, where it greatly influences the control of skeletal muscle activity.

The **secondary somesthetic area** (secondary somatic sensory cortex S2) is in the superior lip of the posterior limb of the lateral fissure. The secondary sensory area is much smaller and less important than the primary sensory area. The face area lies most anterior, and the leg area is posterior. The body is bilaterally represented with the contralateral side dominant. The detailed connections of this area are unknown. Many sensory impulses come from the primary area, and many signals are transmitted from the brainstem. The functional significance of this area is not understood. It has been shown that the neurons respond particularly to transient cutaneous stimuli, such as brush strokes or tapping of the skin.

The **somesthetic association area** occupies the superior parietal lobule extending onto the medial surface of the hemisphere (Brodmann areas 5 and 7). This area has many connections with other sensory areas of the cortex, and its main function is probably to receive and integrate different sensory modalities. For example, it enables one to recognize objects placed in the hand without the help of vision. In other words, it not only receives information concerning the size and shape of an object but also relates this to past sensory experiences; thus, the information may be interpreted, and recognition may occur. A quarter placed in the hand can be distinguished from a dime or a nickel by the size, shape, and feel of the coin without having to use one's eyes.

Occipital Lobe

The **primary visual area** (Brodmann area 17) is situated in the walls of the posterior part of the calcarine sulcus and occasionally extends around the occipital pole onto the lateral surface of the hemisphere (see

Fig. 8-4). Macroscopically, this area can be recognized by the thinness of the cortex and the visual stria; microscopically, it is seen to be a granular type of cortex with only a few pyramidal cells present.

The visual cortex receives afferent fibers from the lateral geniculate body. The fibers first pass forward in the white matter of the temporal lobe and then turn back to the primary visual cortex in the occipital lobe. The visual cortex receives fibers from the temporal half of the ipsilateral retina and the nasal half of the contralateral retina. The right half of the field of vision, therefore, is represented in the visual cortex of the left cerebral hemisphere and vice versa. Note that the superior retinal quadrants (inferior field of vision) pass to the superior wall of the calcarine sulcus, while the inferior retinal quadrants (superior field of vision) pass to the inferior wall of the calcarine sulcus.

The macula lutea, which is the central area of the retina and the area for most perfect vision, is represented on the cortex in the posterior part of area 17 and accounts for one-third of the visual cortex. The visual impulses from the peripheral parts of the retina terminate in concentric circles anterior to the occipital pole in the anterior part of area 17.

The **secondary visual area** (Brodmann areas 18 and 19) surrounds the primary visual area on the medial and lateral surfaces of the hemisphere. This area receives afferent fibers from area 17 and other cortical areas as well as from the thalamus. The function of the secondary visual area is to relate the visual information received by the primary visual area to past visual experiences, thus enabling the individual to recognize and appreciate what he or she is seeing.

The **occipital eye field** is thought to exist in the secondary visual area in humans. Stimulation produces conjugate deviation of the eyes, especially to the opposite side. The function of this eye field is believed to be reflex and associated with movements of the eye when it is following an object. The occipital eye fields of both hemispheres are connected by nervous pathways and also are thought to be connected to the superior colliculus. By contrast, the frontal eye field controls voluntary scanning movements of the eye and is independent of visual stimuli.

Temporal Lobe

The **primary auditory area** (Brodmann areas 41 and 42) includes the gyrus of Heschl and is situated in the inferior wall of the lateral sulcus (see Fig. 8-4A). Area 41 is a granular type of cortex; area 42 is homotypical and is mainly an auditory association area.

Projection fibers to the auditory area arise principally in the medial geniculate body and form the **auditory radiation of the internal capsule**. The anterior part of the primary auditory area is concerned with the reception of sounds of low frequency, and the posterior part of the area is concerned with the sounds of high frequency. A unilateral lesion of the auditory area produces partial deafness in both ears, the greater loss being in the contralateral ear. This can be explained on the basis that the medial geniculate body receives fibers mainly from the organ of Corti of the opposite side as well as some fibers from the same side.

The **secondary auditory area** (auditory association cortex) is situated posterior to the primary auditory area in the lateral sulcus and in the superior temporal gyrus (Brodmann area 22). It receives impulses from the primary auditory area and from the thalamus. The secondary auditory area is thought to be necessary for the interpretation of sounds and for the association of the auditory input with other sensory information.

The **sensory** speech area of Wernicke is localized in the left dominant hemisphere, mainly in the superior temporal gyrus, with extensions around the posterior end of the lateral sulcus into the parietal region. The Wernicke area is connected to the Broca area by a bundle of nerve fibers called the **arcuate** fasciculus. It receives fibers from the visual cortex in the occipital lobe and the auditory cortex in the superior temporal gyrus. The Wernicke area permits understanding of written and spoken language and enables a person to read a sentence, understand it, and say it out loud (Figs. 8-6 and 8-7).

Because the Wernicke area represents the site on the cerebral cortex where somatic, visual, and auditory association areas all come together, it should be regarded as an area of very great importance.

Other Cortical Areas

The **taste area** is situated at the lower end of the postcentral gyrus in the superior wall of the lateral sulcus and in the adjoining area of the insula (Brodmann area 43). Ascending fibers from the nucleus solitarius probably ascend to the ventral posteromedial nucleus of the thalamus, where they synapse on neurons that send fibers to the cortex.

The **vestibular area** is believed to be situated near the part of the postcentral gyrus concerned with sensations of the face. Its location lies opposite the auditory area in the superior temporal gyrus. The vestibular area and the vestibular part of the inner ear are concerned with appreciation of the positions and movements of the head in space. Through its nerve connections, the movements of the eyes and the muscles of the trunk and limbs are influenced in the maintenance of posture.

The **insula** is an area of the cortex that is buried within the lateral sulcus and forms its floor (see Fig. 7-9). It can be examined only when the lips of the lateral sulcus are separated widely. Histologically, the posterior part is granular and the anterior part is agranular, thus resembling the adjoining cortical areas. Its fiber connections are incompletely known. This area is thought to be important for planning or coordinating the articulatory movements necessary for speech.

Association Cortex

The primary sensory areas with their granular cortex and the primary motor areas with their agranular cortex form only a small part of the total cortical surface area. The remaining areas have all six cellular layers

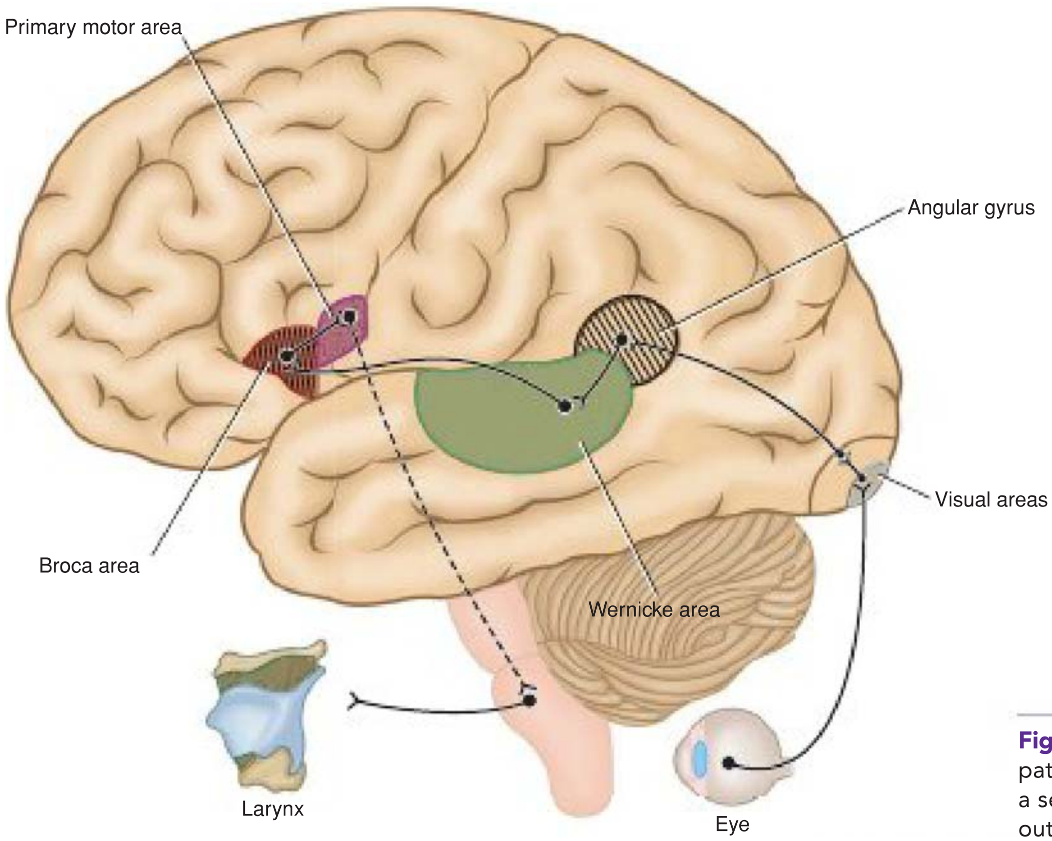


Figure 8-6 Probable nerve pathways involved in reading a sentence and repeating it out loud.

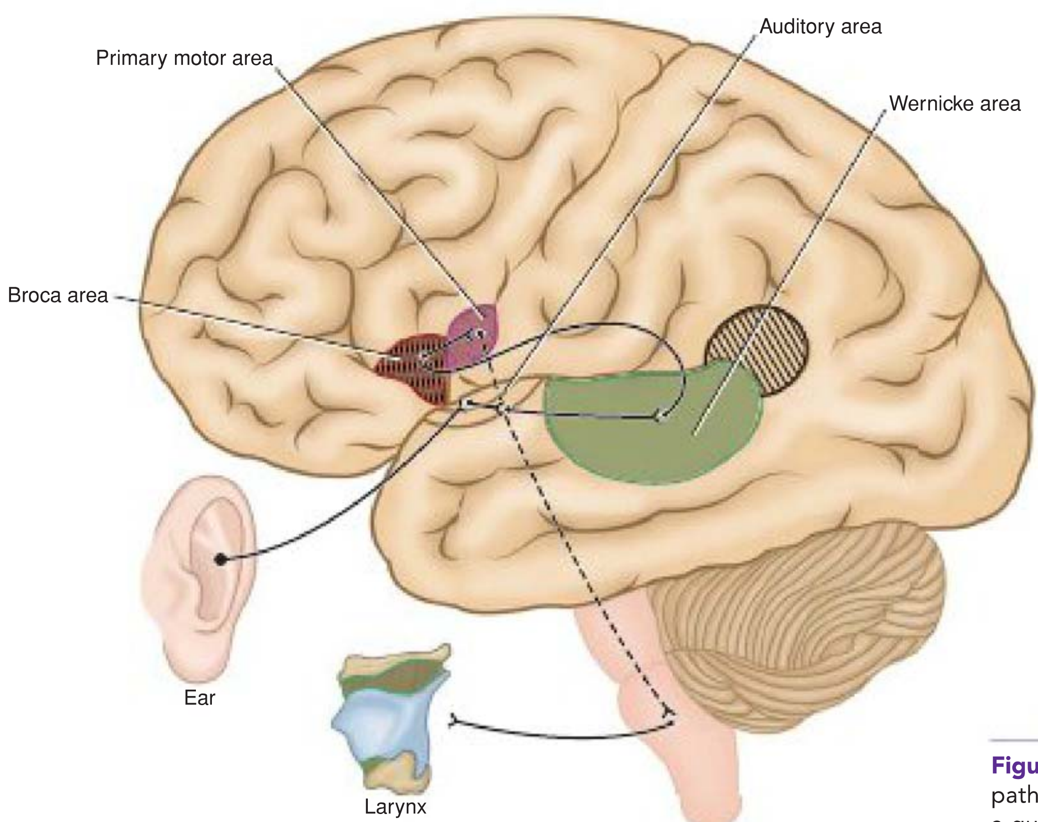


Figure 8-7 Probable nerve pathways involved with hearing a question and answering it.

and, therefore, are referred to as homotypical cortex. Classically, these large remaining areas were known as association areas, although precisely what they associate is not known. The original concept—that they receive information from the primary sensory areas that is to be integrated and analyzed in the association cortex and then fed to the motor areas—has not been established. As the result of clinical studies and animal experimentation, it has now become apparent that these areas of the cortex have multiple inputs and outputs and are very much concerned with behavior, discrimination, and interpretation of sensory experiences. Three main association areas are recognized: prefrontal, anterior temporal, and posterior parietal. The prefrontal cortex is discussed on page 291.

The anterior temporal cortex is thought to play a role in the storage of previous sensory experiences. Stimulation may cause the individual to recall objects seen or music heard in the past.

In the posterior parietal cortex, visual information from the posterior occipital cortex and the sensory input of touch and pressure and proprioception from the anterior parietal cortex is integrated into concepts of size, form, and texture. This ability is known as **stereognosis**. A conscious appreciation of the body image is also assembled in the posterior parietal cortex. The brain knows at all times where each part of the body is located in relation to its environment. This information is so important when performing body movements. The right side of the body is represented in the left hemisphere, and the left side of the body is represented in the right hemisphere.

CEREBRAL DOMINANCE

Anatomical examination of the two cerebral hemispheres shows that the cortical gyri and fissures are almost identical. Moreover, nervous pathways projecting to the cortex do so largely contralaterally and equally to identical cortical areas. In addition, the cerebral commissures, especially the corpus callosum and the anterior commissure, provide a pathway for information that is received in one hemisphere to be transferred to the other. Nevertheless, certain nervous activity is predominantly performed by one of the two cerebral hemispheres. Handedness, perception of language, and speech are functional areas of behavior that are controlled by the dominant hemisphere in most individuals. By contrast, spatial perception, recognition of faces, and music are interpreted by the nondominant hemisphere (Fig. 8-8).

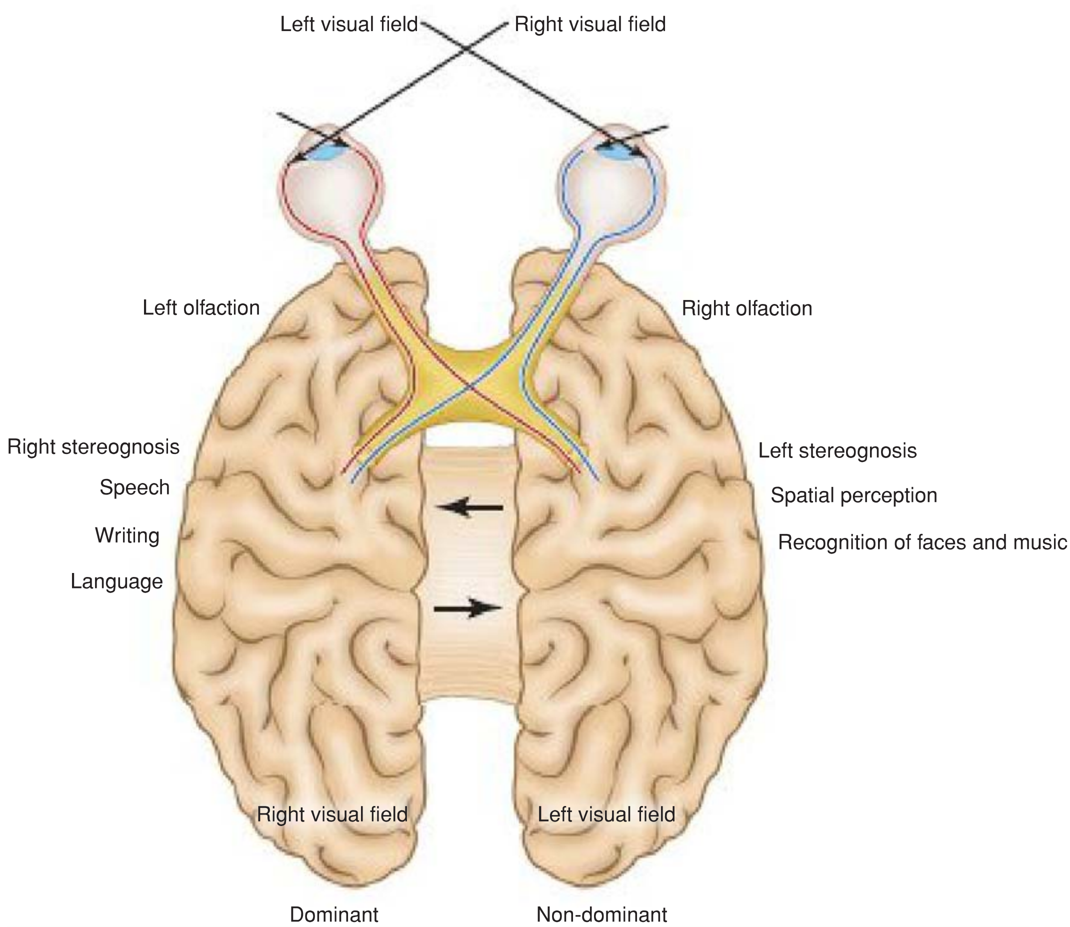


Figure 8-8 Nervous activities performed predominantly by dominant and nondominant hemispheres.

More than 90% of the adult population is right handed and, therefore, is left-hemisphere dominant. About 96% of the adult population is left-hemisphere dominant for speech.

In their work on human fetuses and neonates, Yakolev and Rakic have shown that more descending fibers in the left pyramid cross over the midline in the decussation than vice versa. This would suggest that the anterior horn cells on the right side of the spinal cord have a greater corticospinal innervation than those on the left side in most individuals, which might explain the dominance of the right hand.

Other researchers have shown that the speech area of the adult cortex is larger on the left than on the right, whereas the two hemispheres of the newborn are believed to have equipotential capabilities. During childhood, one hemisphere slowly comes to dominate the other, and only after the first decade does the dominance become fixed. This would explain why a 5-year-old child with damage to the dominant hemisphere can easily learn to become left-handed and speak well, whereas this is almost impossible in the adult.

Clinical Notes

General Considerations

The cerebral cortex should be regarded as the last receiving station involved along a line of stations receiving information from the eyes and ears and organs of general sensation. The function of the cortex is, in simple terms, to discriminate, and it relates the received information to past memories. The enriched sensory input is then presumably discarded, stored, or translated into action. In this whole process, interplay between the cortex and basal nuclei is provided by the many cortical and subcortical nervous connections.

Cerebral Cortex Lesions

In humans, the effect of destruction of different areas of the cerebral cortex has been studied by examining patients with lesions resulting from cerebral tumors, vascular accidents, surgery, or head injuries. Moreover, electrical recordings have been taken from different areas of the cortex during surgical exposure of the cerebral cortex or when stimulating different parts of the cortex in the conscious patient. One thing that has emerged from these studies is that the human cerebral cortex possesses, in a remarkable degree, the ability to reorganize the remaining intact cortex so that a certain amount of cerebral recovery is possible after brain lesions.

Motor Cortex

Lesions of the primary **motor cortex** in one hemisphere result in paralysis of the contralateral extremities, with the finer and more skilled movements suffering most. Destruction of the **primary motor area** (area 4) produces more severe paralysis than destruction of the **secondary motor area** (area 6). Destruction of both areas produces the most complete form of contralateral paralysis.

Lesions of the **secondary motor area** alone produce difficulty in the performance of skilled movements, with little loss of strength.

The **Jacksonian epileptic seizure** is due to an irritative lesion of the primary motor area (area 4). The convulsion begins in the part of the body represented in the primary motor area that is being irritated. The convulsive movement may be restricted to one part of the body, such as the face or the foot, or it may spread to involve many regions, depending on the spread of irritation of the primary motor area.

MUSCLE SPASTICITY

A discrete lesion of the primary motor cortex (area 4) results in little change in the muscle tone. However, larger lesions involving the primary and secondary motor areas (areas 4 and 6), which are the most common, result in muscle spasm. The explanation for this is that the primary motor cortex gives origin to corticospinal and corticonuclear tracts, and the secondary motor cortex gives origin to extrapyramidal tracts that pass to the basal ganglia and the reticular formation. The corticospinal and corticonuclear tracts tend to increase muscle tone, but the extrapyramidal fibers transmit inhibitory impulses that lower muscle tone (see pp. 167-168). Destruction of the secondary motor area removes the inhibitory influence, and consequently, the muscles are spastic.

Frontal Eye Field

Destructive lesions of the frontal eye field of one hemisphere cause the two eyes to deviate to the side of the lesion and an inability to turn the eyes to the opposite side. The involuntary tracking movement of the eyes when following moving objects is unaffected, because the lesion does not involve the visual cortex in the occipital lobe.

Irritative lesions of the frontal eye field of one hemisphere cause the two eyes to periodically deviate to the opposite side of the lesion.

Broca Motor Speech Area

Destructive lesions in the left inferior frontal gyrus result in the loss of ability to produce speech, that is, **expressive aphasia**. The patients, however, retain the ability to think the words they wish to say, they can write the words, and they can understand their meaning when they see or hear them.

Wernicke Sensory Speech Area

Destructive lesions restricted to the Wernicke speech area in the dominant hemisphere produce a loss of ability to understand the spoken and written word, that is, **receptive aphasia**. Since the Broca area is unaffected, speech is unimpaired, and the patient can produce fluent speech. However, the patient is unaware of the meaning of the words he or she uses and uses incorrect words or even nonexistent words. The patient is also unaware of any mistakes.

Motor and Sensory Speech Areas

Destructive lesions involving both the Broca and Wernicke speech areas result in loss of the production of speech and the understanding of the spoken and written word, that is, **global aphasia**.

Patients who have lesions involving the **insula** have difficulty in pronouncing phonemes in their proper order and usually produce sounds that are close to the target word but are not exactly correct.

Dominant Angular Gyrus

Destructive lesions in the angular gyrus in the posterior parietal lobe (often considered a part of the Wernicke area) divide the pathway between the visual association area and the anterior part of the Wernicke area. This results in the patient being unable to read (**alexia**) or write (**agraphia**).

Prefrontal Cortex

Destruction of the prefrontal region does not produce any marked loss of intelligence. It is an area of the cortex that is capable of associating experiences that are necessary for the production of abstract ideas, judgment, emotional feeling, and personality. Tumors or traumatic destruction of the prefrontal cortex result in the person's losing initiative and judgment. Emotional changes that occur include a tendency to euphoria. The patient no longer conforms to the accepted mode of social behavior and becomes careless of dress and appearance.

Prefrontal Cortex and Schizophrenia

The prefrontal cortex has a rich dopaminergic innervation. A failure of this innervation may be responsible for some of the symptoms of schizophrenia, which include important disorders of thought. PET scans have shown that the blood flow in the prefrontal cortex in schizophrenic patients challenged with executive type functions is much less than in normal individuals.

Frontal Leukotomy and Frontal Lobectomy

Frontal leukotomy (cutting the fiber tracts of the frontal lobe) and frontal lobectomy (removal of the frontal lobe) are surgical procedures that have been used to reduce the emotional responsiveness of patients with obsessive emotional states and intractable pain. The surgical technique was developed to remove the frontal association activity so that past experience is not recalled and the possibilities of the future are not considered; thus, introspection is lessened.

A patient suffering severe pain, such as may be experienced in the terminal stages of cancer, will still feel the pain following frontal lobectomy, but he or she will no longer worry about the pain and, therefore, will not suffer. It should be pointed out that the introduction of effective tranquilizing and mood-elevating drugs has made these operative procedures largely obsolete.

Sensory Cortex

The lower centers of the brain, principally the thalamus, relay a large part of the sensory signals to the cerebral cortex for analysis. The sensory cortex is necessary for the appreciation of spatial recognition, recognition of relative intensity, and recognition of similarity and difference.

Lesions of the **primary somesthetic area** of the cortex result in contralateral sensory disturbances, which are most severe in the distal parts of the limbs. Crude painful, tactile, and thermal stimuli often return, but this is believed to be due to the function of the thalamus. The patient remains unable to judge degrees of warmth, unable to localize tactile stimuli accurately, and unable to judge weights of objects. Loss of muscle tone may also be a symptom of lesions of the sensory cortex.

Lesions of the secondary somesthetic area of the cortex do not cause recognizable sensory defects.

Somesthetic Association Area

Lesions of the superior parietal lobule interfere with the patient's ability to combine touch, pressure, and proprioceptive impulses, so he or she is unable to appreciate texture, size, and form. This loss of integration of sensory impulses is called **astereognosis**. For example, with the eyes closed, the individual would be unable to recognize a key placed in the hand.

Destruction of the posterior part of the parietal lobe, which integrates somatic and visual sensations, will interfere with the appreciation of body image on the opposite side of the body. The individual may fail to recognize the opposite side of the body as his or her own. The patient may fail to wash it or dress it or to shave that side of the face or legs.

Primary Visual Area

Lesions involving the walls of the posterior part of one calcarine sulcus result in a loss of sight in the opposite visual field, that is, **crossed homonymous hemianopia**. Interestingly, the central part of the visual field is apparently normal when tested. This so-called macular sparing is probably due to the patient's shifting the eyes very slightly while the visual fields are being examined. The following clinical defects should be understood. Lesions of the upper half of one primary visual area—the area above the calcarine sulcus—result in **inferior quadrantic hemianopia**, whereas lesions involving one visual area below the calcarine sulcus result in **superior quadrantic hemianopia**. Lesions of the occipital pole produce central scotomas. The most common causes of these lesions are vascular disorders, tumors, and injuries from gunshot wounds.

Secondary Visual Area

Lesions of the secondary visual area result in a loss of ability to recognize objects seen in the opposite field of vision. The reason for this is that the area of cortex that stores past visual experiences has been lost.

Primary Auditory Area

Because the primary auditory area in the inferior wall of the lateral sulcus receives nerve fibers from both cochleae, a lesion of one cortical area will produce slight bilateral loss of hearing, but the loss will be greater in the opposite ear. The main defect noted is a loss of ability to locate the source of the sound. Bilateral destruction of the primary auditory areas causes complete deafness.

Secondary Auditory Area

Lesions of the cortex posterior to the primary auditory area in the lateral sulcus and in the superior temporal gyrus result in an inability to interpret sounds. The patient may experience **word deafness (acoustic verbal agnosia)**.

Cerebral Dominance and Cerebral Damage

Although both hemispheres are almost identical in structure, handedness, perception of language, speech, spatial judgment, and areas of behavior are controlled by one hemisphere and not the other in the majority of the adult population. About 90% of people are right-handed, and the control resides in the left hemisphere. The remainder are left-handed, and a few individuals are ambidextrous. In 96% of individuals, speech and understanding of spoken and written language are controlled by the left hemisphere. Thus, in most adults, the left cerebral hemisphere is dominant.

From a clinical point of view, the age at which cerebral dominance comes into effect is important. For example, when cerebral damage occurs before the child has learned to speak, speech usually develops and is maintained in the remaining intact hemisphere. This transference of speech control is much more difficult in older persons.

Cerebral Cortical Potentials

Electrical recordings taken from inside neurons of the cerebral cortex show a negative resting potential of about 60 mV. The action potentials overshoot the zero potential. Note that resting potential shows marked fluctuation, which is probably due to the continuous but variable reception of afferent impulses from other neurons. Spontaneous electrical activity can be recorded from the cortical surface rather than intracellularly; such recordings are known as **electrocorticograms**. Similar recordings can be made by placing the electrodes on the scalp. The result of this latter procedure is referred to as the **electroencephalogram**. The changes of electrical potential recorded usually are very small and in the order of 50 mV. Characteristically, three frequency bands may be recognized in the normal individual; they are referred to as **alpha**, **beta**, and **delta rhythms**. Abnormalities of the electroencephalogram may be of great value clinically in helping to diagnose cerebral tumors, epilepsy, and cerebral abscess. An electrically silent cortex indicates cerebral death.

Consciousness

A conscious person is awake and aware of himself or herself and the surroundings. For normal consciousness, active functioning of two main parts of the nervous system, the reticular formation (in the brainstem) and the cerebral cortex, is necessary. The reticular formation is responsible for the state of wakefulness. The cerebral cortex is necessary for the state of awareness, that is, the state in which the individual can respond to stimuli and interact with the environment. Eye opening is a brainstem function; speech is a cerebral cortex function. Drugs that produce unconsciousness, such as anesthetics, selectively depress the **reticular alerting mechanism**, while those that cause wakefulness have a stimulating effect on this mechanism.

A physician should be able to recognize the different signs and symptoms associated with different stages of consciousness, namely, **lethargy**, **stupor**, and **coma** (unconsciousness). In a lethargic individual, the speech is slow, and voluntary movement is diminished and slow. The movement of the eyes is slow. A stupored patient will speak only if stimulated with painful stimuli. The voluntary movements are nearly absent, the eyes are closed, and very little spontaneous eye movement occurs. A deeply stupored patient will not speak; severe pain will elicit mass movements of different parts of the body. The eyes will show even less spontaneous movement.

An unconscious patient will not speak and will respond only reflexly to painful stimuli, or not at all; the eyes are closed and do not move.

Clinicians commonly observe a patient with, for example, intracranial bleeding pass progressively from consciousness to lethargy, stupor, and coma, and then, if recovery occurs, pass in the reverse direction. For these altered states of unconsciousness to occur, the thalamocortical system and the reticular formation must be either directly involved bilaterally or indirectly affected by distortion or pressure.

Persistent Vegetative State

A person can have an intact reticular formation but a nonfunctioning cerebral cortex. That person is awake (i.e., the eyes are open and move around) and has sleep–wake cycles; however, the person has no awareness and, therefore, cannot respond to stimuli such as a verbal command or pain. This condition, known as a **persistent vegetative state**, is usually seen following severe head injuries or an anoxic cerebral insult. Unfortunately, the lay observer thinks the patient is "conscious."

To be wakeful without having awareness is possible; however, having awareness without wakefulness is not. The cerebral cortex requires the input from the reticular formation in order to function.

Sleep

Sleep is a changed state of consciousness. The pulse rate, respiratory rate, and blood pressure fall; the eyes deviate upward; the pupils contract but react to light; the tendon reflexes are lost; and the plantar reflex may become extensor. A sleeping person is not, however, unconscious, because he or she may be awakened quickly by the cry of a child, for example, even though he or she has slept through the background noise of an air-conditioner.

Sleep is facilitated by reducing the sensory input and by fatigue. This results in decreased activity of the reticular formation and the thalamocortical activating mechanism. Whether this decreased activity is a passive phenomenon or whether the reticular formation is actively inhibited is not known.

Epilepsy

Epilepsy is a symptom in which a sudden transitory disturbance of the normal physiology of the brain occurs, usually the cerebral cortex, that ceases spontaneously and tends to recur. The condition is usually associated with a disturbance of normal electrical activity and, in its most typical form, is accompanied by seizures. In partial seizures, the abnormality occurs in only one part of the brain and the patient does not lose consciousness. In generalized seizures, the abnormal activity involves large areas of the brain bilaterally, and the individual loses consciousness.

In some patients with generalized seizures, nonconvulsive attacks may occur, in which the patient suddenly stares blankly into space. This syndrome is referred to as **petit mal**. The majority of patients with generalized seizures have a sudden loss of consciousness, with accompanying tonic muscle spasm and clonic contraction as well as transient apnea and often loss of bowel and bladder control. The convulsions usually last from a few seconds to a few minutes.

In most patients with epilepsy, the cause is unknown. Some patients appear to have a hereditary predisposition; in a few patients, a local lesion, such as a cerebral tumor or scarring of the cortex following trauma, is the cause.

Key Concepts

Cerebral Cortex Structure

- The cerebral cortex forms a complete covering of the cerebral hemisphere. It is composed of gray matter thrown into convolutions, or gyri, to increase surface area.
- Pyramidal and fusiform cells are found in the cortex and have axons that either terminates in the deeper cortical layers, or more commonly, enters the white matter of the cerebral hemisphere as a projection, association, or commissural fiber.
- Stellate, horizontal, and cells of Martinotti typically terminate on dendrites or axons of cells found within other layers of the cortex.
- From superficial to deep, the six cortical layers are molecular, external granular, external pyramidal, internal granular, internal pyramidal, and multiform layers.

Cortical Areas

- Within each cerebral lobe, there are specialized regions of cortex with unique behavioral functions.

Frontal Lobe

- The precentral area of the frontal lobe can be divided into posterior and anterior regions. The posterior region, occupying the precentral gyrus, is referred to as the primary motor area because activation of the cells in this region results in isolated movements of muscles on the contralateral side of the body.
- The movement areas in the motor cortex are organized with the lower limb structures represented on the medial aspect of the gyrus and ascending to trunk, upper limb, and face, laterally on the gyrus.
- The supplementary motor area and frontal eye field are both associated with the middle frontal gyrus. The latter is associated with conjugate movements of the eyes.
- Broca area is responsible for speech production and is located in the inferior frontal gyrus; paralysis of this area results in speech paralysis.

Parietal Lobe

- The primary somesthetic (primary sensory) area occupies the postcentral gyrus of the parietal lobe. Sensations for parts of the body are organized in a somatotopic map beginning with feet on the medial most aspect of the gyrus and the head on the most lateral aspect of the gyrus.

Occipital Lobe

- The primary visual area is found within the cortex of the calcarine sulcus. This cortex receives afferent information from the lateral geniculate body, which received information from the retina.

Temporal Lobe

- The primary auditory area includes the gyrus of Heschl and is situated in the inferior wall of the lateral sulcus. The sensory speech area of Wernicke is localized in the left dominate hemisphere, in the superior temporal gyrus. This area permits the understanding of written and spoken language.

Clinical Problem Solving

1. During a pathology class, a student is shown a slide illustrating a particular form of cerebral tumor. A small area of the cerebral cortex is visible at the edge of the section. The instructor asks the student whether the tissue has been removed from a motor or sensory area of the cortex. What is the main difference in structure between the motor and sensory areas of the cerebral cortex?
2. A 43-year-old man is examined by a neurologist for a suspected brain tumor. The patient is tested for stereognosis, that is, the appreciation of form in three dimensions. With the patient's eyes closed, a hairbrush is placed in his right hand, and he is asked to recognize the object. He is unable to recognize the brush even after the neurologist moves the brush about in the patient's hand. On opening his eyes, the patient immediately recognizes the brush. (a) Name the area of the cerebral cortex likely to be diseased in this patient. (b) Do you think moving the object around in the patient's hand is necessary?
3. A 65-year-old man visits his physician because he notices that he has been dragging his right foot when walking for the past 3 weeks. On physical examination, he is found to have an increase in tone of the

flexor muscles of the right arm, and, when he walks, he tends to hold his right arm adducted and flexed. He also holds his right fist tightly clenched. On study of the patient's gait, he is seen to have difficulty in flexing his right hip and knee. Slight but definite weakness and increased tone of the muscles of the right leg is noted. As the patient walks, he moves his right leg in a semicircle and places his forefoot on the ground before the heel. Examination of the right shoe shows evidence of increased wear beneath the right toes. Given that this patient had a cerebrovascular lesion involving the cerebral cortex, which area of the cortex was involved to cause these symptoms?

4. While examining an unconscious patient, a clinician notes that when the patient's head is gently rotated to the right, the two eyes deviated to the left. On rotation of the patient's head to the left, the patient's eyes still look to the left. Which area of the cortex is likely to be damaged in this patient?
5. A 25-year-old soldier is wounded in combat by an explosive device. A small piece of shrapnel enters the right side of his skull over the precentral gyrus. Five years later, he is examined by a physician during a routine physical checkup and is found to have weakness of the left leg. The physician cannot detect any increase in muscle tone in his left leg. Explain why most patients with damage to the motor area of the cerebral cortex have spastic muscle paralysis, while a few patients retain normal muscle tone.
6. A distinguished neurobiologist gives a lecture on the physiology of the cerebral cortex to the freshman medical student class. After reviewing the structure of the different areas of the cerebral cortex and the functional localization of the cerebral cortex, he states that our knowledge of the cytoarchitecture of the human cerebral cortex has contributed very little to our understanding of the normal functional activity of the cerebral cortex. Do you agree with his statement? What do you understand by the term *vertical chain theory*?
7. An 18-year-old boy receives a gunshot wound that severely damages his left precentral gyrus. On recovering from the incident, he leaves the hospital with spastic paralysis of the right arm and leg. However, he still possesses some coarse voluntary movements of the right shoulder, hip, and knee. Explain the presence of these residual movements on the right side.
8. A 53-year-old professor and chairman of an anatomy department sustains a severe head injury while rock climbing. During the ascent of a crevasse, his companion's ice axe falls from his belt and struck the professor's head, causing a depressed fracture of the frontal bone. After convalescing from his accident, the professor returns to his position in the medical school, but faculty and the student body quickly notice that the professor's social behavior has changed dramatically. His lectures, although amusing, no longer have direction. Although previously a smartly dressed man, he now has an unkempt appearance. The organization of the department started to deteriorate rapidly. Finally, he is removed from office after urinating into the trash basket in one of the classrooms. Use your knowledge of neuroanatomy to explain the professor's altered behavior.
9. A 50-year-old woman with a cerebrovascular lesion is found to experience difficulty in understanding spoken speech, although she fully understands written speech. Which area of the cerebral cortex was damaged?
10. A 62-year-old man, on recovering from a stroke, is found to have difficulty in understanding written speech (alexia) but can easily understand spoken speech and written symbols. Which area of the cerebral cortex is damaged in this patient?
11. What is understood by the following terms: (a) *coma*, (b) *sleep*, and (c) *electroencephalogram*? Name three neurologic conditions in which the diagnosis may be assisted by an electroencephalogram.

Answers and Explanations to Clinical Problem Solving

1. The cerebral cortex is made up of six identifiable layers. In the motor cortex in the precentral gyrus, the second and fourth layers lack of granular cells, and the third and fifth layers in the somesthetic cortex in the postcentral gyrus lack of pyramidal cells. The motor cortex is thicker than the sensory cortex.
2. (a) The area likely to be diseased is the left parietal lobe with advanced destruction of the superior parietal lobule. This is the somesthetic association area, where the sensations of touch, pressure, and proprioception are integrated. (b) Yes, the patient must be allowed to finger the object so that these different sensations can be appreciated.
3. This patient had a cerebrovascular lesion involving the left precentral gyrus. The damage to the pyramidal cells that give origin to the corticospinal fibers was responsible for the right-sided paralysis. The increased tone of the paralyzed muscles was due to the loss of inhibition caused by involvement of the extrapyramidal fibers (see p. 290).
4. Destructive lesions of the frontal eye field of the left cerebral hemisphere caused the two eyes to deviate to the side of the lesion and an inability to turn the eyes to the opposite side. The frontal eye field is thought to control voluntary scanning movements of the eye and is independent of visual stimuli.
5. A small discrete lesion of the primary motor cortex results in little change in muscle tone. Larger lesions involving the primary and secondary motor areas, which are the most common, result in muscle spasm. The explanation for this is given on page 290.

6. The extensive histologic research of Brodmann, Campbell, Economo, and the Vogts has allowed the cerebral cortex to be divided into areas that have a different microscopic arrangement and different types of cells. These cortical maps are fundamentally similar, and the one proposed by Brodmann is used widely. Because the functional significance of many areas of the human cerebral cortex is not known, closely correlating structure with function has not been possible. In general, the motor cortices are thicker than the sensory cortices, and the motor cortex has less prominent second and fourth granular layers and has large pyramidal cells in the fifth layer. Other areas with a different structure may have similar functional roles. More recent studies using electrophysiologic techniques have indicated that dividing the cerebral cortex according to its thalamocortical projections is more accurate. The vertical chain mechanism of the cerebral cortex is fully described on page 283.
7. In this patient, the persistence of coarse voluntary movements of the right shoulder, hip, and knee joints can be explained on the basis that coarse postural movements are controlled by the premotor area of the cortex and the basal ganglia, and these areas were spared in this patient.
8. The professor's altered behavior was due to a severe lesion involving both frontal lobes of the cerebrum secondary to the depressed fracture of the frontal bone. While destruction of the prefrontal cortex does not cause a marked loss of intelligence, it does result in the individual losing initiative and drive, and often the patient no longer conforms to the accepted modes of social behavior.
9. The understanding of spoken speech requires the normal functioning of the secondary auditory area, which is situated posterior to the primary auditory area in the lateral sulcus and in the superior temporal gyrus. This area is believed to be necessary for the interpretation of sounds, and the information is passed on to the sensory speech area of Wernicke.
10. The understanding of written speech requires the normal functioning of the secondary visual area of the cerebral cortex, which is situated in the walls of the posterior part of the calcarine sulcus on the medial and lateral surfaces of the cerebral hemisphere. The function of the secondary visual area is to relate visual information received by the primary visual area to past visual experiences. This information is then passed on to the dominant angular gyrus and relayed to the anterior part of the Wernicke speech area (see p. 283).
11. (a) *Coma* is the term applied to an unconscious patient. The patient will not speak and will respond only reflexly to painful stimuli. Deeply comatose individuals will make no response. The eyes are closed and do not move. (b) *Sleep* is a changed state of consciousness; it is discussed on page 292. (c) An *electroencephalogram* is a recording of the electrical activity of the cerebral cortex made by placing electrodes on the scalp. Detection of abnormalities of the alpha, beta, and delta rhythms may assist in the diagnosis of cerebral tumors, epilepsy, and cerebral abscesses.

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 cerebral cortex:
   (a) The cerebral cortex is thinnest over the crest of a gyrus and thickest in the depth of a sulcus.
   (b) The largest giant pyramidal cells are found in the postcentral gyrus.
   (c) In the visual cortex, the outer band of Baillarger is thin and can only be seen under a microscope.
   (d) The molecular layer is the most superficial layer of the cerebral cortex and is composed of the small cell bodies of the granular cells.
   (e) From a functional point of view, the cerebral cortex is organized into vertical units of activity.
2. The following statements concern the precentral area of the frontal lobe of the cerebral cortex:
   (a) The anterior region is known as the *primary motor area*.
   (b) The primary motor area is responsible for skilled movements on the opposite side of the body.
   (c) The function of the primary motor area is to store programs of motor activity, which are conveyed to the premotor area for the execution of movements.
   (d) Individual skeletal muscles are represented in the primary motor area.
   (e) The area of cortex controlling a particular movement is not proportional to the skill involved.
3. The following statements concern the motor speech area of Broca:
   (a) In most individuals, this area is important on the left or dominant hemisphere.
   (b) The Broca speech area brings about the formation of words by its connections with the secondary motor area.
   (c) It is not connected to the sensory speech area of Wernicke.
   (d) It is located in the superior frontal gyrus between the anterior and ascending rami and

the ascending and posterior rami of the lateral fissure.
(e) Brodmann areas 34 and 35 represent the motor speech area.

4. The following statements concern the primary somesthetic area:
   (a) It occupies the lower part of the precentral gyrus.
   (b) Histologically, it contains large numbers of pyramidal cells and few granular cells.
   (c) The opposite half of the body is represented inverted.
   (d) Although most sensations reach the cortex from the contralateral side of the body, sensations from the hand go to both sides.
   (e) The area extends onto the anterior part of the paracentral lobule.
5. The following statements concern the visual areas of the cortex:
   (a) The primary visual area is located in the walls of the parieto-occipital sulcus.
   (b) The visual cortex receives afferent fibers from the medial geniculate body.
   (c) The right half of the visual field is represented in the visual cortex of the right cerebral hemisphere.
   (d) The superior retinal quadrants pass to the inferior portion of the visual cortex.
   (e) The secondary visual area (Brodmann areas 18 and 19) is surrounded by the primary visual area on the medial and lateral surfaces of the hemisphere.
6. The following statements concern the superior temporal gyrus:
   (a) The primary auditory area is situated in the inferior wall of the lateral sulcus.
   (b) The main projection fibers to the primary auditory area arise from the thalamus.
   (c) The sensory speech area of Wernicke is localized in the inferior temporal gyrus in the dominant hemisphere.
   (d) A unilateral lesion of the auditory area produces complete deafness in both ears.
   (e) The secondary auditory area is sometimes referred to as Brodmann areas 41 and 42.
7. The following statements concern the association areas of the cerebral cortex:
   (a) They form a small area of the cortical surface.
   (b) The prefrontal area is concerned with the makeup of the individual's personality.
   (c) They are concerned with the interpretation of motor experiences.
   (d) Appreciation of the body image is assembled in the anterior parietal cortex, and the right side of the body is represented in the left hemisphere.
   (e) The association areas have only four layers of cortex.
8. The following statements concern cerebral dominance:
   (a) The cortical gyri of the dominant and nondominant hemispheres are arranged differently.
   (b) More than 90% of the adult population is right-handed and, therefore, is left-hemisphere dominant.
   (c) About 96% of the adult population is right-hemisphere dominant for speech.
   (d) The nondominant hemisphere interprets handedness, perception of language, and speech.
   (e) After puberty, the dominance of the cerebral hemispheres becomes fixed.

Matching Questions. Directions: The following questions apply to Figure 8-9. Match the numbers listed on the left with the most likely words designating lettered

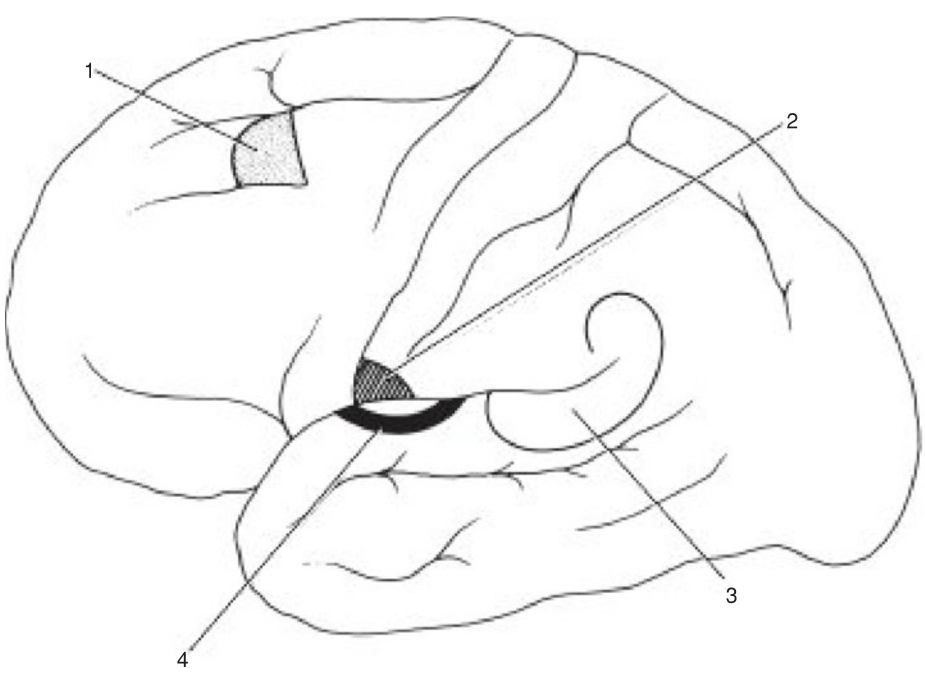


Figure 8-9 Lateral view of the left cerebral hemisphere.

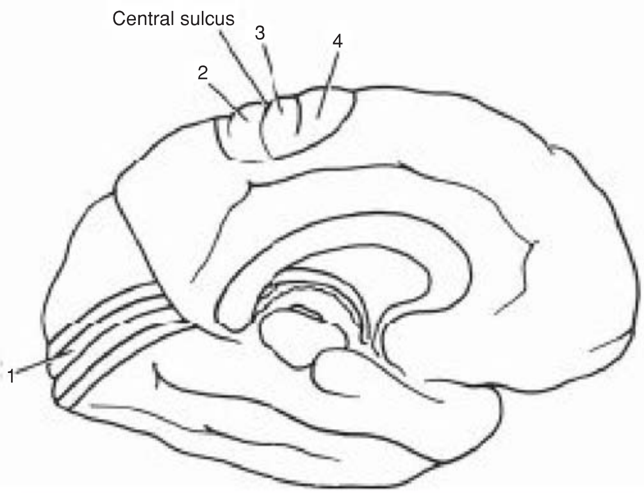


Figure 8-10 Medial view of the left cerebral hemisphere.

functional areas of the cerebral cortex listed on the right. Each lettered option may be selected once, more than once, or not at all.

9. Number 1
10. Number 2
11. Number 3
12. Number 4

(a) Primary motor area
(b) Secondary auditory area
(c) Frontal eye field
(d) Primary somesthetic area
(e) None of the above

The following questions apply to Figure 8-10. Match the numbers listed on the left with the most likely lettered words designating functional areas of the cerebral cortex listed on the right. Each lettered option may be selected once, more than once, or not at all.

13. Number 1
14. Number 1
15. Number 1
16. Number 1

(a) Premotor area
(b) Primary somesthetic area
(c) Primary visual area
(d) Primary motor area
(e) None of the above

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

A 54-year-old woman was seen by a neurologist because her sister had noticed a sudden change in her behavior. On questioning, the patient stated that after waking up from a deep sleep about a week ago, she noticed that the left side of her body did not feel as if it belonged to her. Later, the feeling worsened, and she became unaware of the existence of her left side. Her sister told the neurologist that the patient now neglects to wash the left side of her body.

17. The neurologist examined the patient and found the following most likely signs **except**:
    (a) The patient did not look toward her left side.
    (b) She readily reacted to sensory stimulation of her skin on the left side.
    (c) On being asked to move her left leg, she promptly did so.
    (d) Muscular weakness of the upper and lower limbs on the left side was evident.
    (e) On being asked to walk across the examining room, she tended not to use her left leg as much as her right leg.
18. The neurologist made the following likely conclusions **except**:
    (a) The diagnosis of left hemiasomatognosia (loss of appreciation of the left side of the body) was made.
    (b) This condition probably resulted from a lesion of the left parietal lobe.
    (c) In addition, the patient exhibited left hemiakinesia (unilateral motor neglect).
    (d) A lesion was likely in areas 6 and 8 of the medial and lateral premotor regions of the right frontal lobe.
    (e) The failure to look toward the left side (visual extinction) suggested a lesion existed in the right parieto-occipital lobes.

Answers and Explanations to Review Questions

1. E is correct. From a functional standpoint, the cerebral cortex is organized into vertical units of activity. A. The cerebral cortex is thickest over the crest of a gyrus and thinnest in the depth of a sulcus. B. The largest giant pyramidal cells are found in the precentral gyrus (see Fig. 8-1). C. In the visual cortex, the outer band of Baillarger is so thick that it can be seen with the naked eye (see Fig. 8-3). D. The molecular layer is the most superficial layer of the cerebral cortex and is composed mainly of a dense network of tangentially oriented nerve fibers (see Fig. 8-2).
2. B is correct. The primary motor area of the frontal lobe is responsible for skilled movements on the opposite side of the body. A. In the frontal lobe of the cerebral hemisphere, the posterior region is known as the primary motor area (see Fig. 8-4). C. The function of the premotor area is to store programs of motor activity, which are conveyed to the primary motor area for the execution of movements. D. The individual skeletal muscles are not represented in the primary motor area. E. The area of cerebral cortex controlling a particular movement is proportional to the skill of the movement.
3. A is correct. In most individuals, the speech area of Broca is important on the left or dominant hemisphere. B. The Broca speech area brings about the formation of words by its connections with the primary motor area. C. The Broca speech area is connected to the sensory speech area of Wernicke. D. The speech area of Broca is in the inferior frontal gyrus between the anterior and ascending rami

and the ascending and posterior rami of the lateral fissure (see Fig. 8-4). E. Brodmann areas 44 and 45 represent the motor speech area (see Fig. 8-4).

4. C is correct. In the primary somesthetic area, the opposite half of the body is represented inverted. A. The primary somesthetic area occupies the postcentral gyrus (see Fig. 8-4). B. Histologically, the primary somesthetic area contains large numbers of granular cells and few pyramidal cells. D. Most sensations from different parts of the body reach the cortex from the contralateral side of the body; those from the hand also only go to the contralateral side. E. The primary somesthetic area extends onto the posterior part of the paracentral lobule (see Fig. 8-4).
5. D is correct. The superior retinal quadrants pass to the inferior portion of the visual cortex. A. The primary visual cortex is located in the walls of the posterior part of the calcarine sulcus (see Fig. 8-4). B. The visual cortex receives afferent fibers from the lateral geniculate body. C. The right half of the visual field is represented in the visual cortex of the left cerebral hemisphere. E. The secondary visual area (Brodmann areas 18 and 19) surrounds the primary visual area on the medial and lateral surfaces of the hemisphere (see Fig. 8-4).
6. A is correct. The primary auditory area is situated in the inferior wall of the lateral sulcus (see Fig. 8-4). B. The main projection fibers to the primary auditory area arise from the medial geniculate body. C. The sensory speech area of Wernicke is localized in the superior temporal gyrus in the dominant hemisphere (see Fig. 8-4). D. A unilateral lesion of the auditory area produces partial deafness in both ears. E. The primary auditory area is sometimes referred to as Brodmann areas 41 and 42.
7. B is correct. The prefrontal area is concerned with the makeup of the individual's personality. A. The association areas of the cerebral cortex form a large area of the cortical surface. C. The association areas are concerned with the interpretations of sensory experiences. D. Appreciation of the body image is assembled in the posterior parietal cortex, and the right side of the body is represented in the left hemisphere. E. The association areas have all six cellular layers and are referred to as *homotypical cortex*.
8. B is correct. More than 90% of the adult population is right-handed and, therefore, is left-hemisphere dominant. A. The cortical gyri of the dominant and nondominant hemispheres are arranged in the same way. C. About 96% of the adult population is left-hemisphere dominant for speech. D. The nondominant hemisphere interprets spatial perception, recognition of faces, and music. E. After the first decade of life, the dominance of the cerebral hemispheres becomes fixed.

The answers for Figure 8-9, which shows the lateral view of the left cerebral hemisphere, are as follows:

9. C is correct; 1 is the frontal eye field.
10. E is correct; 2 is the secondary somesthetic area (see Fig. 8-4).
11. E is correct; 3 is the Wernicke sensory speech area (see Fig. 8-4).
12. B is correct; 4 is the secondary auditory area (see Fig. 8-4).

The answers for Figure 8-10, which shows the medial view of the left cerebral hemisphere, are as follows:

13. C is correct; 1 is the primary visual area (see Fig. 8-4).
14. B is correct; 2 is the primary somesthetic area (see Fig. 8-4).
15. D is correct; 3 is the primary motor area (see Fig. 8-4).
16. A is correct; 4 is the premotor area (see Fig. 8-4).
17. D is correct. The patient exhibited no weakness of her muscles on the left side despite the fact that her sister stated that she tended not to use her left leg.
18. B is correct. An MRI revealed a tumor in the right parieto-occipital lobes; a further lesion was present in the right frontal lobe.

9 Reticular Formation and Limbic System

CHAPTER OBJECTIVE

- To provide a brief overview of the structure and function of the reticular formation
- To present the parts of the limbic system and its functions

A 24-year-old medical student is rushed by ambulance to the emergency department after an accident on his motorcycle. On examination, he is found to be unconscious and shows evidence of severe injury to the right side of his head. He fails to respond when spoken to, and he does not make any response to deep painful pressure applied over his supraorbital nerve. The plantar reflex is extension, and the corneal, tendon, and pupillary reflexes are absent. The patient is clearly in a deep coma. Further neurologic examination reveals nothing that might add to the diagnosis. A computed tomography scan shows a large depressed fracture of the right parietal bone of the skull.

After a week in the intensive care unit, the patient's condition changes. He suddenly shows signs of being awake but not aware of his environment or inner needs. To the delight of his family, he follows them with his eyes and responds in a limited manner to primitive postural and reflex movements; he does not, however, speak and does not respond to commands. Although he has sleep–wake cycles, he does not respond appropriately to pain. The patient's neurologic condition is unchanged 6 months later.

The neurologist determines that the patient is awake but not aware of his surroundings. He explains to the family that the part of the brain referred to as the *reticular formation* in the brainstem had survived the accident and is responsible for the patient apparently being awake and able to breathe without assistance. However, because his cerebral cortex is dead, the patient will remain in this vegetative state.

Not very long ago, the reticular system was believed to be a vague network of nerve cells and fibers occupying the central core of the brainstem with no particular function. Today, it is known to play a key role in many important activities of the nervous system.

Limbic system was a term loosely used to describe the part of the brain between the cerebral cortex and the hypothalamus, a little understood area of the brain. Today, it is known to play a vital role in emotion, behavior, drive, and memory.

RETICULAR FORMATION

The reticular formation, as its name suggests, resembles a net (reticular) that is made up of nerve cells and nerve fibers. The net extends up through the axis of the central nervous system (CNS) from the spinal cord to the cerebrum. It is strategically placed among the important nerve tracts and nuclei. It receives input from most of the sensory systems and has efferent fibers that descend and influence nerve cells at all CNS levels. The exceptionally long dendrites of the neurons of the reticular formation permit input from widely placed ascending and descending pathways. Through its many connections, it can influence skeletal muscle activity, somatic and visceral sensations, the autonomic and endocrine systems, and even the level of consciousness.

General Arrangement

The reticular formation consists of a deeply placed continuous network of nerve cells and fibers that extend from the spinal cord through the medulla, the pons, the midbrain, the subthalamus, the hypothalamus, and the thalamus. The diffuse network may be divided into three longitudinal columns: the first occupying the median plane, called the **median column**, and consisting of intermediate-size neurons; the second, called the **medial column**, containing large neurons; and the third, or **lateral column**, containing mainly small neurons (Fig. 9-1).

With classic neuronal staining techniques, the groups of neurons are poorly defined; therefore, tracing an anatomical pathway through the network is difficult. However, with the new techniques of neurochemistry

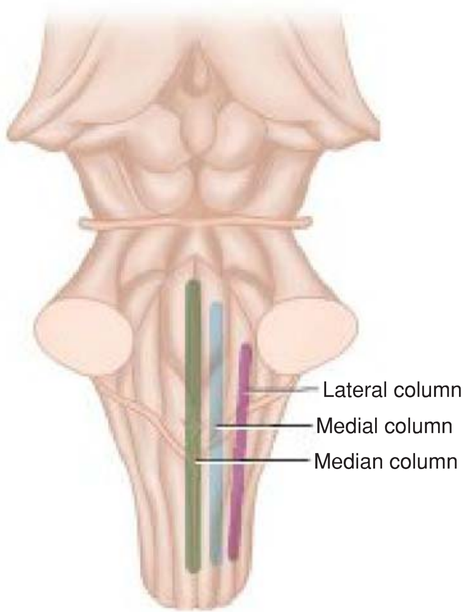


Figure 9-1 Diagram showing the approximate positions of the median, medial, and lateral columns of the reticular formation in the brainstem.

and cytochemical localization, the reticular formation is shown to contain highly organized groups of transmitter-specific cells that can influence functions in specific CNS areas. The monoaminergic groups of cells, for example, are located in well-defined areas throughout the reticular formation.

Polysynaptic pathways exist, and both crossed and uncrossed ascending and descending pathways are present, involving many neurons that serve both somatic and visceral functions.

Inferiorly, the reticular formation is continuous with the interneurons of the gray matter of the spinal cord, while superiorly, impulses are relayed to the cerebral cortex; a substantial projection of fibers also leaves the reticular formation to enter the cerebellum.

Afferent Projections

Many different afferent pathways project onto the reticular formation from most parts of the CNS (Fig. 9-2). Spinoreticular and spinothalamic tracts and the medial lemniscus project from the spinal cord. Ascending afferent tracts including the vestibular, acoustic, and visual pathways project from the cranial nerve nuclei. The cerebelloreticular pathway projects from the cerebellum,

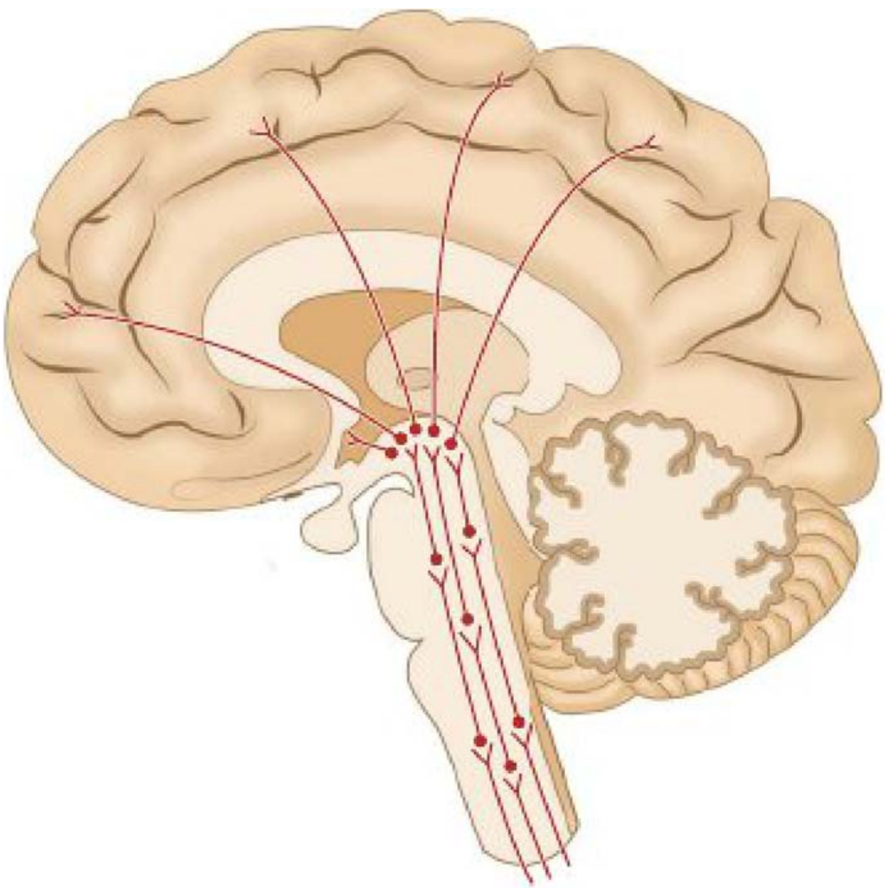


Figure 9-2 Diagram showing the afferent fibers of the reticular formation.

and further afferent tracts project from the subthalamic, hypothalamic, and thalamic nuclei and from the corpus striatum and limbic system. Other important afferent fibers arise in the primary motor cortex of the frontal lobe and from the somesthetic cortex of the parietal lobe.

Efferent Projections

Multiple efferent pathways extend down to the brainstem and spinal cord through the reticulobulbar and reticulospinal tracts to neurons in the motor nuclei of the cranial nerves and the anterior horn cells of the spinal cord. Other descending pathways extend to the sympathetic outflow and the craniosacral parasympathetic outflow of the autonomic nervous system (ANS). Additional pathways extend to the corpus striatum, the cerebellum, the red nucleus, the substantia nigra, the tectum, and the nuclei of the thalamus, subthalamus, and hypothalamus. Most regions of the cerebral cortex receive efferent fibers as well.

Functions

Given the vast number of connections of the reticular formation to all parts of the nervous system, not surprisingly, it serves many functions. A few of the more important functions are considered here.

1. **Control of skeletal muscle.** Through the reticulospinal and reticulobulbar tracts, the reticular formation can influence the activity of the α and γ motor neurons. Thus, the reticular formation can modulate muscle tone and reflex activity. It can also bring about reciprocal inhibition; for example, when the flexor muscles contract, the antagonistic extensors relax. The reticular formation, assisted by the vestibular apparatus of the inner ear and the vestibular spinal tract, plays an important role in maintaining the tone of the antigravity muscles when standing. The so-called respiratory centers of the brainstem, described by neurophysiologists as being in the control of the respiratory muscles, are now considered part of the reticular formation.
2. **Control of facial expression muscles.** The reticular formation is important in controlling the muscles of facial expression when associated with emotion. For example, when a person smiles or laughs in response to a joke, the motor control is provided by the reticular formation on both sides of the brain. The descending tracts are separate from the corticobulbar fibers. This means that a person who has suffered a stroke that involves the corticobulbar fibers and exhibits facial paralysis on the lower part of the face is still able to smile symmetrically (see Fig. 11-25).
3. **Control of somatic and visceral sensations.** By virtue of its central location in the cerebrospinal axis, the reticular formation can influence all ascending pathways that pass to supraspinal levels. The influence may be facilitative or inhibitory. In particular, the reticular formation may have a key role in the "gating mechanism" for the control of pain perception (see p. 146).
4. **Control of the ANS.** Higher control of the ANS, from the cerebral cortex, hypothalamus, and other subcortical nuclei, can be exerted by the reticulobulbar and reticulospinal tracts, which descend to the sympathetic outflow and the parasympathetic craniosacral outflow.
5. **Control of the endocrine system.** Either directly or indirectly through the hypothalamic nuclei, the reticular formation can influence the synthesis or release of releasing or release-inhibiting factors and thereby control the activity of the hypophysis cerebri.
6. **Influence on biologic clocks.** By means of its multiple afferent and efferent pathways to the hypothalamus, the reticular formation probably influences the biologic rhythms.
7. **Reticular activating system.** Arousal and the level of consciousness are controlled by the reticular formation. Multiple ascending pathways carrying sensory information to higher centers are channeled through the reticular formation, which, in turn, projects this information to different parts of the cerebral cortex, causing a sleeping person to awaken. In fact, state of consciousness is now thought to be dependent on the continuous projection of sensory information to the cortex. Different degrees of wakefulness seem to depend on the degree of activity of the reticular formation. Incoming pain sensations strongly increase the activity of the reticular formation, which, in turn, greatly excites the cerebral cortex. Acetylcholine plays a key role as an excitatory neurotransmitter in this process.

Thus, the reticular formation, almost totally ignored in the past, is now being shown to influence practically all activities of the body.

LIMBIC SYSTEM

The word *limbic* means border or margin, and the term *limbic* system was loosely used to include a group of structures that lie in the border zone between the cerebral cortex and the hypothalamus. Research has now shown that the limbic system is involved with many other structures beyond the border zone in the control of emotion, behavior, and drive; it also appears to be important to memory.

Anatomically, the limbic structures include the subcallosal, the cingulate, and the parahippocampal gyri, the hippocampal formation, the amygdaloid nucleus, the mammillary bodies, and the anterior thalamic nucleus (Fig. 9-3). The alveus, the fimbria, the fornix, the mammillothalamic tract, and the stria terminalis constitute the connecting pathways of this system.

Hippocampal Formation

The hippocampal formation consists of the hippocampus, the dentate gyrus, and the parahippocampal gyrus.

The **hippocampus** is a curved elevation of gray matter that extends throughout the entire length of the floor of the inferior horn of the lateral ventricle (Fig. 9-4). Its anterior end is expanded to form the **pes hippocampus.** It is named *hippocampus* because it resembles a seahorse in coronal section. The convex ventricular

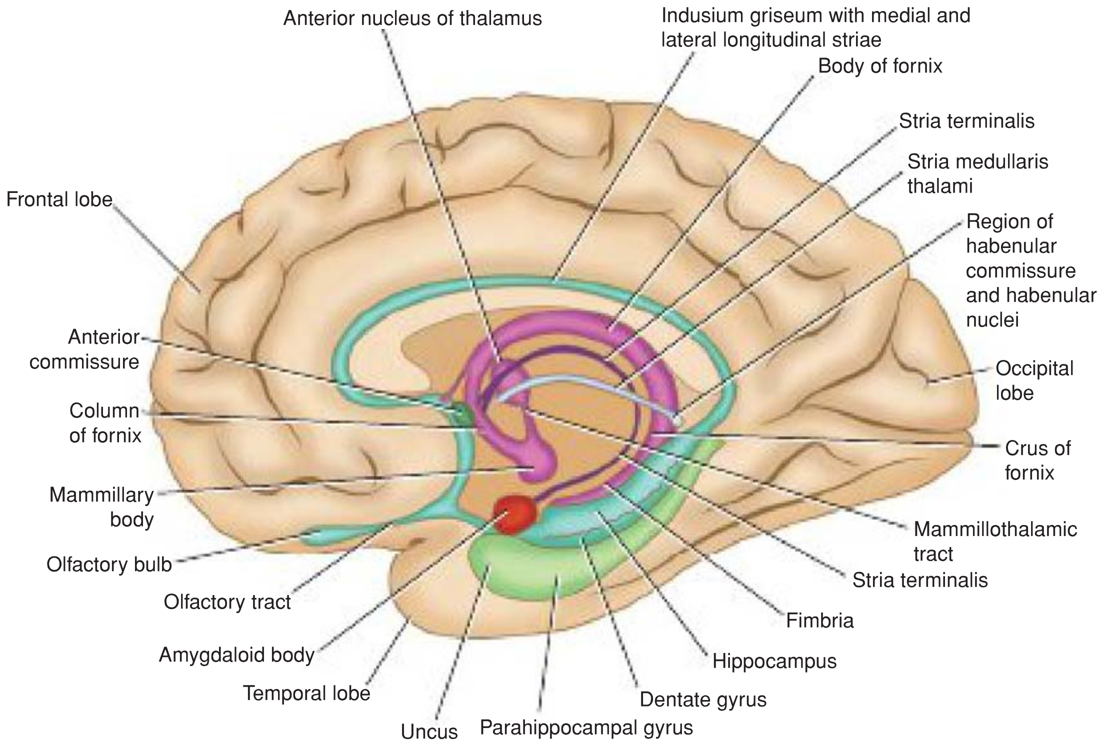


Figure 9-3 Medial aspect of the right cerebral hemisphere showing structures that form the limbic system.

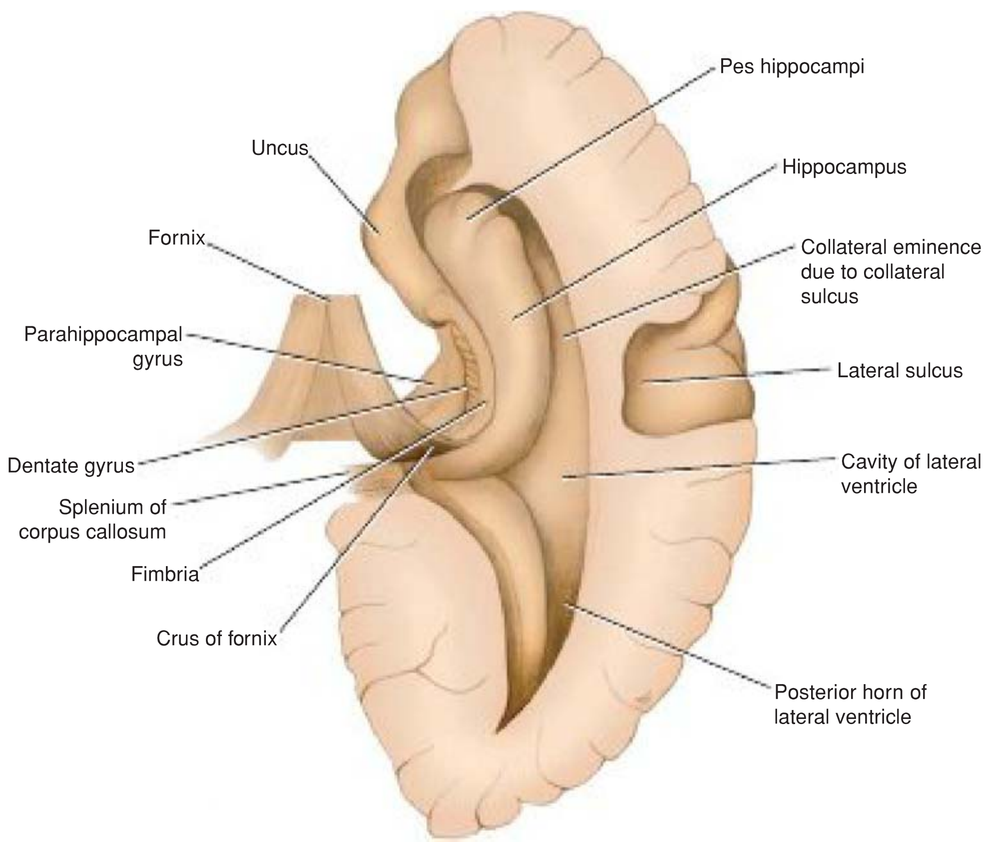


Figure 9-4 Dissection of the right cerebral hemisphere exposing the cavity of the lateral ventricle, showing the hippocampus, the dentate gyrus, and the fornix.

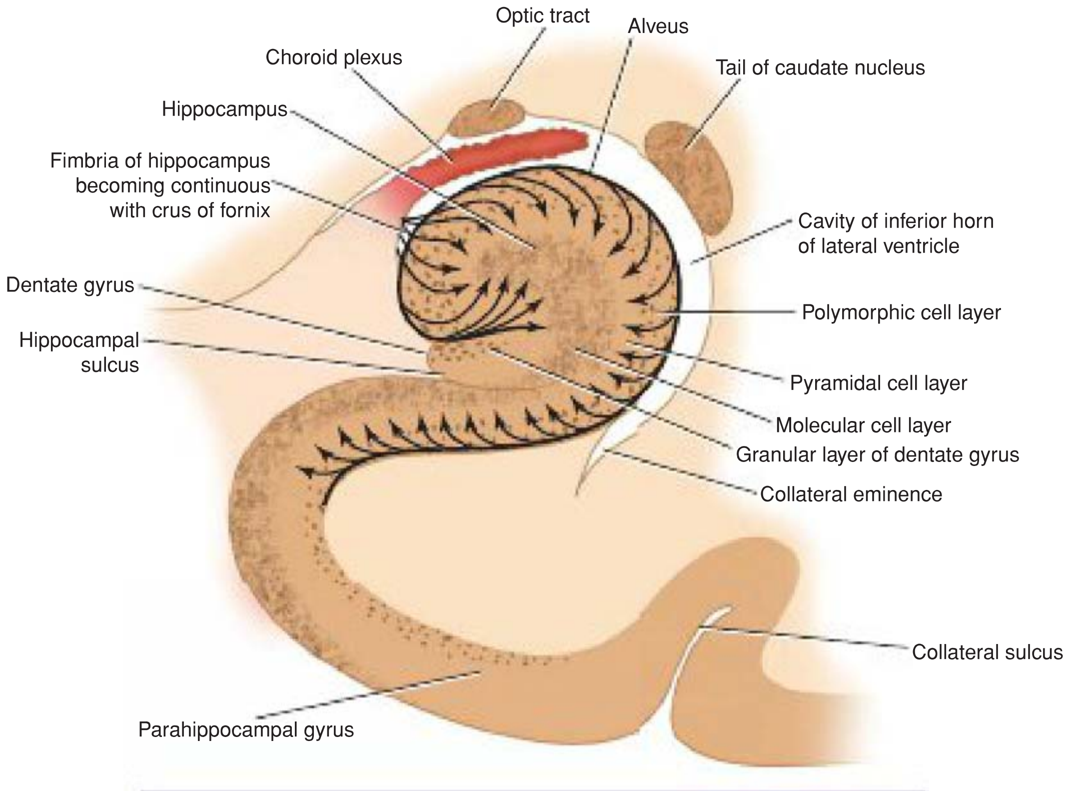


Figure 9-5 Coronal section of the hippocampus and related structures.

surface is covered with ependyma, beneath which lies a thin layer of white matter called the **alveus** (Fig. 9-5). The alveus consists of nerve fibers that have originated in the hippocampus, and these converge medially to form a bundle called the **fimbria**. The fimbria, in turn, becomes continuous with the crus of the fornix. The hippocampus terminates posteriorly beneath the splenium of the corpus callosum.

The **dentate** gyrus is a narrow, notched band of gray matter that lies between the fimbria of the hippocampus and the parahippocampal gyrus (see Fig. 9-4). Posteriorly, the gyrus accompanies the fimbria almost to the splenium of the corpus callosum and becomes continuous with the **indusium** griseum. The indusium griseum is a thin, vestigial layer of gray matter that covers the superior surface of the corpus callosum (Fig. 9-6). Embedded in the superior surface of the indusium griseum are two slender bundles of white fibers on each side called the **medial** and **lateral** longitudinal striae. The striae are the remains of the white matter of the vestigial indusium griseum. Anteriorly, the dentate gyrus is continued into the **uncus**.

The **parahippocampal gyrus** lies between the hippocampal fissure and the collateral sulcus and is continuous with the hippocampus along the medial edge of the temporal lobe (see Figs. 9-4 and 9-5).

Amygdaloid Nucleus

The amygdaloid nucleus is so named because it resembles an almond. It is situated partly anterior and partly superior to the tip of the inferior horn of the lateral ventricle (see Fig. 7-14). It is fused with the tip of the tail of the caudate nucleus, which has passed anteriorly in the roof of the inferior horn of the lateral ventricle. The stria terminalis emerges from its posterior aspect. The amygdaloid nucleus consists of a complex of nuclei that can be grouped into a larger **basolateral group** and smaller **corticomedial group**.

The mammillary bodies and the anterior nucleus of the thalamus are considered elsewhere in this text.

Connecting Pathways of the Limbic System

The connecting pathways of the limbic system are the alveus, the fimbria, the fornix, the mammillothalamic tract, and the stria terminalis.

The **alveus** consists of a thin layer of white matter that lies on the superior or ventricular surface of the hippocampus (see Fig. 9-5). It is composed of nerve fibers that originate in the hippocampal cortex. The fibers converge on the medial border of the hippocampus to form a bundle called the **fimbria**.

The fimbria now leaves the posterior end of the hippocampus as the **crus of the fornix** (see Fig. 9-4). The crus from each side curves posteriorly and superiorly beneath the splenium of the corpus callosum and around the posterior surface of the thalamus. The two crura now converge to form the **body of the fornix**, which is applied closely to the undersurface of the corpus callosum (see Fig. 9-3). As the two crura come together, they are connected by transverse fibers called

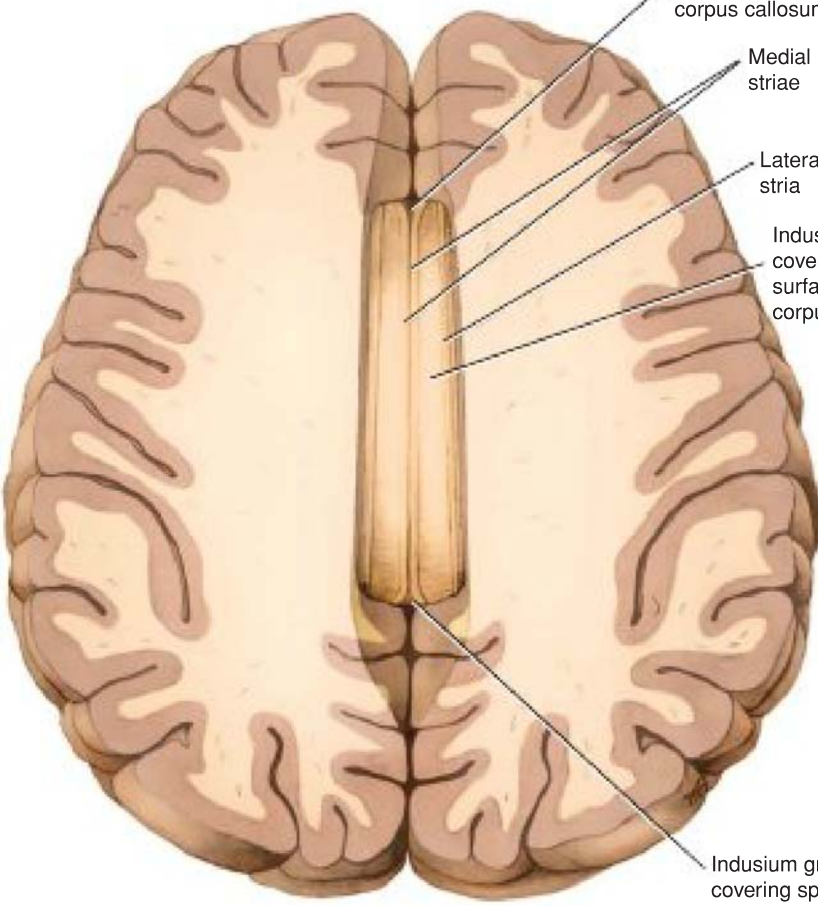


Figure 9-6 Dissection of both cerebral hemispheres showing the superior surface of the corpus callosum.

the **commissure of the fornix** (see Fig. 7-16). These fibers decussate and join the hippocampi of the two sides.

Anteriorly, the body of the fornix is connected to the undersurface of the corpus callosum by the **septum pellucidum**. Inferiorly, the body of the fornix is related to the tela choroidea and the ependymal roof of the third ventricle.

The body of the fornix splits anteriorly into two anterior **columns of the fornix**, each of which curves anteriorly and inferiorly over the interventricular foramen (foramen of Monro). Then, each column disappears into the lateral wall of the third ventricle to reach the **mammillary body** (see Fig. 9-3).

The **mammillothalamic tract** provides important connections between the mammillary body and the anterior nuclear group of the thalamus.

The **stria terminalis** emerges from the posterior aspect of the amygdaloid nucleus and runs as a bundle of nerve fibers posteriorly in the roof of the inferior horn of the lateral ventricle on the medial side of the tail of the caudate nucleus. It follows the curve of the caudate nucleus and comes to lie in the floor of the body of the lateral ventricle.

Hippocampal Structure and the Dentate Gyrus

The cortical structure of the parahippocampal gyrus is six layered (see Fig. 9-5). As the cortex is traced into the hippocampus, there is a gradual transition from a six- to a three-layered arrangement. These three layers are the superficial **molecular layer**, consisting of nerve fibers and scattered small neurons; the **pyramidal layer**, consisting of many large pyramid-shaped neurons; and the inner **polymorphic layer**, which is similar in structure to the polymorphic layer of the cortex seen elsewhere.

The dentate gyrus also has three layers, but the pyramidal layer is replaced by the granular layer. The granular layer is composed of densely arranged rounded or oval neurons that give rise to axons that terminate on the dendrites of the pyramidal cells in the hippocampus. A few of the axons join the fimbria and enter the fornix.

Afferent Connections of the Hippocampus

Afferent connections of the hippocampus may be divided into six groups (Fig. 9-7):

1. Fibers arising in the cingulate gyrus pass to the hippocampus.

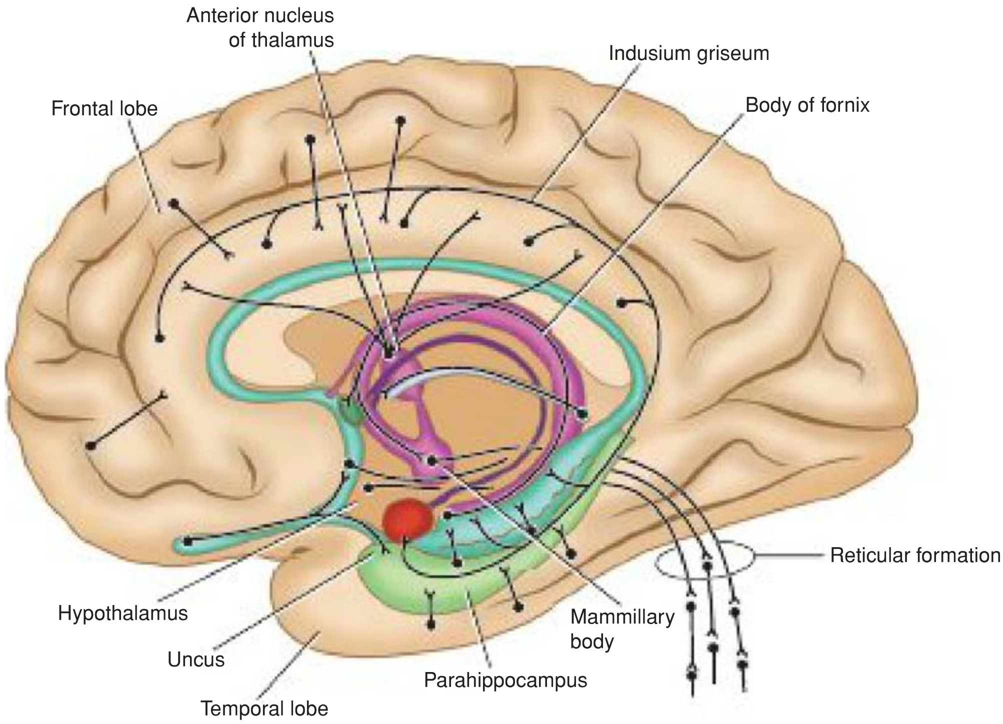


Figure 9-7 Diagram showing some important afferent and efferent connections of the limbic system.

2. Fibers arising from the septal nuclei (nuclei lying within the midline close to the anterior commissure) pass posterior in the fornix to the hippocampus.
3. Fibers arising from one hippocampus pass across the midline to the opposite hippocampus in the commissure of the fornix.
4. Fibers from the indusium griseum pass posteriorly in the longitudinal striae to the hippocampus.
5. Fibers from the entorhinal area or olfactory-associated cortex pass to the hippocampus.
6. Fibers arising from the dentate and parahippocampal gyri travel to the hippocampus.

Efferent Connections of the Hippocampus

Axons of the large pyramidal cells of the hippocampus emerge to form the alveus and the fimbria. The fimbria continues as the crus of the fornix. The two crura converge to form the body of the fornix. The body of the fornix splits into the two columns of the fornix, which curve downward and forward in front of the interventricular foramina. The fibers within the fornix are distributed to the following regions (see Fig. 9-7):

1. Fibers pass posterior to the anterior commissure to enter the mammillary body, where they end in the medial nucleus.
2. Fibers pass posterior to the anterior commissure to end in the anterior nuclei of the thalamus.
3. Fibers pass posterior to the anterior commissure to enter the tegmentum of the midbrain.
4. Fibers pass anterior to the anterior commissure to end in the septal nuclei, the lateral preoptic area, and the anterior part of the hypothalamus.
5. Fibers join the stria medullaris thalami to reach the habenular nuclei.

Consideration of the above complex anatomical pathways indicates that the structures comprising the limbic system not only are interconnected but also send projection fibers to many different parts of the nervous system. Physiologists now recognize the importance of the hypothalamus as being the major output pathway of the limbic system.

Limbic System Functions

The limbic system, via the hypothalamus and its connections with outflow of the ANS and its control of the endocrine system, is able to influence many aspects of emotional behavior. These include particularly the reactions of fear and anger and the emotions associated with sexual behavior.

Evidence also suggests that the hippocampus is concerned with converting recent memory to long-term memory. A lesion of the hippocampus results in the individual being unable to store long-term memory. Memory of remote past events before the lesion developed is unaffected. This condition is called **anterograde amnesia**. Note that injury to the amygdaloid nucleus and the hippocampus produces greater memory loss than injury to either one of these structures alone.

Evidence does not show that the limbic system has an olfactory function. Its various afferent and efferent connections provide pathways for the integration and effective homeostatic responses to a wide variety of environmental stimuli.

Clinical Notes

Reticular Formation

The reticular formation is a continuous network of nerve cells and fibers that extend through the neuroaxis from the spinal cord to the cerebral cortex. The reticular formation not only modulates the control of motor systems but also influences sensory systems. By means of its multiple ascending pathways, which project to different parts of the cerebral cortex, it is believed to influence the state of consciousness.

Loss of Consciousness

In experimental animals, damage to the reticular formation, which spares the ascending sensory pathways, causes persistent unconsciousness. Pathologic lesions of the reticular formation in humans can result in loss of consciousness and even coma. It has been suggested that the loss of consciousness that occurs in epilepsy may be due to inhibition of the activity of the reticular formation in the upper part of the diencephalon.

Limbic System

Because the anatomical connections of the limbic system are extremely complex and their significance is not fully understood, committing all of them to memory is unnecessary. The results of neurophysiologic experiments, which have included stimulation and ablation of different parts of the limbic system in animals, are not entirely clear. Nevertheless, certain important roles have been inferred: (1) The limbic structures are involved in the development of sensations of emotion and with the visceral responses accompanying those emotions, and (2) the hippocampus is concerned with recent memory.

Schizophrenia

The symptoms of schizophrenia include chronically disordered thinking, blunted affect, and emotional withdrawal. Paranoid delusions and auditory hallucinations may also be present. Clinical research has shown that if the limbic receptors to dopamine are blocked by a pharmacologic agent, the worst symptoms of schizophrenia are lessened. Phenothiazine administration, for example, blocks the dopamine receptors in the limbic system. Unfortunately, this drug, as well as most other antipsychotic drugs, has major motor side effects on the dopaminergic receptors within the extrapyramidal system, producing abnormal involuntary movements. Research is now concentrating on finding a drug that will block the limbic dopamine receptors but without effect on the receptors of the extrapyramidal system (substantia nigra–corpus striatum).

Clearly, no direct evidence exists to suggest that excessive production of dopamine by certain neurons actually contributes to schizophrenia.

Amygdaloid Complex Destruction

Unilateral or bilateral destruction of the amygdaloid nucleus and the para-amygdaloid area in patients suffering from aggressive behavior in many cases results in a decrease in aggressiveness, emotional instability, and restlessness; increased interest in food; and hypersexuality but no memory disturbance. Monkeys that have been subjected to bilateral removal of the temporal lobes demonstrate what is known as **Klüver–Bucy syndrome**. They become docile and show no evidence of fear or anger and are unable to appreciate objects visually. They have increased appetite and sexual activity. Moreover, the animals indiscriminately seek partnerships with male and female animals.

Precise stereotactic lesions in the amygdaloid complex in humans reduce emotional excitability and bring about normalization of behavior in patients with severe disturbances. No loss of memory occurs.

Temporal Lobe Dysfunction

Temporal lobe epilepsy may be preceded by an aura of acoustic or olfactory experience. The olfactory aura is usually an unpleasant odor. The patient is often confused, anxious, and docile and may perform automatic and complicated movements, such as undressing in public or driving a car, and then, following the seizure, may have no memory of what occurred previously.

Key Concepts

Reticular Formation

- The reticular formation consists of a deeply placed, continuous network of nerve cells and fibers that extend throughout the medulla, pons, midbrain, subthalamus, hypothalamus, and thalamus.
- It is organized into three longitudinal columns: median, medial, and lateral.
- These columns can modulate 1) muscle tone and reflex activity, 2) somatic and visceral sensations, 3) autonomic nervous system, 4) endocrine functions, 5) biologic clocks, and 6) the reticular activating system (arousal and consciousness).

Limbic System

- This group of structures controls emotion, behavior, drive, and memory and includes the subcallosal, cingulate, and parahippocampal gyri, the hippocampal formation, the amygdaloid nucleus, the mammillary bodies, and the anterior thalamic nucleus.
- The hippocampal formation consists of the hippocampus, dentate gyrus, and parahippocampal gyrus.

Clinical Problem Solving

1. While discussing the neurologic basis of emotions during a ward round, a neurologist asks a third-year medical student what she knows about the Klüver–Bucy syndrome. What would be your answer to that question? Does Klüver–Bucy syndrome ever occur in humans?
2. A 23-year-old woman with a 4-year history of epileptic attacks visits her neurologist. A friend of hers vividly describes one of her attacks. For a few seconds before the convulsions begin, the patient complains of an unpleasant odor, similar to that encountered in a cow shed. This is followed by a shrill cry as she falls to the floor unconscious. Her whole body immediately becomes involved in generalized tonic and clonic movements. Clearly, this patient has a generalized form of epileptic seizure. Using your knowledge of neuroanatomy, suggest which lobe of the brain was initially involved in the epileptic discharge.
3. A 54-year-old man dies in the hospital with a cerebral tumor. He had always been intellectually very bright and could easily recall events in his childhood. For the past 6 months, his family had noticed that he had difficulty in recalling where he had placed things, such as his pipe. He also had difficulty in recalling recent news events, and, just before he died, he could not remember that his brother had visited him the day before. Using your knowledge of neuroanatomy, suggest which part of the brain was being affected by the expanding and highly invasive tumor.

Answers and Explanations to Clinical Problem Solving

1. The Klüver–Bucy syndrome consists of the signs and symptoms found in monkeys following bilateral removal of the temporal lobe. The monkeys become docile and unresponsive and display no signs of fear or anger. They have increased appetite and sexual activity, which is often disinhibited. They are able to see objects but are unable to recognize the objects. Humans in whom the amygdaloid area is destroyed do not usually demonstrate this syndrome. It has, however, been described in humans following the bilateral removal of large areas of the temporal lobes.
2. The olfactory aura that preceded the general convulsions of the epileptic attack would indicate that the temporal lobe of the cerebral cortex was initially involved.
3. An autopsy study revealed extensive invasion of the hippocampus, fornix, and mammillary bodies in both cerebral hemispheres. The hippocampus is apparently involved in the storage and categorizing of afferent information related to recent memory.

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 reticular formation:
   (a) Reticulobulbar and reticulospinal tracts form the afferent pathways from the reticular formation to the motor nuclei of the cranial nerves and the anterior horn cells of the spinal cord, respectively.
   (b) The reticular formation extends through the neuroaxis from the spinal cord to the midbrain.
   (c) The main pathways through the reticular formation may easily be traced from one part of the CNS to another using silver stains.
   (d) Superiorly, the reticular formation is relayed to the cerebral cortex.
   (e) Afferent pathways project into the reticular formation from only a few parts of the CNS.
2. The following statements concern the functions of the reticular formation:
   (a) It influences the activity of the α and γ motor neurons.
   (b) It opposes the actions of the vestibular spinal tract.
   (c) It does not bring about reciprocal inhibition during contraction of the prime mover muscles.
   (d) It plays no part in maintaining the tone of the antigravity muscles.
   (e) It cannot modulate reflex activity.

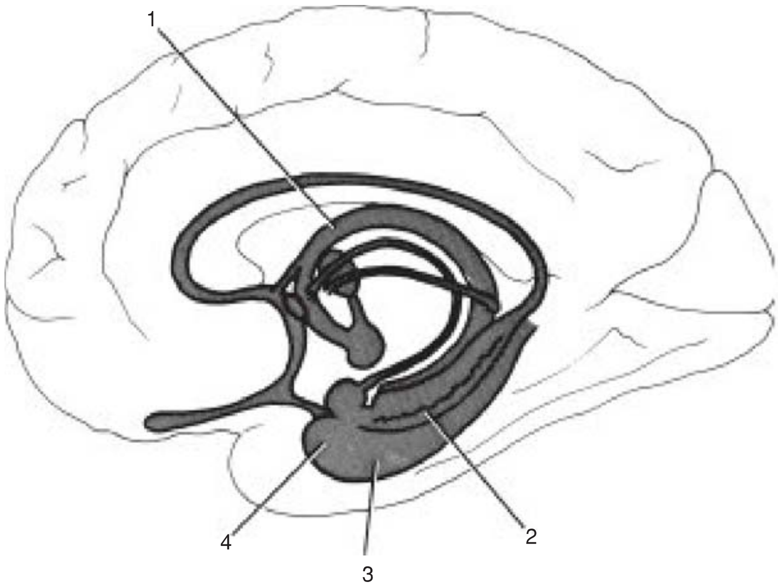


Figure 9-8 Medial aspect of the right cerebral hemisphere showing structures that form the limbic system.

3. The following statements concern the functions of the reticular formation:
   (a) It does not affect the reception of pain.
   (b) It cannot influence all ascending pathways to the supraspinal levels.
   (c) By means of its reticulobulbar and reticulospinal tracts, it can control parasympathetic and sympathetic outflows.
   (d) It has no effect on biologic rhythms.
   (e) It does not influence the degree of wakefulness of an individual.
4. Anatomically, the following structures collectively form the limbic system:
   (a) Amygdaloid nucleus, red nucleus, and vestibular nuclei
   (b) Pulvinar of the thalamus and the substantia nigra
   (c) Hippocampal formation
   (d) Cingulate gyrus and uncus
   (e) Subcallosal, cingulate, and parahippocampal gyri, hippocampal formation, amygdaloid nucleus, mammillary bodies, and anterior thalamic nuclei
5. The following statements concern the efferent connections of the hippocampus:
   (a) They arise from the small granular cells of the cortex.
   (b) They travel through the fornix.
   (c) None of the fibers enter the mammillary body.
   (d) The fibers within the fornix pass posterior to the interventricular foramen.
   (e) Some of the fibers end in thalamic posterior nuclei.
6. The following statements concern the functions of the limbic system:
   (a) It is not concerned with fear and anger.
   (b) It is concerned with visual experiences.
   (c) The hippocampus is concerned with recent memory.
   (d) The limbic system plays an important role in olfactory function.
   (e) It directly influences the activity of the endocrine system.

Matching Questions. Directions: The following questions apply to Figure 9-8. 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.

7. Number 1	(a) Uncus
8. Number 2	(b) Body of fornix
9. Number 3	(c) Parahippocampal gyrus
10. Number 4	(d) Dentate gyrus
	(e) None of the above

Answers and Explanations to Review Questions

1. D is correct. The reticular formation is relayed superiorly to the cerebral cortex. A. The retrobulbar and reticulospinal tracts form the efferent pathways from the reticular formation to the motor nuclei of the cranial nerves and the anterior horn cells of the spinal cord, respectively. B. The reticular formation extends through the neuroaxis from the spinal cord to the thalamus. C. The main pathways through the reticular formation are poorly defined and difficult to trace from one part of the CNS to another using silver stains. E. Afferent pathways project into the reticular formation from most parts of the CNS.

2. A is correct. The reticular formation influences the activity of the α and γ motor neurons. B. The reticular formation does not oppose the actions of the vestibular spinal tract. C. The reticular formation brings about reciprocal inhibition during contraction of the prime mover muscles. D. The reticular formation helps maintain the tone of the antigravity muscles. E. The reticular formation can modulate reflex activity.
3. C is correct. The reticular formation by means of its reticulobulbar and reticulospinal tracts can control the parasympathetic and sympathetic outflows. A. The reticular formation does affect the reception of pain. B. The reticular formation can influence all ascending pathways to the supraspinal levels. D. The reticular formation can affect the biologic rhythms. E. The reticular formation can influence the degree of wakefulness of an individual.
4. E is correct. The limbic system is made up of the subcallosal, the cingulate, and the parahippocampal gyri, the hippocampal formation, the amygdaloid nucleus, the mammillary bodies, and the anterior thalamic nuclei (see Fig. 9-3).
5. B is correct. The efferent connections of the hippocampus travel through the fornix. A. The efferent connections of the hippocampus arise from large pyramidal cells of the cortex. C. Some of the efferent fibers from the hippocampus enter the mammillary bodies. D. The efferent fibers in the fornix pass anterior to the interventricular foramen. E. Some of the efferent fibers from the hippocampus end in the anterior nuclei of the thalamus.
6. C is correct. The hippocampus is concerned with recent memory. A. The limbic system is concerned with the reactions of fear and anger. B. The limbic system is not concerned with visual experiences. D. The limbic system plays no part in olfactory function. E. The limbic system indirectly influences the activity of the endocrine system.

The answers for Figure 9-8 are as follows:

7. B is correct. Number 1 is the body of the fornix.
8. D is correct. Number 2 is the dentate gyrus.
9. C is correct. Number 3 is the parahippocampal gyrus.
10. A is correct. Number 4 is the uncus.

10 Basal Nuclei (Basal Ganglia)

CHAPTER OBJECTIVE

- To describe the basal nuclei and their connections
- To relate basal nuclei functions to diseases commonly affecting this area of the nervous system

A 58-year-old man goes to a neurologist because he has noticed the development of a slight tremor of his left hand. The tremors involve all of the fingers and the thumb and are present at rest but cease during voluntary movement.

On examination, the patient tends to perform all his movements slowly, and his face has very little expression and is almost masklike. On passively moving the patient's arms, the neurologist finds that the muscles show increased tone, with a slight jerky resistance to the movements. When asked to stand up straight, the patient does so but with a stooped posture, and, when he walks, he does so by shuffling across the examining room.

The neurologist makes the diagnosis of Parkinson disease, based on her knowledge of the structure and function of the basal ganglia and their connections to the substantia nigra of the midbrain. She is able to prescribe appropriate drug therapy, which results in a great improvement in the hand tremors.

The basal nuclei play an important role in the control of posture and voluntary movement. Unlike many other parts of the nervous system concerned with motor control, the basal nuclei have no direct input or output connections with the spinal cord.

TERMINOLOGY

The term **basal nuclei** 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.

Clinicians and neuroscientists use a variety of different terminologies to describe the basal nuclei. A summary of the terminologies commonly used is shown in Table 10-1. The subthalamic nuclei, the substantia nigra, and the red nucleus are functionally closely related to the basal nuclei, but they should not be included with them.

The interconnections of the basal nuclei are complex, but in this account, only the more important pathways are considered. The basal nuclei play an important role in the control of posture and voluntary movement.

CORPUS STRIATUM

The corpus striatum (Fig. 10-1; see also Atlas Plate 5) is situated lateral to the thalamus and is almost completely divided by a band of nerve fibers, the **internal capsule**, into the caudate nucleus and the lentiform nucleus. The term *striatum* is used here because of the striated appearance produced by the strands of gray matter passing through the internal capsule and connecting the caudate nucleus to the putamen of the lentiform nucleus (see below).

Table 10-1 Terminology Commonly Used to Describe the Basal Nuclei

Neurologic Structure	Basal Nucleus (Nuclei)[a]
Caudate nucleus	Caudate nucleus
Lentiform nucleus	Globus pallidus plus putamen
Claustrum	Claustrum
Corpus striatum	Caudate nucleus plus lentiform nucleus
Neostriatum (striatum)	Caudate nucleus plus putamen
Amygdaloid body	Amygdaloid nucleus

[a]The term *basal* has been used in the past to denote the position of the nuclei at the base of the forebrain.

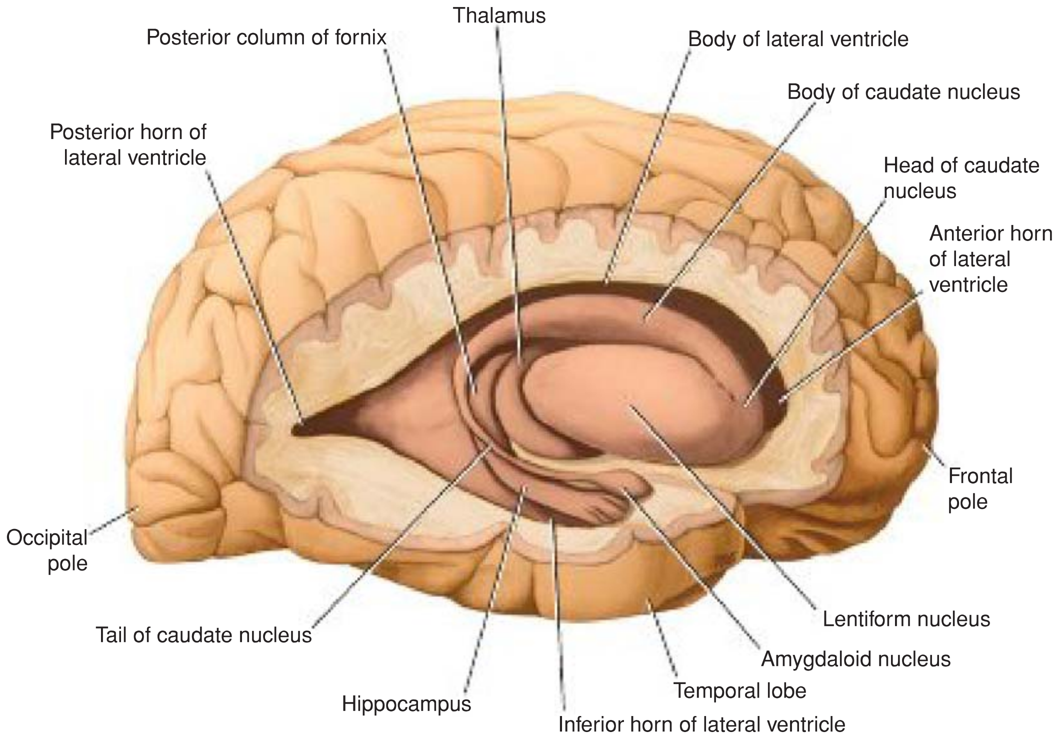


Figure 10-1 Lateral view of the right cerebral hemisphere dissected to show the position of the different basal nuclei.

Caudate Nucleus

The caudate nucleus is a large C-shaped mass of gray matter that is closely related to the lateral ventricle and lies lateral to the thalamus. The lateral surface of the nucleus is related to the internal capsule, which separates it from the lentiform nucleus (Fig. 10-2). For purposes of description, it can be divided into a head, a body, and a tail.

The **head** of the caudate nucleus is large and rounded and forms the lateral wall of the anterior horn of the lateral ventricle (see also Atlas Plate 5). The head is continuous inferiorly with the putamen of the lentiform nucleus (the caudate nucleus and the putamen are sometimes referred to as the **neostriatum** or **striatum**). Just superior to this point of union, strands of gray matter pass through the internal capsule, giving the region a striated appearance, hence the term **corpus striatum.**

The **body** of the caudate nucleus is long and narrow and is continuous with the head in the region of the interventricular foramen. The body of the caudate nucleus forms part of the floor of the body of the lateral ventricle.

The **tail** of the caudate nucleus is long and slender and is continuous with the body in the region of the posterior end of the thalamus. It follows the contour of the lateral ventricle and continues forward in the roof of the inferior horn of the lateral ventricle. It terminates anteriorly in the **amygdaloid nucleus** (see Fig. 10-1).

Lentiform Nucleus

The lentiform nucleus is a wedge-shaped mass of gray matter whose broad convex base is directed laterally and whose blade is directed medially (see Fig. 10-2; see also Atlas Plate 5). 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**, which 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. A vertical plate of white matter divides the nucleus into a larger, darker lateral portion, the **putamen**, and an inner lighter portion, the **globus pallidus**. The paleness of the globus pallidus is due to the presence of a high concentration of myelinated nerve fibers. Inferiorly at its anterior end, the putamen is continuous with the head of the caudate nucleus (see Fig. 10-1).

AMYGDALOID NUCLEUS

The amygdaloid nucleus is situated in the temporal lobe close to the uncus (see Fig. 10-1). The amygdaloid nucleus is considered to be part of the limbic system and is described in Chapter 9. Through its connections, it can influence the body's response to environmental changes. In the sense of fear, for example, it can change

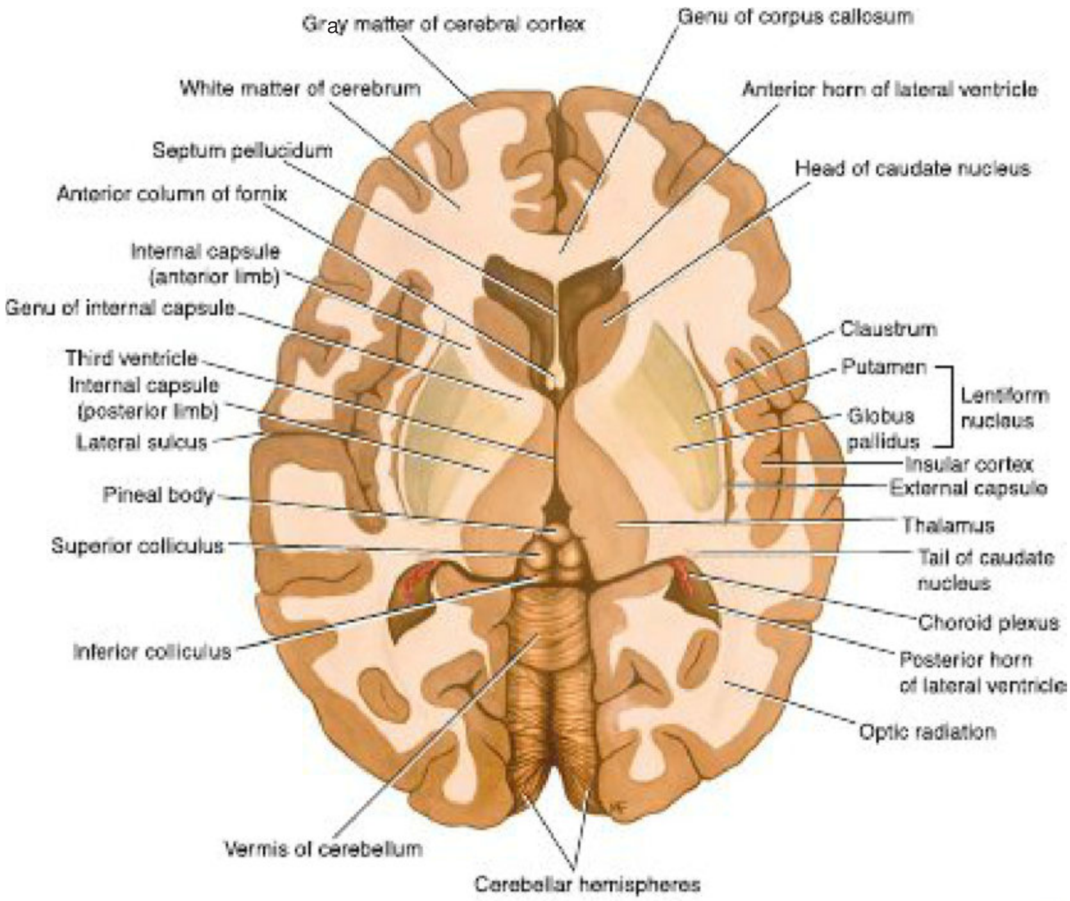


Figure 10-2 Horizontal section of the cerebrum, as seen from above, showing the relationships of the different basal nuclei.

the heart rate, blood pressure, skin color, and rate of respiration.

SUBSTANTIA NIGRA AND SUBTHALAMIC NUCLEI

The substantia nigra of the midbrain and the subthalamic nuclei of the diencephalon are functionally closely related to the activities of the basal nuclei and are described elsewhere (see pp. 211 and 253). The neurons of the substantia nigra are dopaminergic and inhibitory and have many connections to the corpus striatum. The neurons of the subthalamic nuclei are glutaminergic and excitatory and have many connections to the globus pallidus and substantia nigra.

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. 10-2). Lateral to the claustrum is the subcortical white matter of the insula. The function of the claustrum is unknown.

CONNECTIONS OF THE CORPUS STRIATUM AND GLOBUS PALLIDUS

The caudate nucleus and the putamen form the main sites for receiving input to the basal nuclei. The globus pallidus forms the major site from which the output leaves the basal nuclei.

They receive no direct input from or output to the spinal cord.

Corpus Striatum Afferent Fibers

Projections to the corpus striatum include corticostriate, thalamostriate, nigrostriatal, and brainstem striatal fibers.

Corticostriate Fibers

All parts of the cerebral cortex send axons to the caudate nucleus and the putamen (Fig. 10-3). Each part of the cerebral cortex projects to a specific part of the caudate–putamen complex. Most of the projections are from the cortex of the same side. The largest input is from the sensory motor cortex. Glutamate is the neurotransmitter of the corticostriate fibers (Fig. 10-4).

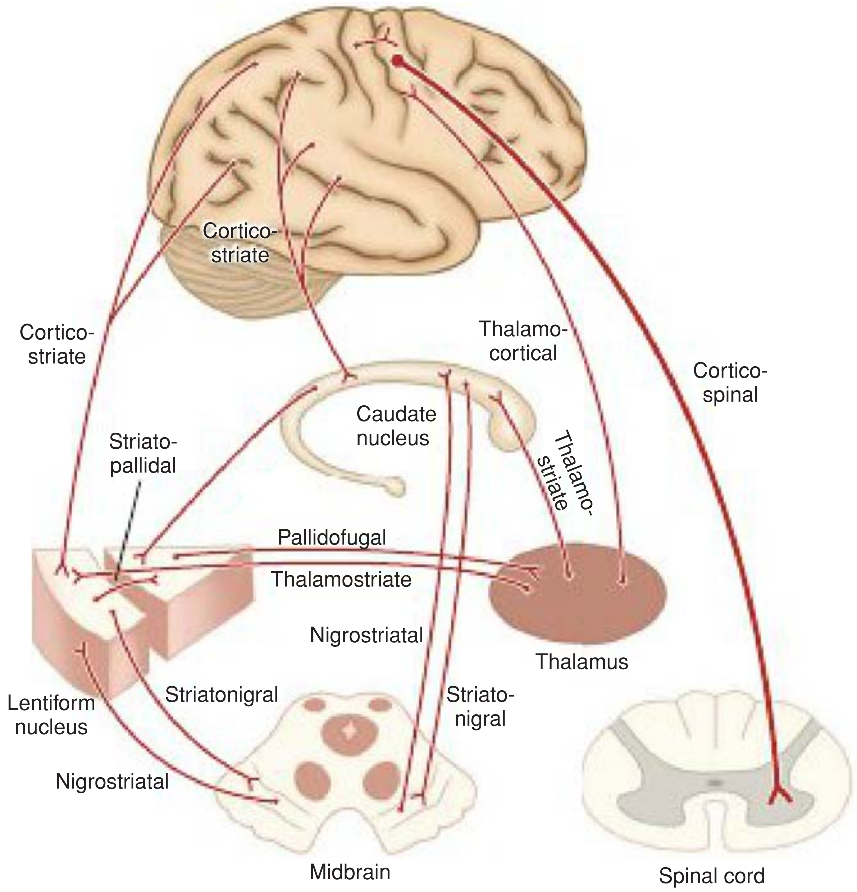


Figure 10-3 Some of the main connections between the cerebral cortex, the basal nuclei, the thalamic nuclei, the brainstem, and the spinal cord.

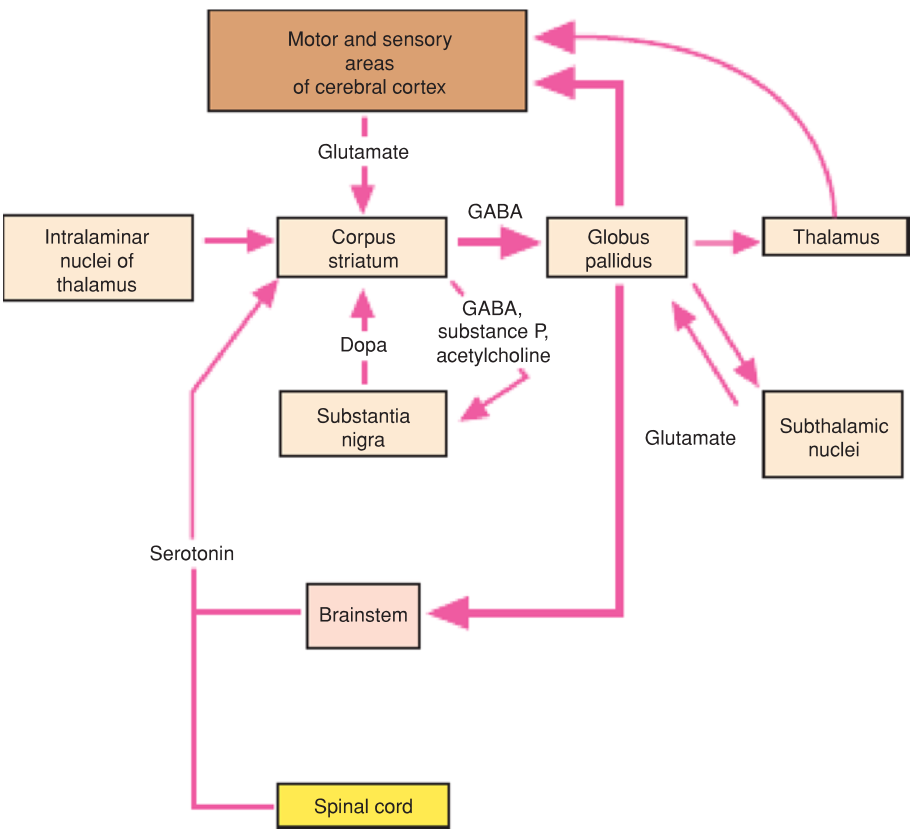


Figure 10-4 Basal nuclei pathways showing the known neurotransmitters.

Thalamostriate Fibers

The intralaminar nuclei of the thalamus send large numbers of axons to the caudate nucleus and the putamen (see Fig. 10-3).

Nigrostriatal Fibers

Neurons in the substantia nigra send axons to the caudate nucleus and the putamen (see Figs. 10-3 and 10-4) and liberate dopamine at their terminals as the neurotransmitter. These fibers are believed to be inhibitory in function.

Brainstem Striatal Fibers

Ascending fibers from the brainstem end in the caudate nucleus and putamen and liberate serotonin at their terminals as the neurotransmitter. These fibers are thought to be inhibitory in function.

Corpus Striatum Efferent Fibers

Projections from the corpus striatum include striatopallidal and striatonigral fibers.

Striatopallidal Fibers

Striatopallidal fibers pass from the caudate nucleus and putamen to the globus pallidus (see Fig. 10-3). They have γ-aminobutyric acid (GABA) as their neurotransmitter (see Fig. 10-4).

Striatonigral Fibers

Striatonigral fibers pass from the caudate nucleus and putamen to the substantia nigra (see Fig. 10-3). Some of the fibers use GABA or acetylcholine as the neurotransmitter, while others use substance P (see Fig. 10-4).

Globus Pallidus Afferent Fibers

Striatopallidal fibers pass from the caudate nucleus and putamen to the globus pallidus. As noted previously, these fibers have GABA as their neurotransmitter (Fig. 10-4).

Globus Pallidus Efferent Fibers

Pallidofugal fibers are complicated and can be divided into groups: (1) the **ansa lenticularis**, which pass to the thalamic nuclei; (2) the **fasciculus lenticularis**, which pass to the subthalamus; (3) the **pallidotegmental** fibers, which terminate in the caudal tegmentum of the midbrain; and (4) the **pallidosubthalamic fibers**, which pass to the subthalamic nuclei.

BASAL NUCLEI FUNCTIONS

The basal nuclei (Fig. 10-5) are joined together and connected with many different regions of the nervous system by a very complex number of neurons.

Basically, the corpus striatum receives afferent information from most of the cerebral cortex, the thalamus,

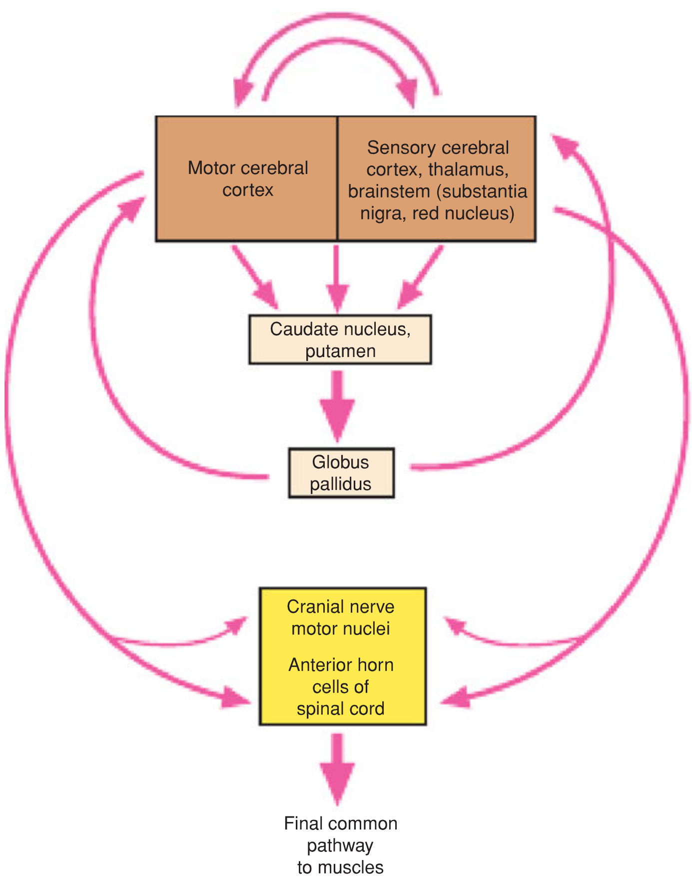


Figure 10-5 Diagram showing the main functional connections of the basal nuclei and how they can influence muscle activity.

the subthalamus, and the brainstem, including the substantia nigra. The information is integrated within the corpus striatum, and the outflow passes back to the areas listed above. This circular pathway is believed to function as follows.

The activity of the basal nuclei is initiated by information received from the premotor and supplemental areas of the motor cortex, the primary sensory cortex, the thalamus, and the brainstem. The outflow from the basal nuclei is channeled through the globus pallidus, which then influences the activities of the motor areas of the cerebral cortex or other motor centers in the brainstem. Thus, the basal nuclei control muscular movements by influencing the cerebral cortex and have no direct control through descending pathways to the brainstem and spinal cord. In this way, the basal nuclei assist in the regulation of voluntary movement and the learning of motor skills.

Writing the letters of the alphabet, drawing a diagram, passing a football, using the vocal cords in talking and singing, and using the eye muscles when looking at an object are a few examples where the basal nuclei influence the skilled cortical motor activities.

Destruction of the primary motor cerebral cortex prevents the individual from performing fine discrete movements of the hands and feet on the opposite side of the body (see p. 290). However, the individual is still capable of performing gross crude movements of the opposite limbs. If destruction of the corpus striatum then takes place, paralysis of the remaining movements of the opposite side of the body occurs.

The basal nuclei not only influence the execution of a particular movement of, say, the limbs but also help prepare for the movements. This may be achieved by controlling the axial and girdle movements of the body and the positioning of the proximal parts of the limbs. The activity in certain neurons of the globus pallidus increases before active movements take place in the distal limb muscles. This important preparatory function enables the trunk and limbs to be placed in appropriate positions before the primary motor part of the cerebral cortex activates discrete movements in the hands and feet.

Clinical Notes

Disorders of the basal nuclei are of two general types. **Hyperkinetic disorders** involve excessive and abnormal movements, such as seen with chorea, athetosis, and ballism. **Hypokinetic disorders** involve a lack or slowness of movement. Parkinson disease includes both types of motor disturbances.

Chorea

In chorea, the patient exhibits involuntary, quick, jerky, irregular movements that are nonrepetitive. Swift grimaces and sudden movements of the head or limbs are good examples.

Huntington Disease

Huntington disease is an autosomal dominant inherited disease, with the onset occurring most often in adult life. Death occurs 15 to 20 years after onset. The disease has been traced to a single gene defect on chromosome 4. This gene encodes a protein, **huntingtin**, the function of which is not known. The codon (CAG) that encodes glutamine is repeated many more times than normal. The disease affects men and women with equal frequency and unfortunately often reveals itself only after they have had children.

Patients have the following characteristic signs and symptoms:

1. **Choreiform movements** first appear as involuntary movements of the extremities and twitching of the face (facial grimacing). Later, more muscle groups are involved, so the patient becomes immobile and unable to speak or swallow.
2. **Progressive dementia** occurs with loss of memory and intellectual capacity.

In this disease, the GABA-secreting, substance P–secreting, and acetylcholine-secreting neurons of the striatonigral-inhibiting pathway degenerate. This results in the dopa-secreting neurons of the substantia nigra becoming overactive; thus, the nigrostriatal pathway inhibits the caudate nucleus and the putamen (Fig. 10-6). This inhibition produces the abnormal movements seen in this disease. Computed tomography scans show enlarged lateral ventricles due to degeneration of the caudate nuclei. Medical treatment of Huntington chorea has been disappointing.

Sydenham Chorea

Sydenham chorea (St. Vitus dance) is a disease of childhood in which rapid, irregular, involuntary movements of the limbs, face, and trunk occur. The condition is associated with rheumatic fever. The antigens of the streptococcal bacteria are similar in structure to the proteins present in the membranes of striatal neurons. The host's antibodies not only combine with the bacterial antigens but also attack the membranes of the neurons of the basal ganglia. This results in the production of choreiform movements, which are fortunately transient, and full recovery is made.

Hemiballismus

Hemiballismus is a form of involuntary movement confined to one side of the body. It usually involves the proximal extremity musculature, and the limb suddenly flies about out of control in all directions. The lesion, which is usually a small stroke, occurs in the opposite subthalamic nucleus or its connections; smooth movements of different parts of the body are integrated in the subthalamic nucleus.

Parkinson Disease

Parkinson disease is a progressive disease of unknown cause that commences between the ages of 45 and 55 years. It is associated with neuronal degeneration in the **substantia nigra** and, to a lesser extent, in the **globus pallidus**, **putamen**, and **caudate nucleus**. The disease affects about 1 million people in the United States.

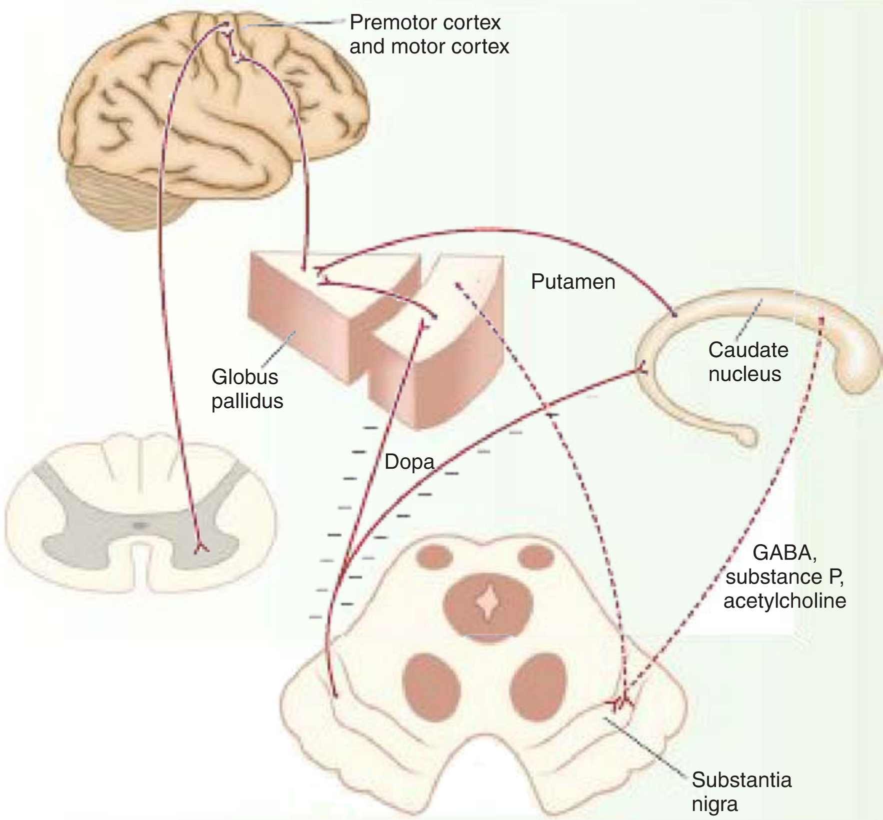


Figure 10-6 Diagram showing the degeneration of the inhibitory pathway between the corpus striatum and the substantia nigra seen in Huntington disease and the consequent reduction in the liberation of GABA, substance P, and acetylcholine in the substantia nigra.

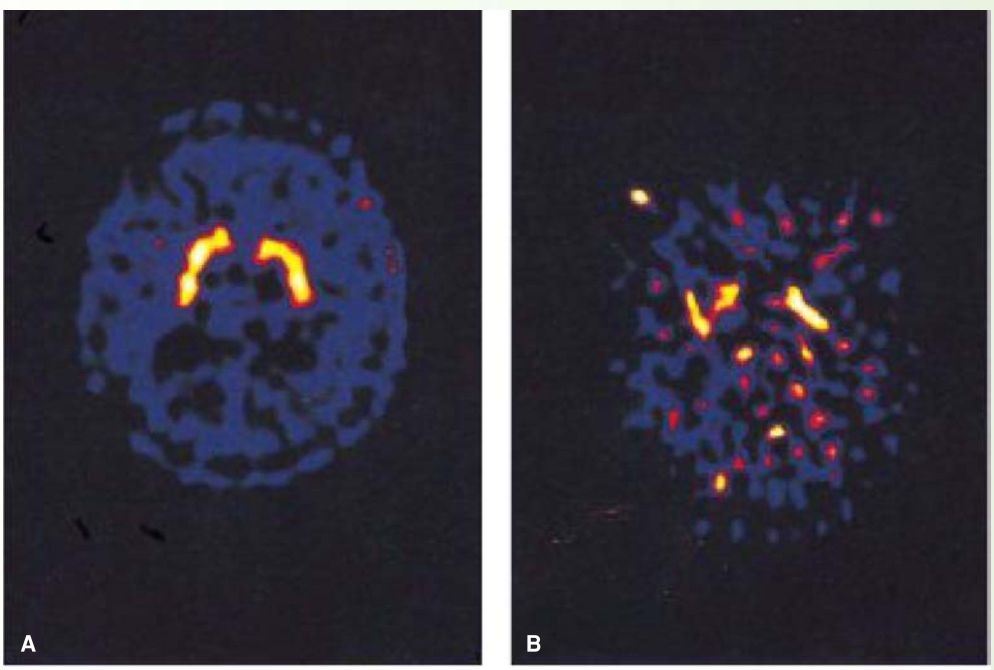


Figure 10-7 Axial (horizontal) positron emission tomography (PET) scans of a normal brain (**A**) and the brain of a patient with early Parkinson disease (**B**) following the injection of 18-F-fluorodopa. The normal brain image shows large amounts of the compound (yellow areas) distributed throughout the corpus striatum in both cerebral hemispheres. In the patient with Parkinson disease, the brain image shows that the total amount of the compound is low, and it is unevenly distributed in the corpus striatum. (Courtesy Dr. Holley Dey.)

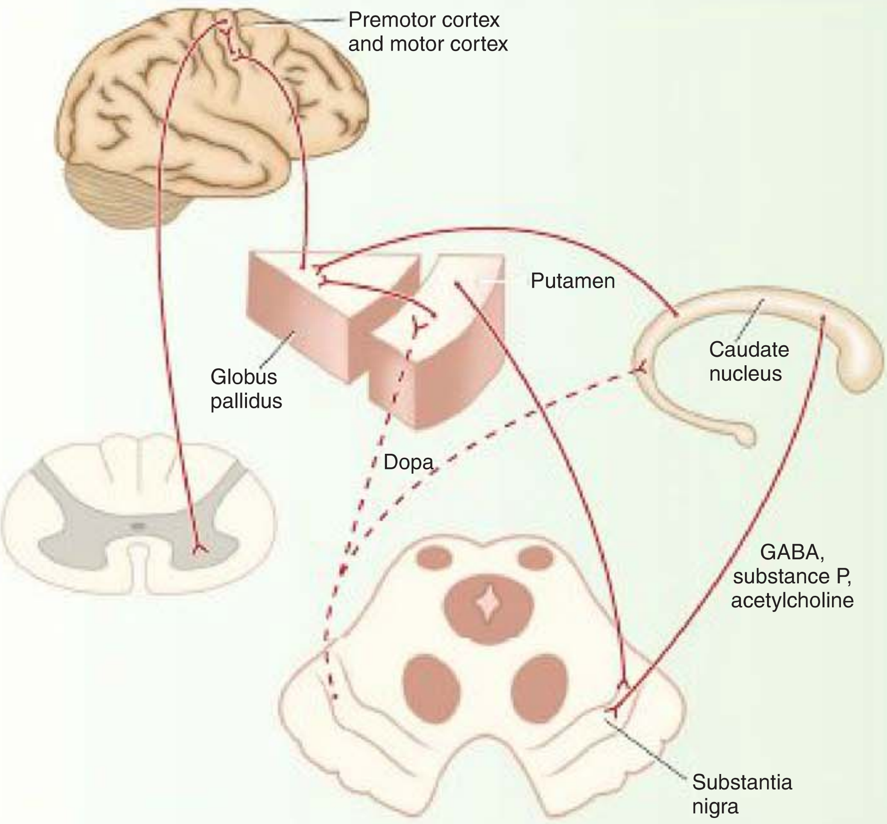


Figure 10-8 Diagram showing the degeneration of the inhibitory pathway between the substantia nigra and the corpus striatum in Parkinson disease and the consequent reduction in the release of the neurotransmitter dopamine in the striatum.

The degeneration of the neurons of the substantia nigra that send their axons to the corpus striatum results in a reduction in the release of the neurotransmitter dopamine within the corpus striatum (Figs. 10-7 and 10-8). This leads to hypersensitivity of the dopamine receptors in the postsynaptic neurons in the striatum.

Patients have the following characteristic signs and symptoms:

1. **Tremor.** This is the result of the alternating contraction of agonists and antagonists. The tremor is slow and occurs most obviously when the limbs are at rest. It disappears during sleep. It should be distinguished from the intention tremor seen in cerebellar disease, which only occurs when purposeful active movement is attempted.
2. **Rigidity.** This differs from the rigidity caused by lesions of the upper motor neurons in that it is present to an equal extent in opposing muscle groups. If the tremor is absent, the rigidity is felt as resistance to passive movement and is sometimes referred to as **plastic** rigidity. If the tremor is present, the muscle resistance is overcome as a series of jerks, called **cogwheel** rigidity.
3. **Bradykinesis.** Initiating (**akinesia**) and performing new movements is difficult. The movements are slow, the face is expressionless, and the voice is slurred and unmodulated. Swinging of the arms in walking is lost.
4. **Postural disturbances.** The patient stands with a stoop, and his or her arms are flexed. The patient walks by taking short steps and often is unable to stop. In fact, he or she may break into a shuffling run to maintain balance.
5. Neither loss of muscle power nor loss of sensibility occurs. Since the corticospinal tracts are normal, the superficial abdominal reflexes are normal, and no Babinski response is seen. The deep tendon reflexes are normal.

In a few types of Parkinson disease, the cause is known. **Postencephalitic** parkinsonism developed following the viral encephalitis outbreak of 1916 to 1917, in which damage occurred to the basal nuclei. **Iatrogenic** parkinsonism can be a side effect of antipsychotic drugs (e.g., phenothiazines). Meperidine analogues (used by drug addicts) and poisoning from carbon monoxide and manganese can also produce the symptoms of parkinsonism. **Atherosclerotic** parkinsonism can occur in elderly hypertensive patients.

Parkinson disease may be treated by elevating the brain dopamine level. Unfortunately, dopamine cannot cross the blood–brain barrier, but its immediate precursor L-dopa can and is used in its place. L-Dopa is taken up by the dopaminergic neurons in the basal nuclei and converted to dopamine. Selegiline, a drug that inhibits monoamine oxidase, which is responsible for destroying dopamine, is also of benefit in the treatment of the disease. Evidence shows that selegiline can slow the process of degeneration of the dopa-secreting neurons in the substantia nigra.

Transplantation of human embryonic dopamine-producing neurons into the caudate nucleus and putamen has been

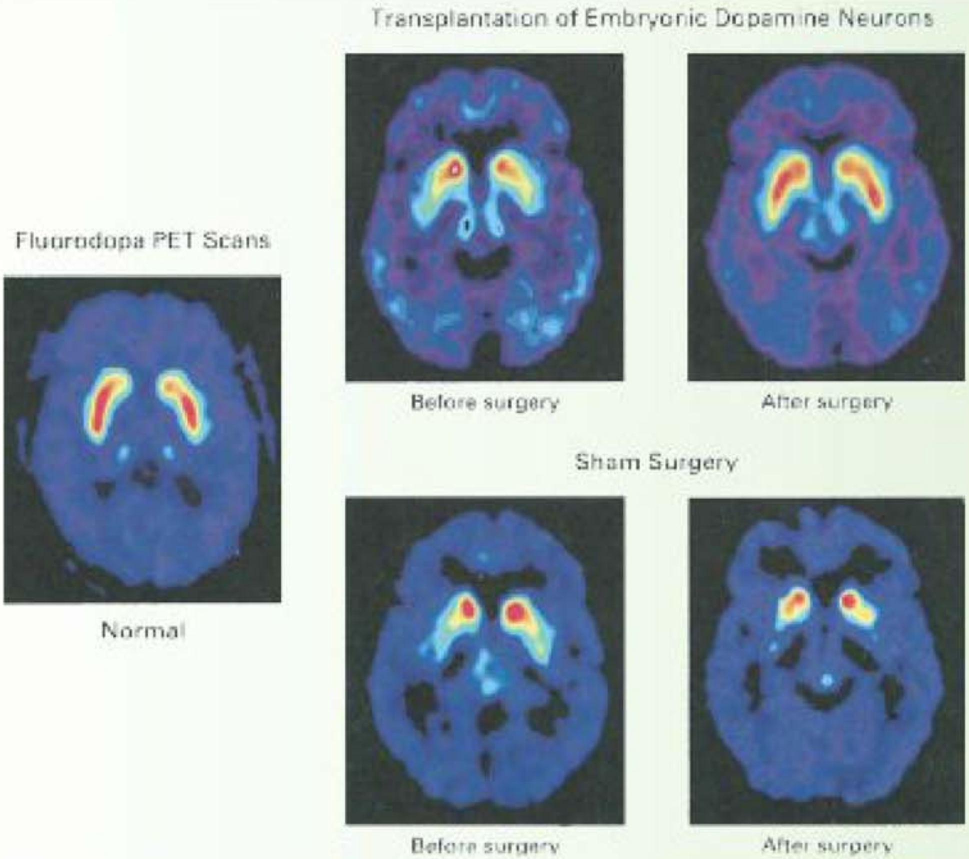


Figure 10-9 Change in 18-F-fluorodopa uptake in the brains of patients with Parkinson disease after transplantation, as shown in fluorodopa PET scans. In the panel on the far left, an axial (horizontal) section through the caudate nucleus and putamen of a normal subject shows intense uptake of 18-F-fluorodopa (red). On the right side, the upper panels show preoperative and 12-month postoperative scans in a patient in the transplantation group. Before surgery, the uptake of 18-F-fluorodopa was restricted to the region of the caudate nucleus. After transplantation, there was increased uptake of 18-F-fluorodopa in the putamen bilaterally. The lower panels show 18-F-fluorodopa scans in a patient in the sham-surgery group. There was no postoperative change in 18-F-fluorodopa uptake. (Courtesy of Freed, C. R., Greene, P. E., Breeze, R. E., et al. (2001). Transplantation of embryonic dopamine neurons for severe Parkinson's disease. *New England Journal of Medicine*, *344*(10), 710–719.)

shown to lead to improvement in motor function in Parkinson disease (Fig. 10-9). Evidence shows that the grafts can survive, and synaptic contacts are made. Unfortunately, many of the grafted neurons do not survive, and in many cases, the clinical improvement is counteracted by the continuing degeneration of the patient's own dopa-producing neurons. Autotransplantation of suprarenal medullary cells can be a source of dopa-producing cells, but in the future, genetically engineered cells could be another source of dopa.

Since most of the symptoms of Parkinson disease are caused by an increased inhibitory output from the basal nuclei to the thalamus and the precentral motor cortex, surgical lesions in the globus pallidus (**pallidotomy**) have been shown to be effective in alleviating parkinsonian signs. At the present time, such procedures are restricted to patients who are no longer responding to medical treatment.

Drug-Induced Parkinsonism

Although Parkinson disease (primary parkinsonism) is the most common type of parkinsonism found in clinical practice, drug-induced parkinsonism is becoming very prevalent. Drugs that block striatal dopamine receptors (D2) are often given for psychotic behavior (e.g., phenothiazines and butyrophenones). Other drugs may deplete striatal dopamine (e.g., tetrabenazines). Drug-induced parkinsonism disappears once the agent is withdrawn.

Athetosis

Athetosis consists of slow, sinuous, writhing movements that most commonly involve the distal segments of the limbs. Degeneration of the globus pallidus occurs with a breakdown of the circuitry involving the basal nuclei and the cerebral cortex.

Key Concepts

- The corpus striatum comprises gray matter that sits lateral to the thalamus and is divided by the internal capsule into the caudate nucleus and lentiform nucleus.
- The caudate nucleus is a large C-shaped structure, forming the lateral wall and floor of the lateral ventricle, and is divided into a head, body, and tail. It terminates anteriorly in the amygdaloid nucleus.
- The lentiform nucleus consists of two nuclei, the putamen and globus pallidus. The paleness of the globus pallidus is due to the high concentration of myelinated nerve fibers.
- The corpus striatum, along with amygdaloid nucleus, substantia nigra, subthalamic nuclei, and claustrum, forms numerous complex afferent and efferent pathways.
- This circular process is initiated by motor information from the cortex, thalamus, and brainstem, processed by structures of the basal ganglia, and then channeled through the globus pallidus to influence muscular movements by returning and influencing the cerebral cortex.
- The basal nuclei not only influence the execution of a particular movement but also help prepare for movements (i.e., placing the trunk in the appropriate position in preparation for the movement by the lower limbs).

Clinical Problem Solving

1. A 10-year-old girl is seen by a neurologist because of the gradual development of involuntary movements. To begin with, the movements are regarded by her parents as general restlessness, but later, abnormal facial grimacing and jerking movements of the arms and legs occur. The child is now having difficulty in performing normal movements of the arms, and walking is becoming increasingly difficult. The abnormal movements appear to be worse in the upper limbs and are more exaggerated on the right side of the body. The movements are made worse when the child becomes excited but disappear completely when she sleeps. The child is recently treated for rheumatic fever. Is there any possible connection between this child's symptoms and the basal nuclei in the cerebral hemispheres?
2. A 40-year-old man complaining of rapid and jerky involuntary movements involving the upper and lower limbs is seen by his physician. The condition started about 6 months ago and is getting progressively worse. He says that he is extremely worried about his health because his father had developed similar symptoms 20 years ago and had died in a mental institution. His wife tells the physician that her husband also suffers from episodes of extreme depression and that she has noticed that he has periods of irritability and impulsive behavior. The physician makes the diagnosis of Huntington chorea. Using your knowledge of neuroanatomy, explain how this disease involves the basal nuclei.
3. A 61-year-old man suddenly develops uncoordinated movements of the trunk and right arm. The right upper limb will suddenly, vigorously, and aimlessly be thrown about, knocking over anything in its path. The patient is recovering from a right-sided hemiplegia, secondary to a cerebral hemorrhage. What is the name given to this clinical sign? Does this condition involve the basal nuclei?

Answers and Explanations to Clinical Problem Solving

1. This child is suffering from Sydenham chorea (see p. 315). This condition occurs, in the majority of cases, in female children between the ages of 5 and 15 years. It is characterized by the presence of rapid, irregular, involuntary movements that are purposeless. The disease is associated with rheumatic fever, and complete recovery is the rule.
2. Huntington chorea is a progressive inherited disease that usually appears between the ages of 30 and

45 years. The involuntary movements are usually more rapid and jerky than those seen in patients with Sydenham chorea. Progressive mental changes lead to dementia and death. The GABA-secreting, substance P–secreting, and acetylcholine-secreting neurons of the striatonigral pathway progressively degenerate. This results in the dopamine-secreting neurons of the substantia nigra becoming overactive; thus, the nigrostriatal pathway inhibits the caudate nucleus and the putamen. This causes the involuntary movements. Atrophy of the caudate nucleus and putamen occurs.

3. The clinical sign is known as hemiballismus. The sudden onset is usually caused by vascular impairment due to hemorrhage or occlusion. Yes, hemiballismus does involve the basal nuclei; it is the result of destruction of the contralateral subthalamic nucleus or its neuronal connections, causing the violent, uncoordinated movements of the axial and proximal limb muscles.

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 basal nuclei (ganglia):
   (a) The caudate nucleus and the red nucleus form the neostriatum (striatum).
   (b) The head of the caudate nucleus is connected to the putamen.
   (c) The tegmentum of the midbrain forms part of the basal nuclei.
   (d) The internal capsule lies lateral to the globus pallidus.
   (e) The basal nuclei are formed of white matter.
2. The following statements concern the basal nuclei (ganglia):
   (a) The amygdaloid nucleus is connected to the caudate nucleus.
   (b) The lentiform nucleus is completely divided by the external capsule into the globus pallidus and the putamen.
   (c) The claustrum does not form part of the basal nuclei.
   (d) The corpus striatum lies medial to the thalamus.
   (e) The function of the claustrum is well known.
3. The following statements concern the basal nuclei (ganglia):
   (a) The corpus striatum is made up of the caudate nucleus and the amygdaloid nucleus.
   (b) The head of the caudate nucleus lies lateral to the internal capsule.
   (c) The insula forms part of the basal nuclei.
   (d) The tail of the caudate nucleus lies in the roof of the lateral ventricle.
   (e) The subthalamic nuclei are functionally closely related to the basal nuclei and are considered to be part of them.
4. The following statements concern the caudate nucleus:
   (a) It is divided into a head, neck, trunk, and tail.
   (b) It is an M-shaped mass of gray matter.
   (c) The body of the caudate nucleus forms part of the roof of the body of the lateral ventricle.
   (d) The head lies medial to the anterior horn of the lateral ventricle.
   (e) The tail terminates anteriorly in the amygdaloid nucleus.
5. The following statements concern the afferent corticostriate fibers to the corpus striatum:
   (a) Each part of the cerebral cortex is randomly projected to different parts of the corpus striatum.
   (b) Glutamate is not the neurotransmitter.
   (c) All parts of the cerebral cortex send fibers to the caudate nucleus and putamen.
   (d) The smallest input is from the sensory motor part of the cerebral cortex.
   (e) Most of the projections are from the cortex of the opposite side.
6. The following statements concern the nigrostriatal fibers:
   (a) The neurons in the substantia nigra send axons to the putamen.
   (b) Acetylcholine is the neurotransmitter.
   (c) The nigrostriatal fibers are stimulatory in function.
   (d) The caudate nucleus does not receive axons from the substantia nigra.
   (e) Parkinson disease is caused by an increase in the release of dopamine within the corpus striatum.
7. The following statements concern the efferent fibers of the corpus striatum:
   (a) Many of the efferent fibers descend directly to the motor nuclei of the cranial nerves.
   (b) Some of the striatopallidal fibers have GABA as the neurotransmitter.
   (c) The striatonigral fibers pass from the red nucleus to the substantia nigra.
   (d) Many of the efferent fibers pass directly to the cerebellum.
   (e) The anterior horn cells of the spinal cord are influenced directly by the efferent fibers from the corpus striatum.

8. The following statements concern the functions of the basal nuclei (ganglia):
   (a) The corpus striatum integrates information received directly from the cerebellar cortex.
   (b) The outflow of the basal nuclei is channeled through the globus pallidus to the sensory areas of the cerebral cortex, thus influencing muscular activities.
   (c) The globus pallidus only influences the movements of the axial part of the body.
   (d) The activities of the globus pallidus precede the activities of the motor cortex concerned with discrete movements of the hands and feet.
   (e) The activities of the basal nuclei are suppressed by information received from the sensory cortex, the thalamus, and the brainstem.

Matching Questions. Directions: The following questions apply to Figure 10-10. Match the numbers listed below 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.

9. Number 1	(a) Anterior horn of lateral ventricle
10. Number 2	(b) Internal capsule
11. Number 3	(c) Claustrum
12. Number 4	(d) Putamen
13. Number 5	(e) External capsule
14. Number 6	(f) Globus pallidus
	(g) None of the above

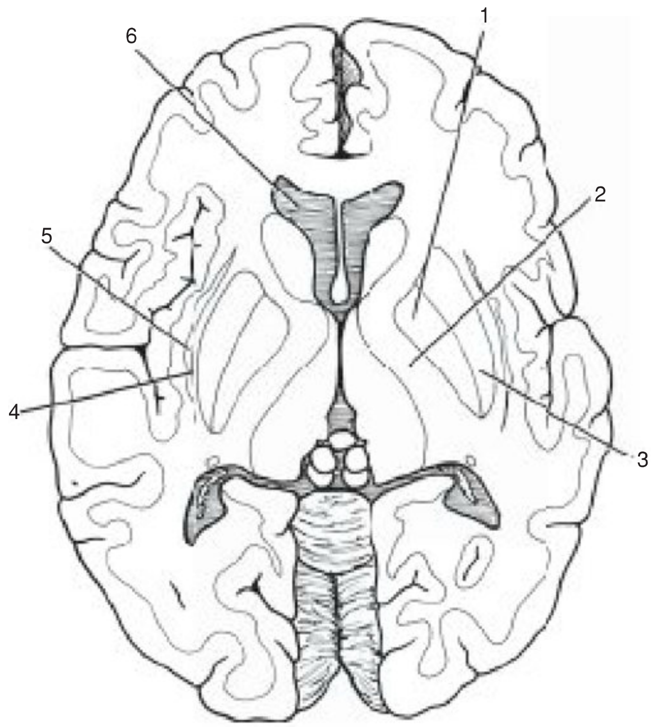


Figure 10-10 Horizontal section of the cerebrum.

Answers and Explanations to Review Questions

1. B is correct. The head of the caudate nucleus is connected to the putamen of the lentiform nucleus (see Fig. 10-1). A. The caudate nucleus and the putamen form the neostriatum. C. The tegmentum of the midbrain does not form part of the basal nuclei. D. The internal capsule lies medial to the apex of the globus pallidus (see Fig. 10-2). E. The basal nuclei are formed of gray matter.
2. A is correct. The amygdaloid nucleus is connected to the caudate nucleus (see Fig. 10-1). B. The lentiform nucleus is not divided by the external capsule into the globus pallidus and the putamen (see Fig. 10-2). C. The claustrum forms part of the basal nuclei. D. The corpus striatum lies lateral to the thalamus (see Fig. 10-2). E. The function of the claustrum is unknown.
3. D is correct. The tail of the caudate nucleus lies in the roof of the lateral ventricle (see Fig. 10-2). A. The corpus striatum is made up of the caudate nucleus and the lentiform nucleus. B. The head of the caudate nucleus lies medial to the internal capsule (see Fig. 10-2). C. The insula does not form part of the basal nuclei. E. The subthalamic nuclei are functionally closely related to the basal nuclei but are not considered to be part of them.
4. E is correct. The tail of the caudate nucleus terminates anteriorly in the amygdaloid nucleus (see Fig. 10-1). A. The caudate nucleus is divided into the head, body, and tail (see Fig. 10-1). B. The caudate nucleus is a C-shaped mass of gray matter (see Fig. 10-1). C. The body of the caudate nucleus forms part of the floor of the body of the lateral ventricle (see Fig. 10-1). D. The head of the caudate nucleus lies lateral to the anterior horn of the lateral ventricle (see Fig. 10-2).
5. C is correct. All parts of the cerebral cortex send fibers to the caudate nucleus and putamen. A. Each part of the cerebral cortex is projected to specific parts of the corpus striatum. B. Glutamate is the neurotransmitter at the nerve endings of the corticostriate fibers to the corpus striatum (see Fig. 10-4). D. The largest input to the different parts of the corpus striatum is from the sensory motor part of the cerebral cortex. E. Most of the projection fibers are from the cerebral cortex of the same side.
6. A is correct. The neurons in the substantia nigra send axons to the putamen (see Fig. 10-3). B. Dopamine is the neurotransmitter at the nerve endings of the nigrostriatal fibers. C. The nigrostriatal fibers are inhibitory in function. D. The caudate nucleus

does receive axons from the substantia nigra. E. Parkinson disease is caused by a reduction in the release of dopamine within the corpus striatum.

7. B is correct. Some of the striatopallidal fibers have GABA as the neurotransmitter. A. None of the efferent fibers from the corpus striatum descend directly to the motor nuclei of the cranial nerves. C. The striatonigral fibers pass from the caudate nucleus to the substantia nigra (see Fig. 10-3). D. No efferent fibers from the corpus striatum pass directly to the cerebellum. E. The anterior horn cells of the spinal cord are not influenced directly by the efferent fibers from the corpus striatum.
8. D is correct. The activities of the globus pallidus precede the activities of the motor cerebral cortex concerned with discrete movements of the hands and feet. A. The corpus striatum does not integrate information received directly from the cerebellar cortex. B. The outflow of the basal nuclei is channeled through the globus pallidus to the motor areas of the cerebral cortex, thus influencing muscular activities. C. The globus pallidus influences movements of the entire body. E. The activities of the basal nuclei are initiated by information received from the sensory cortex, the thalamus, and the brainstem.

The answers for Figure 10-10, which shows a horizontal section of the cerebrum, are as follows:

9. F is correct. Structure 1 is the globus pallidus.
10. B is correct. Structure 2 is the internal capsule.
11. D is correct. Structure 3 is the putamen.
12. E is correct. Structure 4 is the external capsule.
13. C is correct. Structure 5 is the claustrum.
14. A is correct. Structure 6 is the anterior horn of the lateral ventricle.

11 Cranial Nerve Nuclei

CHAPTER OBJECTIVES

- To learn the basic information regarding the motor and sensory nuclei of the cranial nerves, including their locations and central connections
- Understand the functional ramifications of lesions to cranial nerve nuclei versus damage of the cranial nerve proper

A 49-year-old man wakes up one morning to find the right side of his face paralyzed. When examined by his local medical practitioner, he is found to have complete paralysis of the entire right side of the face. He is also found to have severe hypertension. The patient talks with slightly slurred speech. The physician tells the patient that he has suffered a mild stroke, and he is admitted to the hospital.

The patient is later seen by a neurologist who disagrees with the diagnosis. The original physician grouped together the facial paralysis, the slurred speech, and the hypertension and, in the absence of other findings, made the incorrect diagnosis of cerebral hemorrhage. A lesion of the corticonuclear fibers on one side of the brain will cause paralysis only of the muscles of the lower part of the opposite side of the face. This patient has complete paralysis of the entire right side of the face, which could only be caused by a lesion of the lower motor neuron. The correct diagnosis was Bell palsy, an inflammation of the connective tissue sheath of the facial nerve, which temporarily interfered with the functions of the axons of the right facial nerve. This case provides a good example of how knowledge of the central connections of a cranial nerve enables a physician to make the correct diagnosis.

The cranial nerves are commonly damaged by trauma or disease, and testing for their integrity forms part of every physical examination.

CRANIAL NERVES

The 12 pairs of cranial nerves (CNs) leave the brain and pass through foramina and fissures in the skull. All the nerves are distributed in the head and neck, except CN X, which also supplies structures in the thorax and abdomen. The CNs are named as follows:

1. Olfactory
2. Optic
3. Oculomotor
4. Trochlear
5. Trigeminal
6. Abducens
7. Facial
8. Vestibulocochlear
9. Glossopharyngeal
10. Vagus
11. Accessory
12. Hypoglossal

See Atlas Plates 1, 6, and 8.

CRANIAL NERVE ORGANIZATION

The olfactory, optic, and vestibulocochlear nerves are entirely sensory. The oculomotor, trochlear, abducens, accessory, and hypoglossal nerves are entirely motor. The trigeminal, facial, glossopharyngeal, and vagus nerves are both sensory and motor nerves. The letter symbols commonly used to indicate the functional components of each cranial nerve are shown in Table 11-1. The cranial nerves have central motor and/or sensory nuclei within the brain and peripheral nerve fibers that emerge from the brain and exit from the skull to reach their effector or sensory organs.

The different components of the cranial nerves, their functions, and the openings in the skull through which the nerves leave the cranial cavity are summarized in Table 11-2.

Cranial Nerve Motor Nuclei

The motor nuclei of the cranial nerves receive impulses from the cerebral cortex through the corticonuclear

Table 11-1 The Letter Symbols Commonly Used to Indicate the Functional Components of Each Cranial Nerve

Component	Function	Letter Symbols
Afferent Fibers	**Sensory**	
General somatic afferent	General sensations	GSA
Special somatic afferent	Hearing, balance, vision	SSA
General visceral afferent	Viscera	GVA
Special visceral afferent	Smell, taste	SVA
Efferent Fibers		
General somatic efferent	Somatic striated muscles	GSE
General visceral efferent	Glands and smooth muscles (parasympathetic innervation)	GVE
Special visceral efferent	Branchial arch striated muscles	SVE

Table 11-2 Cranial Nerves

Number	Name	Components[a]	Function	Opening in Skull
I	Olfactory	Sensory (SVA)	Smell	Openings in cribriform plate of ethmoid
II	Optic	Sensory (SSA)	Vision	Optic canal
III	Oculomotor	Motor (GSE, GVE)	Raises upper eyelid, turns eyeball upward, downward, and medially; constricts pupil; accommodates eye	Superior orbital fissure
IV	Trochlear	Motor (GSE)	Assists in turning eyeball downward and laterally	Superior orbital fissure
V	Trigeminal[b]			
	Ophthalmic division	Sensory (GSA)	Cornea, skin of forehead, scalp, eyelids, and nose; also mucous membrane of paranasal sinuses and nasal cavity	Superior orbital fissure
	Maxillary division	Sensory (GSA)	Skin of face over maxilla; teeth of upper jaw; mucous membrane of nose, the maxillary sinus, and palate	Foramen rotundum
	Mandibular division	Motor (SVE)	Muscles of mastication, mylohyoid, anterior belly of digastric, tensor veli palatini, and tensor tympani	Foramen ovale
		Sensory (GSA)	Skin of cheek, skin over mandible and side of head, teeth of lower jaw and temporomandibular joint; mucous membrane of mouth and anterior part of tongue	
VI	Abducent	Motor (GSE)	Lateral rectus muscle turns eyeball laterally	Superior orbital fissure
VII	Facial	Motor (SVE)	Muscles of face and scalp, stapedius muscle, posterior belly of digastric, and stylohyoid muscles	Internal acoustic meatus, facial canal, stylomastoid foramen
		Sensory (SVA)	Taste from anterior two-thirds of tongue, from floor of mouth and palate	
		Secretomotor (GVE) parasympathetic	Submandibular and sublingual salivary glands, the lacrimal gland, and glands of nose and palate	

(continued)

Table 11-2 Cranial Nerves (*Continued*)

Number	Name	Components[a]	Function	Opening in Skull
VIII	Vestibulocochlear			
	Vestibular	Sensory (SSA)	From utricle and saccule and semicircular canals—position and movement of head	Internal acoustic meatus
	Cochlear	Sensory (SSA)	Organ of Corti—hearing	
IX	Glossopharyngeal	Motor (SVE)	Stylopharyngeus muscle—assists swallowing	Jugular foramen
		Secretomotor (GVE) parasympathetic	Parotid salivary gland	
		Sensory (GVA, SVA, GSA)	General sensation and taste from posterior third of tongue and pharynx; carotid sinus (baroreceptor); and carotid body (chemoreceptor)	
X	Vagus	Motor (GVE, SVE) Sensory (GVA, SVA, GSA)	Heart and great thoracic blood vessels; larynx, trachea, bronchi, and lungs; alimentary tract from pharynx to splenic flexure of colon; liver, kidneys, and pancreas	Jugular foramen
XI	Accessory			
	Cranial root	Motor (SVE)	Muscles of soft palate (except tensor veli palatini), pharynx (except stylopharyngeus), and larynx (except cricothyroid) in branches of vagus	Jugular foramen
	Spinal root	Motor (SVE)	Sternocleidomastoid and trapezius muscles	
XII	Hypoglossal	Motor (GSE)	Muscles of tongue (except palatoglossus) controlling its shape and movement	Hypoglossal canal

[a]The letter symbols are explained in Table 11-1.
[b]The trigeminal nerve also carries proprioceptive impulses from the muscles of mastication and the facial and extraocular muscles.

(corticobulbar) fibers. These fibers originate from the pyramidal cells in the inferior part of the precentral gyrus (area 4) and from the adjacent part of the postcentral gyrus. The corticonuclear fibers descend through the **corona radiata** and the **genu of the internal capsule**. They pass through the midbrain just medial to the corticospinal fibers in the **basis pedunculi** and end by synapsing either directly with the lower motor neurons within the cranial nerve nuclei or indirectly through the **internuncial neurons**. The corticonuclear fibers thus constitute the **first-order neuron** of the descending pathway, the internuncial neuron constitutes the **second-order neuron**, and the lower motor neuron constitutes the **third-order neuron**.

The majority of the corticonuclear fibers to the motor cranial nerve nuclei cross the median plane before reaching the nuclei. Bilateral connections are present for all the cranial motor nuclei except for part of the facial nucleus that supplies the muscles of the lower part of the face and a part of the hypoglossal nucleus that supplies the genioglossus muscle.

Somatic Motor and Branchiomotor Nuclei

The somatic motor and branchiomotor nerve fibers of a cranial nerve are the axons of nerve cells situated within the brain. These nerve cell groups form motor nuclei and innervate striated muscle. Each nerve cell with its processes is referred to as a **lower motor neuron**. Such a nerve cell is, therefore, equivalent to the motor cells in the anterior gray columns of the spinal cord.

General Visceral Motor Nuclei

The general visceral motor nuclei form the cranial outflow of the parasympathetic portion of the autonomic nervous system. They are the **Edinger–Westphal nucleus** of the oculomotor nerve, the **superior salivatory** and **lacrimal nuclei** of the facial nerve, the **inferior salivatory nucleus** of the glossopharyngeal nerve, and the **dorsal motor nucleus** of the vagus. These nuclei receive numerous afferent fibers, including descending pathways from the hypothalamus.

Cranial Nerve Sensory Nuclei

Sensory nuclei of the cranial nerves include somatic and visceral afferent nuclei. The sensory or afferent parts of a cranial nerve are the axons of nerve cells outside the brain and are situated in ganglia on the nerve trunks (equivalent to posterior root ganglion of a spinal nerve) or may be situated in a sensory organ, such as the nose, eye, or ear. These cells and their processes form the **first-order neuron**. The central processes of these cells enter the brain and terminate by synapsing with cells forming the sensory nuclei. These cells and their processes form the **second-order neuron**. Axons from these nuclear cells now cross the midline and ascend to other sensory nuclei, such as the thalamus, where they synapse. The nerve cells of these nuclei form the **third-order neuron**, and their axons terminate in the cerebral cortex.

OLFACTORY NERVES (CRANIAL NERVE I)

The olfactory nerves arise from the olfactory receptor nerve cells in the olfactory mucous membrane located in the upper part of the nasal cavity above the level of the superior concha (Fig. 11-1). The **olfactory receptor cells** are scattered among supporting cells. Each receptor cell consists of a small bipolar nerve cell with

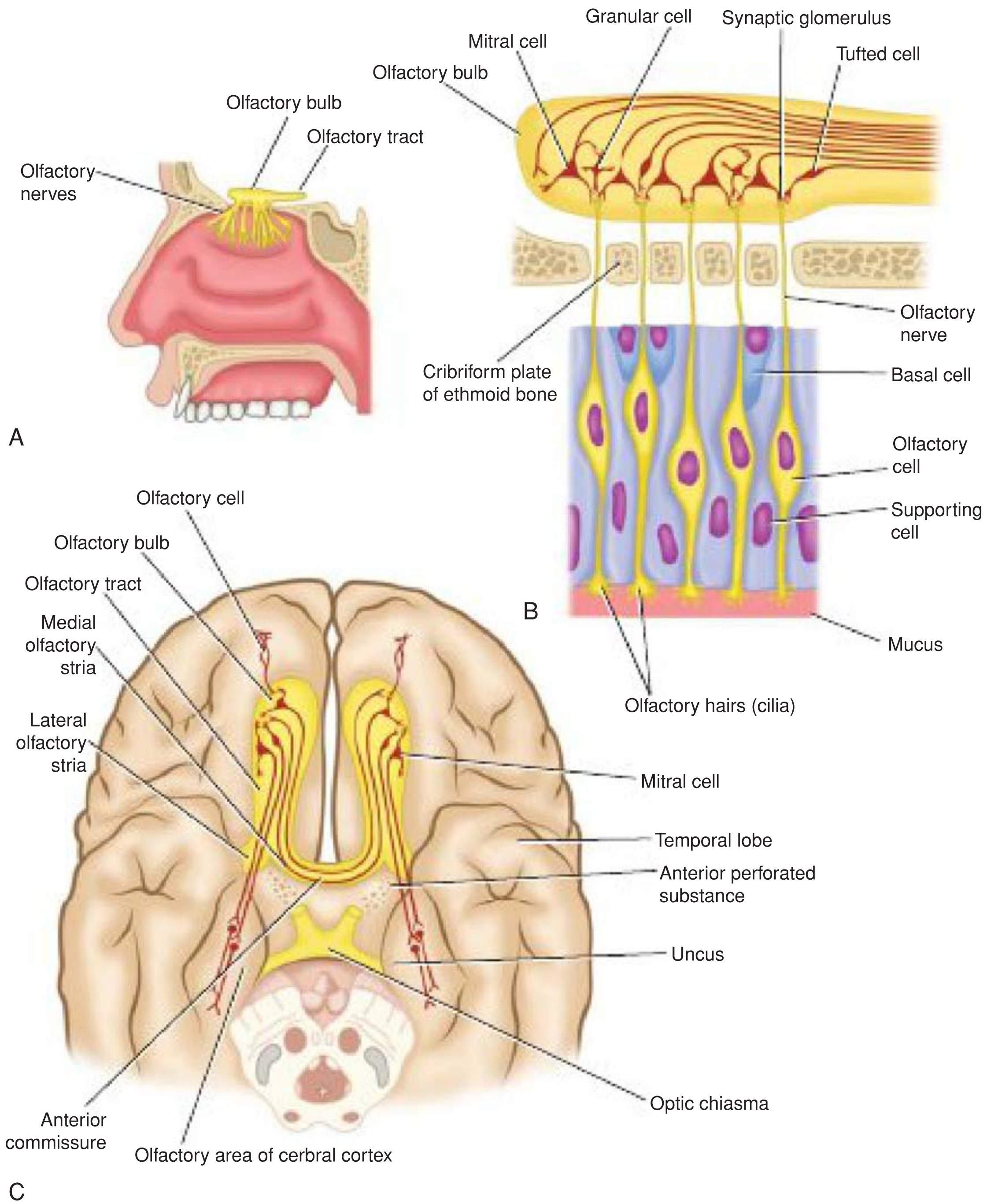


Figure 11-1 **A:** Distribution of olfactory nerves on the lateral wall of the nose. **B:** Connections between the olfactory cells and the neurons of the olfactory bulb. **C:** Connections between the olfactory cell and the rest of the olfactory system.

a coarse peripheral process that passes to the surface of the membrane and a fine central process. From the coarse peripheral process, a number of short cilia arise, the **olfactory hairs**, which project into the mucus covering the surface of the mucous membrane. These projecting hairs react to odors in the air and stimulate the olfactory cells.

The fine central processes form the **olfactory nerve fibers** (see Fig. 11-1A,B). Bundles of these nerve fibers pass through the openings of the cribriform plate of the ethmoid bone to enter the olfactory bulb. The olfactory nerve fibers are unmyelinated and are covered with Schwann cells.

Olfactory Bulb

This ovoid structure possesses several types of nerve cells, the largest of which is the **mitral cell** (see Fig. 11-1C). The incoming olfactory nerve fibers synapse with the dendrites of the mitral cells and form rounded areas known as **synaptic glomeruli**. Smaller nerve cells, called **tufted cells** and **granular cells**, also synapse with the mitral cells. The olfactory bulb, in addition, receives axons from the contralateral olfactory bulb through the olfactory tract.

Olfactory Tract

This narrow band of white matter runs from the posterior end of the olfactory bulb beneath the inferior surface of the frontal lobe of the brain (see Fig. 11-1B). It consists of the axons of the mitral and tufted cells of the bulb and some centrifugal fibers from the opposite olfactory bulb.

As the olfactory tract reaches the **anterior perforated substance**, it divides into **medial** and **lateral olfactory striae**. The lateral stria carries the axons to the **olfactory area of the cerebral cortex**, namely, the **periamygdaloid** and **prepiriform areas** (see Fig. 11-1C). The medial olfactory stria carries the fibers that cross the median plane in the anterior commissure to pass to the olfactory bulb of the opposite side.

The periamygdaloid and prepiriform areas of the cerebral cortex are often known as the **primary olfactory cortex**. The **entorhinal area** (**area 28**) of the parahippocampal gyrus, which receives numerous connections from the primary olfactory cortex, is called the **secondary olfactory cortex**. These areas of the cortex are responsible for the appreciation of olfactory sensations. Note that in contrast to all other sensory pathways, the olfactory afferent pathway has only two neurons and reaches the cerebral cortex without synapsing in one of the thalamic nuclei.

The primary olfactory cortex sends nerve fibers to many other centers within the brain to establish connections for emotional and autonomic responses to olfactory sensations.

OPTIC NERVE (CRANIAL NERVE II)

The fibers of the optic nerve are the axons of the cells in the **ganglionic layer** of the retina. They converge on the **optic disc** and exit from the eye, about 3 or 4 mm to the nasal side of its center, as the optic nerve (Fig. 11-2). The fibers of the optic nerve are myelinated, but the sheaths are formed from oligodendrocytes rather than Schwann cells, since the optic nerve is comparable to a tract within the central nervous system.

The optic nerve leaves the orbital cavity through the optic canal and unites with the optic nerve of the opposite side to form the **optic chiasma**.

Optic Chiasma

The optic chiasma is situated at the junction of the anterior wall and floor of the third ventricle. Its anterolateral angles are continuous with the optic nerves, and the posterolateral angles are continuous with the optic tracts. In the chiasma, the fibers from the nasal (medial) half of each retina, including the nasal half of the **macula**, cross the midline and enter the optic tract of the opposite side, while the fibers from the temporal (lateral) half of each retina, including the temporal half of the **macula**, pass posteriorly in the optic tract of the same side.

Optic Tract

The optic tract emerges from the optic chiasma and passes posterolaterally around the cerebral peduncle. Most of the fibers now terminate by synapsing with nerve cells in the **lateral geniculate body**, which is a small projection from the posterior part of the thalamus. A few of the fibers pass to the **pretectal nucleus** and the **superior colliculus** of the midbrain and are concerned with light reflexes (Fig. 11-3).

Lateral Geniculate Body

The lateral geniculate body is a small, oval swelling projecting from the **pulvinar of the thalamus**. It consists of six layers of cells, on which synapse the axons from the optic tract. The axons of the nerve cells within the geniculate body leave it to form the **optic radiation** (see Fig. 11-2).

Optic Radiation

The fibers of the optic radiation are the axons of the nerve cells of the lateral geniculate body. The tract passes posteriorly through the retrolenticular part of the **internal capsule** and terminates in the **visual cortex** (**area 17**), which occupies the upper and lower lips of the calcarine sulcus on the medial surface of the cerebral hemisphere. The visual association cortex (areas 18 and 19) is responsible for recognition of objects and perception of color.

Visual Pathway and Binocular Vision Neurons

Four neurons conduct visual impulses to the visual cortex: (1) **rods** and **cones**, which are specialized receptor neurons in the retina; (2) **bipolar neurons**, which connect the rods and cones to the ganglion cells; (3) **ganglion**

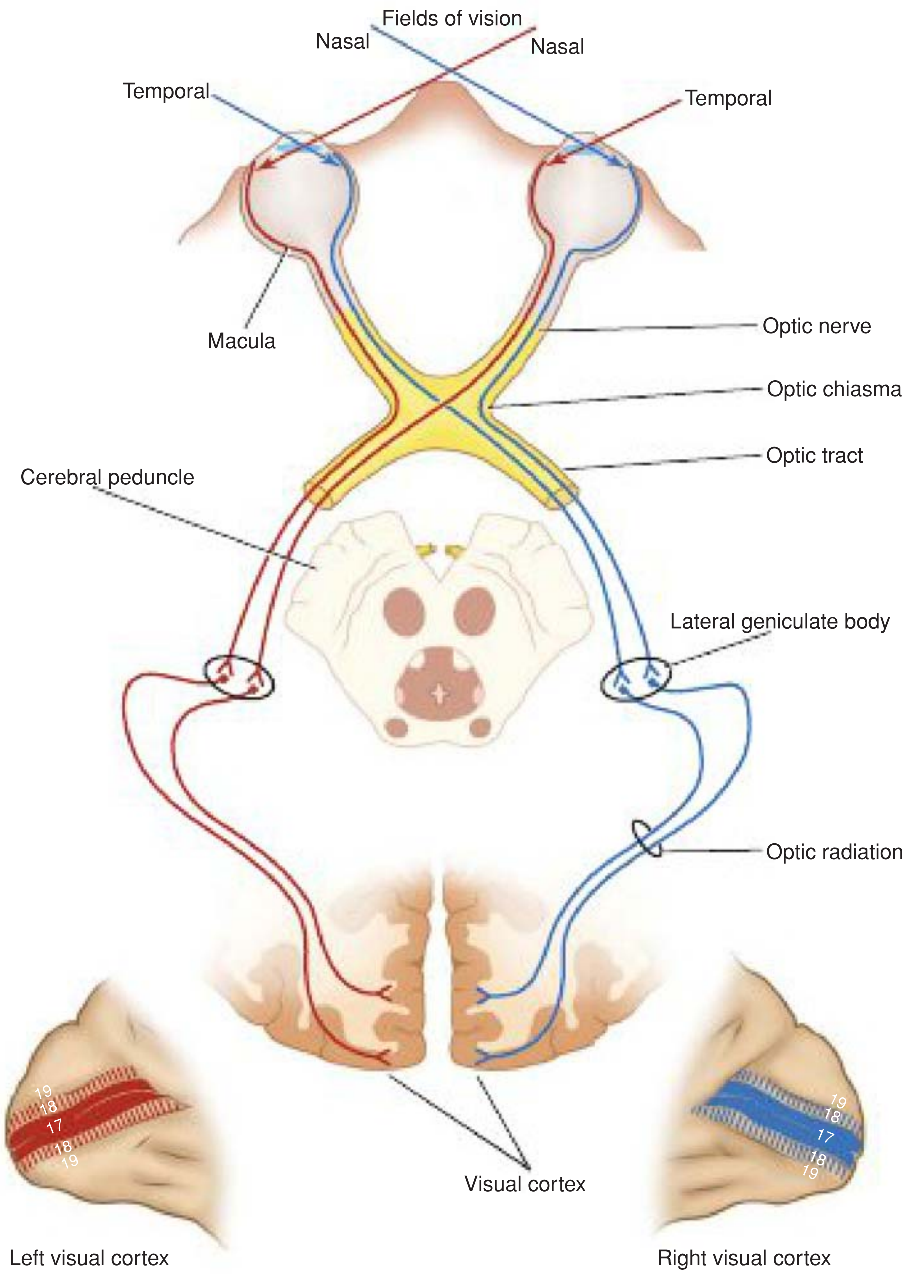


Figure 11-2 Optic pathway.

cells, whose axons pass to the lateral geniculate body; and (4) **neurons of the lateral geniculate body**, whose axons pass to the cerebral cortex.

In binocular vision, the right and left fields of vision are projected on portions of both retinae. The image of an object in the right field of vision is projected on the nasal half of the right retina and the temporal half of the left retina. In the optic chiasma, the axons from these two retinal halves are combined to form the left optic tract. The lateral geniculate body neurons now project the complete right field of vision on the visual cortex of the left hemisphere and the left visual field on the visual cortex of the right hemisphere. The lower retinal quadrants (upper field of vision) project on the lower wall of the calcarine sulcus, while the upper retinal quadrants (lower field of vision) project on the upper wall of the sulcus. Note also that the **macula lutea** is represented on the posterior part of area 17, and the periphery of the retina is represented anteriorly.

Visual Reflexes

Several unique neuronal pathways exert involuntary control over our vision for optimal visual function, protection, and cognitive processing.

Direct and Consensual Light Reflexes

If a light is shone into one eye, the pupils of both eyes normally constrict. The constriction of the pupil on which the light is shone is called the **direct light reflex**;

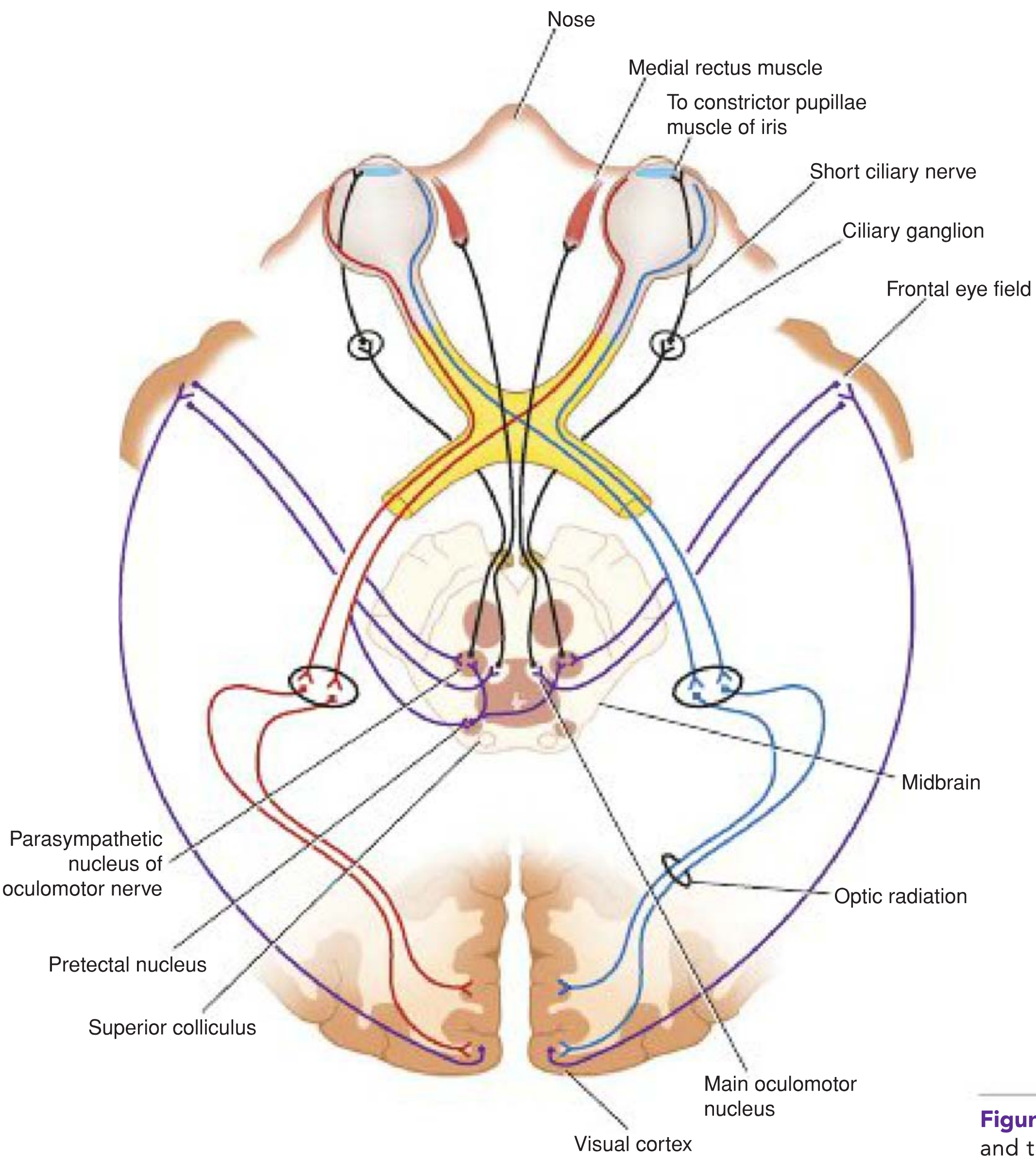


Figure 11-3 Optic pathway and the visual reflexes.

the constriction of the opposite pupil, even though no light fell on that eye, is called the **consensual light reflex** (see Fig. 11-3).

The afferent impulses travel through the optic nerve, optic chiasma, and optic tract. Here, a small number of fibers leave the optic tract and synapse on nerve cells in the **pretectal nucleus**, which lies close to the superior colliculus. The impulses are passed by axons of the pretectal nerve cells to the parasympathetic nuclei (**Edinger–Westphal nuclei**) of the third cranial nerve on **both sides**. Here, the fibers synapse and the parasympathetic nerves travel through the third cranial nerve to the **ciliary ganglion** in the orbit. Finally, postganglionic parasympathetic fibers pass through the **short ciliary nerves** to the eyeball and the **constrictor pupillae muscle** of the iris. Both pupils constrict in the consensual light reflex because the pretectal nucleus sends fibers to the parasympathetic nuclei on both sides of the midbrain. The fibers that cross the median plane do so close to the cerebral aqueduct in the posterior commissure.

Accommodation Reflex

When the eyes are directed from a distant to a near object, contraction of the medial recti brings about convergence of the ocular axes; the lens thickens to increase its refractive power by contraction of the ciliary muscle; and the pupils constrict to restrict the light waves to the thickest central part of the lens. The afferent impulses travel through the optic nerve, the optic chiasma, the optic tract, the lateral geniculate body, and the optic radiation to the visual cortex. The visual cortex is connected to the eye field of the frontal cortex. From here, cortical fibers descend through the internal capsule to the oculomotor nuclei in the midbrain. The oculomotor nerve travels to the medial recti muscles. Some of the descending cortical fibers synapse with the parasympathetic nuclei (Edinger–Westphal nuclei) of the third cranial nerve on **both sides**. Here, the fibers synapse, and the parasympathetic nerves travel through the third cranial nerve to the ciliary ganglion in the orbit. Finally, postganglionic parasympathetic fibers pass through the short ciliary nerves to the **ciliary muscle** and the **constrictor pupillae muscle** of the iris.

Corneal Reflex

Light touching of the cornea or conjunctiva results in blinking of the eyelids. Afferent impulses from the cornea or conjunctiva travel through the ophthalmic division of the trigeminal nerve to the sensory nucleus of the trigeminal nerve (Fig. 11-4A). Internuncial neurons connect with the motor nucleus of the facial nerve on both sides through the medial longitudinal fasciculus. The facial nerve and its branches supply the orbicularis oculi muscle, which causes closure of the eyelids.

Visual Body Reflexes

The automatic scanning movements of the eyes and head that are made when reading, the automatic movement of the eyes, head, and neck toward the source of

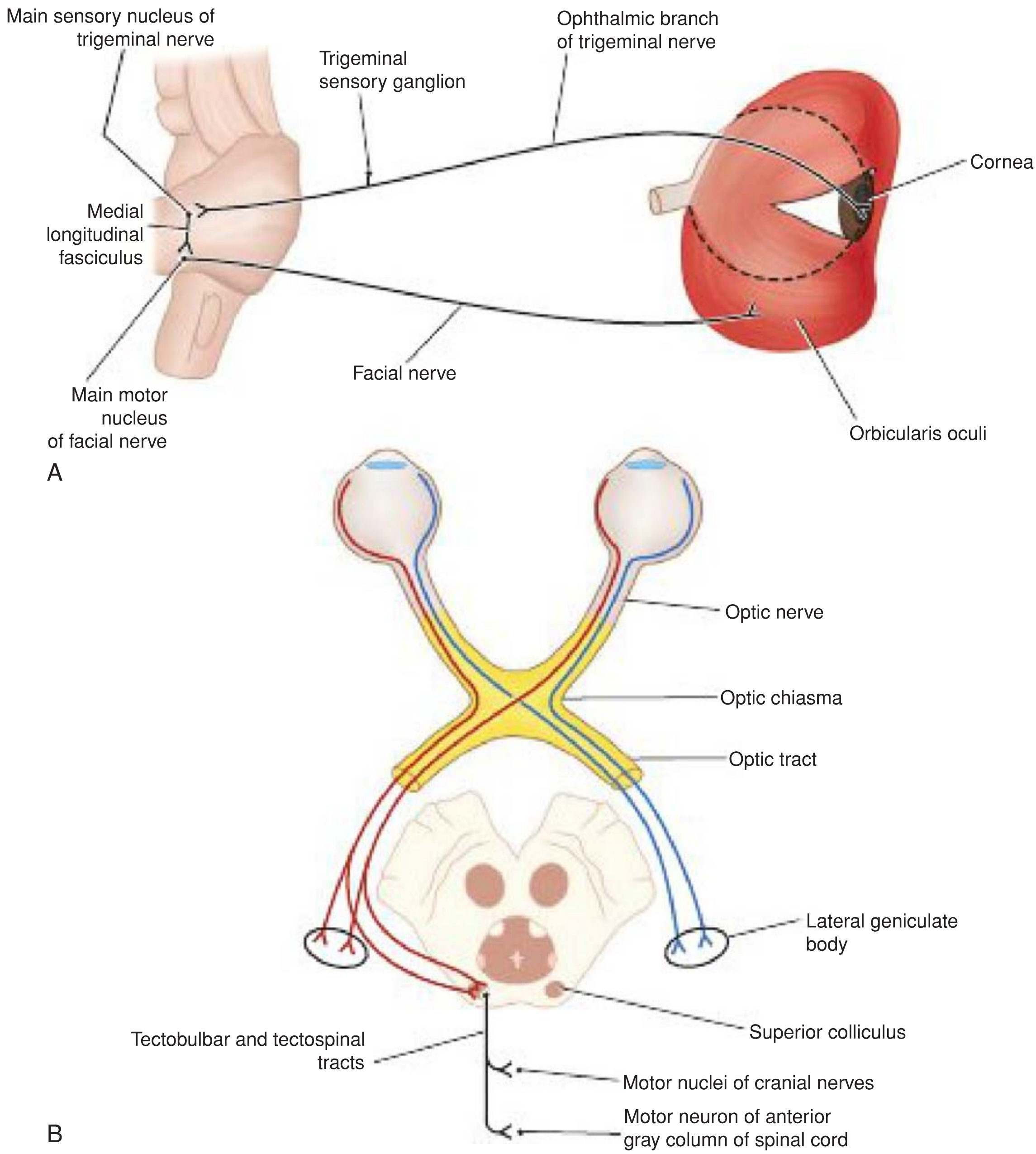


Figure 11-4 **A:** Corneal reflex. **B:** Visual body reflex.

the visual stimulus, and the protective closing of the eyes and even the raising of the arm for protection are reflex actions that involve the following reflex arcs (see Fig. 11-4B). The visual impulses follow the optic nerves, optic chiasma, and optic tracts to the superior colliculi. Here, the impulses are relayed to the tectospinal and tectobulbar (tectonuclear) tracts and to the neurons of the anterior gray columns of the spinal cord and cranial motor nuclei.

Pupillary Skin Reflex

The pupil will dilate if the skin is painfully stimulated by pinching. The afferent sensory fibers are believed to have connections with the efferent preganglionic sympathetic neurons in the lateral gray columns of the first and second thoracic segments of the spinal cord. The **white rami communicantes** of these segments pass to the sympathetic trunk, and the preganglionic fibers ascend to the superior **cervical sympathetic ganglion**. The postganglionic fibers pass through the **internal carotid plexus**, **long ciliary nerves**, and **short ciliary nerves** to the dilator pupillae muscle of the iris.

OCULOMOTOR NERVE (CRANIAL NERVE III)

The oculomotor nerve is entirely motor in function.

Oculomotor Nerve Nuclei

The oculomotor nerve has two motor nuclei: (1) the main motor nucleus and (2) the accessory parasympathetic nucleus.

The **main oculomotor nucleus** is situated in the anterior part of the gray matter that surrounds the **cerebral aqueduct of the midbrain** (Fig. 11-5). It lies at the level of the **superior colliculus**. The nucleus consists of groups of nerve cells that supply all the extrinsic muscles of the eye except the superior oblique and the lateral rectus. The outgoing nerve fibers pass anteriorly through the red nucleus and emerge on the anterior surface of the midbrain in the **interpeduncular fossa**. The main oculomotor nucleus receives corticonuclear fibers from both cerebral hemispheres. It receives tectobulbar fibers from the superior colliculus and, through this route, receives information from the visual cortex. It also receives fibers from the medial longitudinal fasciculus, by which it is connected to the nuclei of the fourth, sixth, and eighth cranial nerves.

The **accessory** parasympathetic nucleus (**Edinger–Westphal** nucleus) is situated posterior to the main oculomotor nucleus (see Fig. 11-5A). The axons of the nerve cells, which are preganglionic, accompany the other oculomotor fibers to the orbit. Here, they synapse in the **ciliary** ganglion, and postganglionic fibers pass through the **short** ciliary nerves to the constrictor pupillae of the iris and the ciliary muscles. The accessory parasympathetic nucleus receives corticonuclear fibers for the accommodation reflex, and fibers from the pretectal nucleus for the direct and consensual light reflexes (see Fig. 11-3).

Oculomotor Nerve Course

The oculomotor nerve emerges on the anterior surface of the midbrain (see Fig. 11-5A). It passes forward between the posterior cerebral and the superior cerebellar arteries. It then continues into the middle cranial fossa in the lateral wall of the cavernous sinus. Here, it divides into a superior and an inferior ramus, which enter the orbital cavity through the superior orbital fissure.

The oculomotor nerve supplies the following extrinsic muscles of the eye: the levator palpebrae superioris, superior rectus, medial rectus, inferior rectus, and inferior oblique. It also supplies, through its branch to the ciliary ganglion and the short ciliary nerves, parasympathetic nerve fibers to the following intrinsic muscles: the constrictor pupillae of the iris and ciliary muscles.

Therefore, the oculomotor nerve is entirely motor and is responsible for lifting the upper eyelid; turning the eye upward, downward, and medially; constricting the pupil; and accommodating the eye.

TROCHLEAR NERVE (CRANIAL NERVE IV)

The trochlear nerve is entirely motor in function.

Trochlear Nerve Nucleus

The trochlear nucleus is situated in the anterior part of the gray matter that surrounds the **cerebral aqueduct of the midbrain** (Fig. 11-6). It lies inferior to the oculomotor nucleus at the level of the **inferior colliculus**. The nerve fibers, after leaving the nucleus, pass posteriorly around the central gray matter to reach the posterior surface of the midbrain.

The trochlear nucleus receives corticonuclear fibers from both cerebral hemispheres. It receives the tectobulbar fibers, which connect it to the visual cortex through the superior colliculus (see Fig. 11-6A). It also receives fibers from the **medial longitudinal fasciculus**, by which it is connected to the nuclei of the third, sixth, and eighth cranial nerves.

Trochlear Nerve Course

The trochlear nerve, the most slender of the cranial nerves and the only one to leave the posterior surface of the brainstem, emerges from the midbrain and **immediately decussates with the nerve of the opposite side**. The trochlear nerve passes forward through the middle cranial fossa in the lateral wall of the cavernous sinus and enters the orbit through the superior orbital fissure. The nerve supplies the superior oblique muscle of the eyeball. The trochlear nerve is entirely

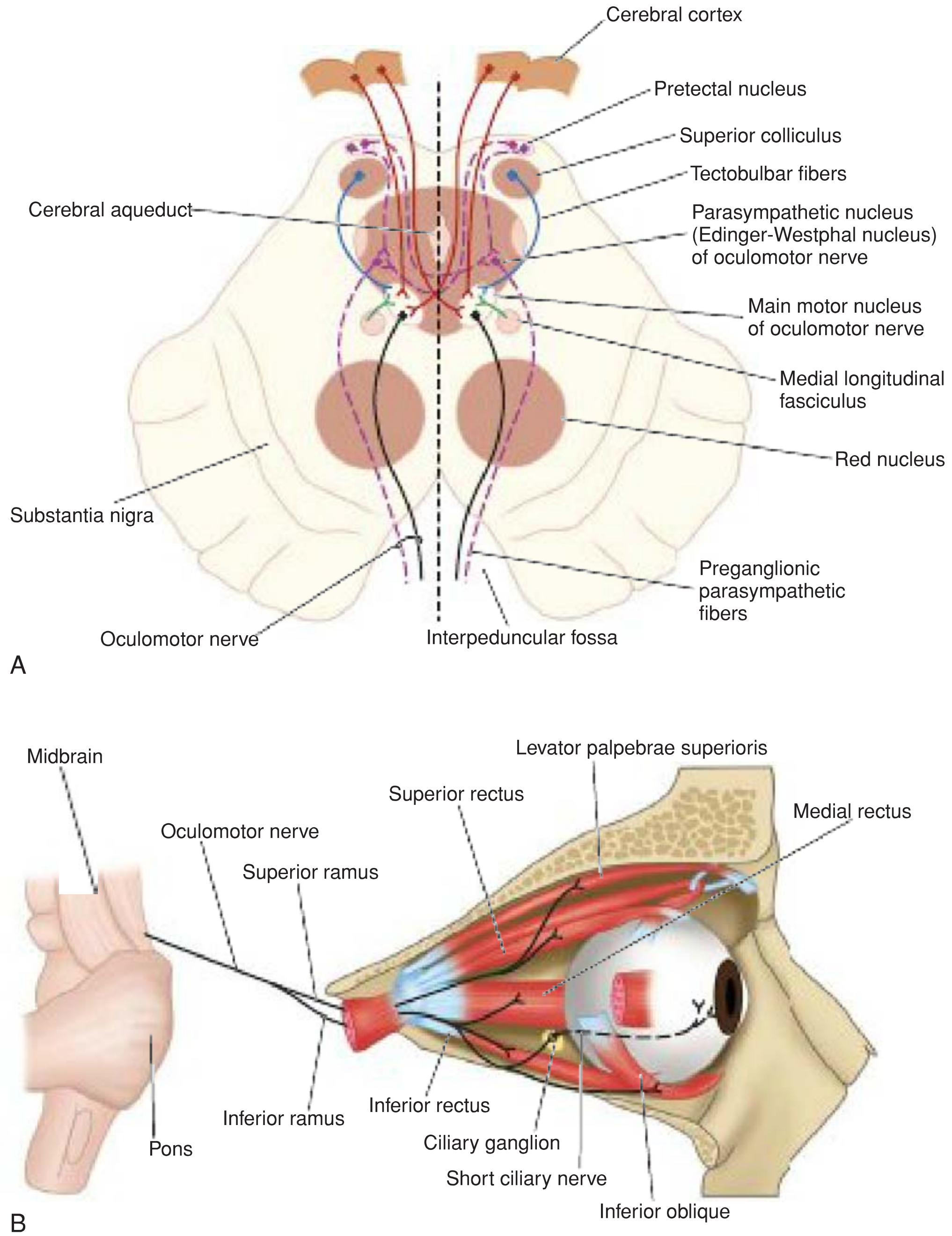


Figure 11-5 **A:** Oculomotor nerve nuclei and their central connections. **B:** The distribution of the oculomotor nerve.

motor and assists in turning the eye downward and laterally.

TRIGEMINAL NERVE (CRANIAL NERVE V)

The trigeminal nerve is the largest cranial nerve and contains both sensory and motor fibers (Fig. 11-7). It is the sensory nerve to the greater part of the head and the motor nerve to several muscles, including the muscles of mastication.

Trigeminal Nerve Nuclei

The trigeminal nerve has four nuclei: (1) the main sensory nucleus, (2) the spinal nucleus, (3) the mesencephalic nucleus, and (4) the motor nucleus.

Main Sensory Nucleus

The main sensory nucleus lies in the posterior part of the pons, lateral to the motor nucleus (see Fig. 11-7A). It is continuous below with the spinal nucleus.

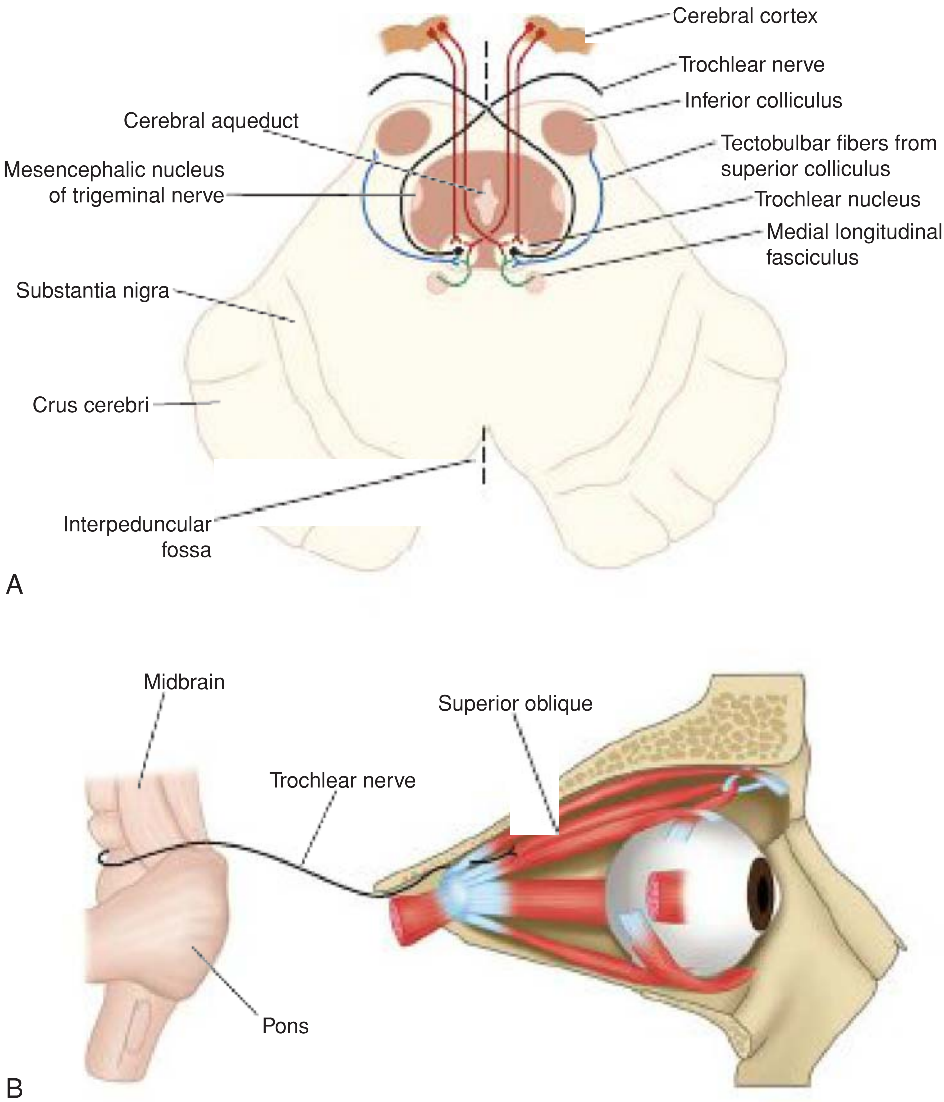


Figure 11-6 **A:** Trochlear nerve nucleus and its central connections. **B:** Distribution of the trochlear nerve.

Spinal Nucleus

The spinal nucleus is continuous superiorly with the main sensory nucleus in the pons and extends inferiorly through the whole length of the medulla oblongata and into the upper part of the spinal cord as far as the second cervical segment (see Fig. 11-7B).

Mesencephalic Nucleus

The mesencephalic nucleus is composed of a column of unipolar nerve cells situated in the lateral part of the gray matter around the cerebral aqueduct. It extends inferiorly into the pons as far as the main sensory nucleus (see Fig. 11-7).

Motor Nucleus

The motor nucleus is situated in the pons, medial to the main sensory nucleus (see Fig. 11-7).

Trigeminal Nerve Sensory Components

The sensations of pain, temperature, touch, and pressure from the skin of the face and mucous membranes travel along axons whose cell bodies are situated in the **semilunar** or **trigeminal** sensory ganglion (see Fig. 11-7B). The central processes of these cells form the large sensory root of the trigeminal nerve. About half the fibers divide into ascending and descending branches when they enter the pons; the remainder ascend or descend without division. The ascending branches terminate in the main sensory nucleus, and the descending branches terminate in the spinal nucleus. The sensations of touch and pressure are conveyed by nerve fibers that terminate in the main sensory nucleus. The sensations of pain and temperature pass to the spinal nucleus. The sensory fibers from the ophthalmic division of the trigeminal nerve terminate in the inferior part of the spinal nucleus;

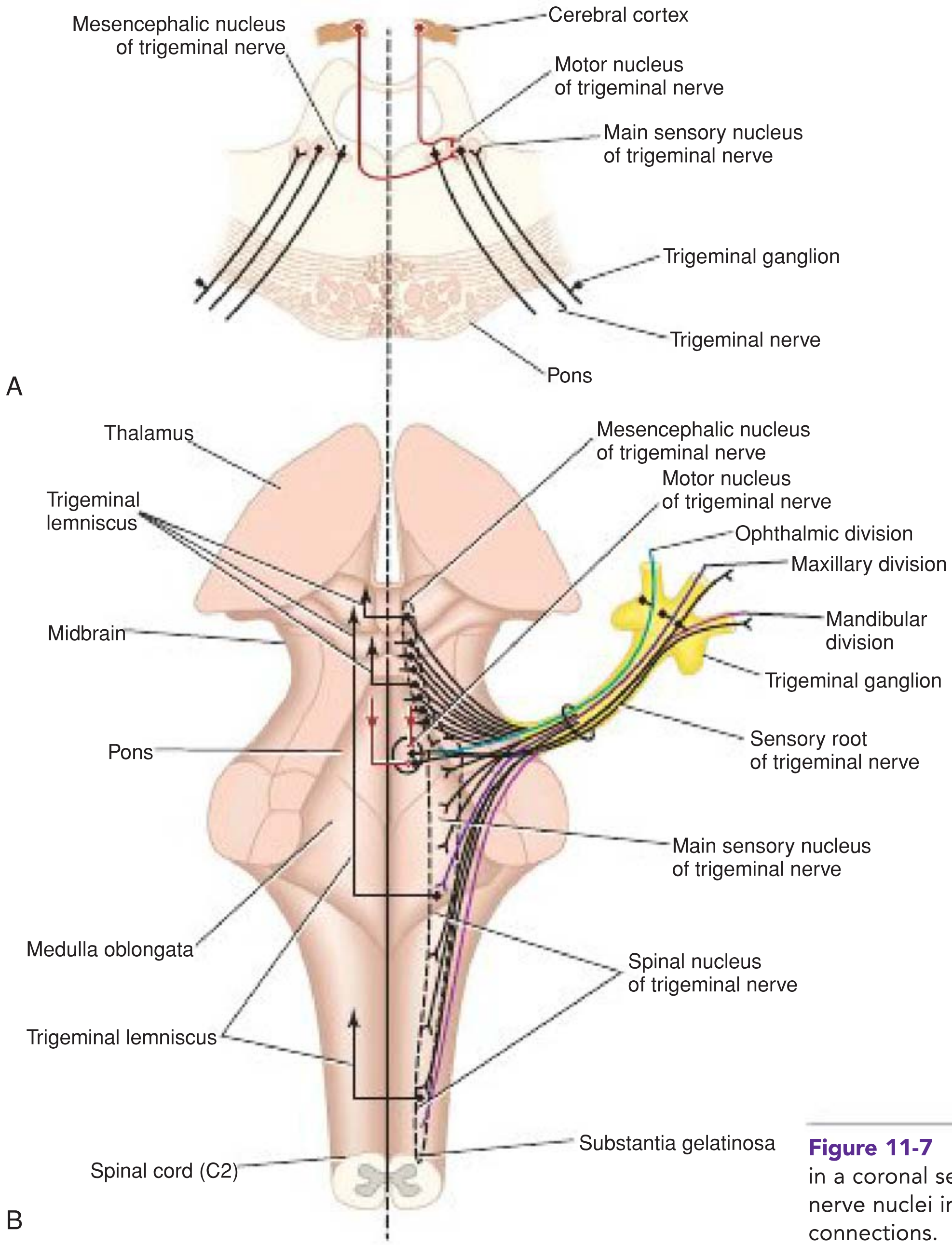


Figure 11-7 **A:** Trigeminal nerve nuclei seen in a coronal section of the pons. **B:** Trigeminal nerve nuclei in the brainstem and their central connections.

fibers from the maxillary division terminate in the middle of the spinal nucleus; and fibers from the mandibular division end in the superior part of the spinal nucleus.

Proprioceptive impulses from the muscles of mastication and from the facial and extraocular muscles are carried by fibers in the sensory root of the trigeminal nerve that have bypassed the semilunar or trigeminal ganglion. The fibers' cells of origin are the unipolar cells of the mesencephalic nucleus.

The axons of the neurons in the main sensory and spinal nuclei and the central processes of the cells in the mesencephalic nucleus now cross the median plane and ascend as the trigeminal lemniscus to terminate on the nerve cells of the ventral posteromedial nucleus of the thalamus. The axons of these cells now travel through the internal capsule to the postcentral gyrus (areas 3, 1, and 2) of the cerebral cortex.

Trigeminal Nerve Motor Component

The motor nucleus receives corticonuclear fibers from both cerebral hemispheres (see Fig. 11-7). It also receives fibers from the reticular formation, the red nucleus, the tectum, and the medial longitudinal fasciculus. In addition, it receives fibers from the mesencephalic nucleus, thereby forming a monosynaptic reflex arc.

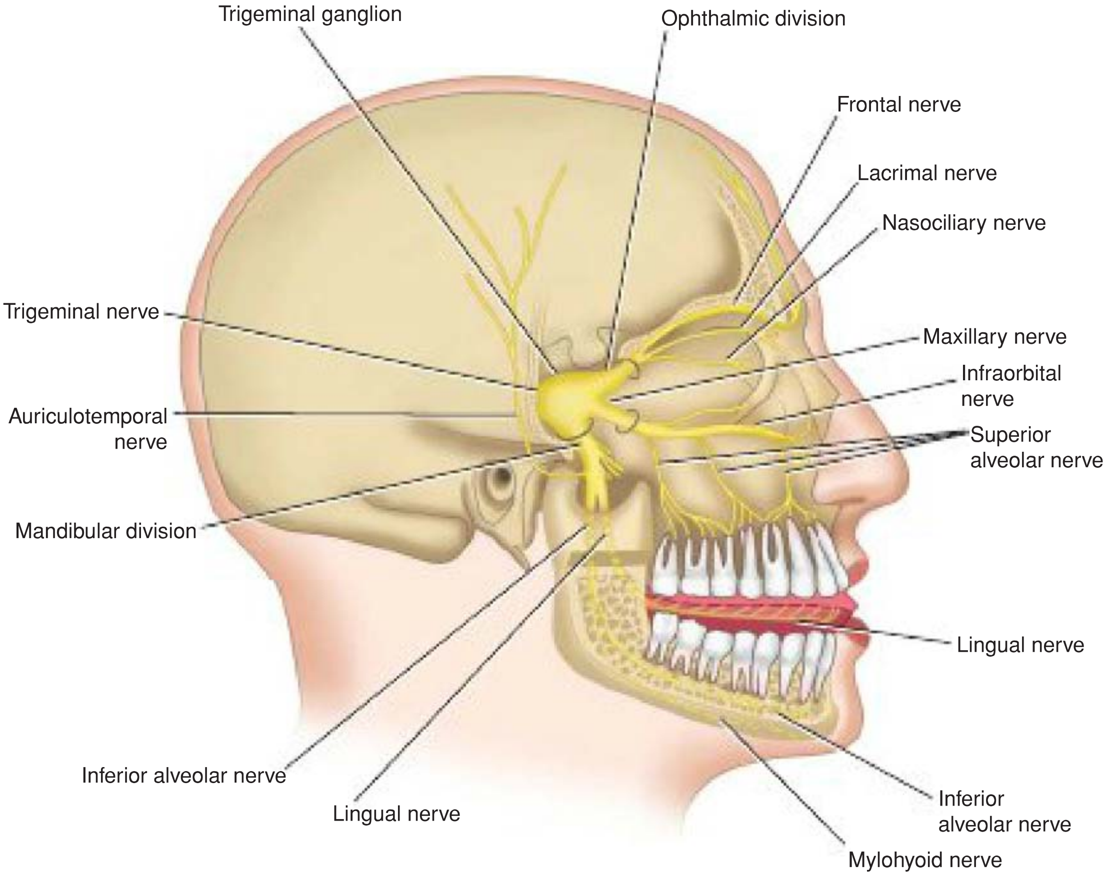


Figure 11-8 Distribution of the trigeminal nerve.

The cells of the motor nucleus give rise to the axons that form the motor root. The motor nucleus supplies the **muscles of mastication**, the **tensor tympani**, the **tensor veli palatini**, and the **mylohyoid** and the **anterior belly of the digastric muscle**.

Trigeminal Nerve Course

The trigeminal nerve leaves the anterior aspect of the pons as a small motor root and a large sensory root. The nerve passes forward out of the posterior cranial fossa and rests on the upper surface of the apex of the petrous part of the temporal bone in the middle cranial fossa. The large sensory root now expands to form the crescent-shaped **trigeminal ganglion**, which lies within a pouch of dura mater called the **trigeminal** or **Meckel cave**. The ophthalmic, maxillary, and mandibular nerves arise from the anterior border of the ganglion (Fig. 11-8). The ophthalmic nerve (V_1) contains only sensory fibers and leaves the skull through the superior orbital fissure to enter the orbital cavity. The maxillary nerve (V_2) also contains only sensory fibers and leaves the skull through the foramen rotundum. The mandibular nerve (V_3) contains both sensory and motor fibers and leaves the skull through the foramen ovale.

The sensory fibers to the skin of the face from each division supply a distinct zone (Fig. 11-9), there being little or no overlap of the dermatomes (compared with the overlap of the dermatomes of the spinal nerves). As noted previously, the motor fibers in the mandibular division are mainly distributed to muscles of mastication.

ABDUCENS NERVE (CRANIAL NERVE VI)

The abducens nerve is a small motor nerve that supplies the **lateral rectus muscle** of the eyeball.

Abducens Nerve Nucleus

The small motor nucleus is situated beneath the floor of the upper part of the fourth ventricle, close to the midline and beneath the **colliculus facialis** (Fig. 11-10A). The nucleus receives afferent corticonuclear fibers from both cerebral hemispheres. It receives the tectobulbar tract from the superior colliculus, by which the visual cortex is connected to the nucleus. It also receives fibers from the medial longitudinal fasciculus, by which it is connected to the nuclei of the third, fourth, and eighth cranial nerves (see Fig. 11-9).

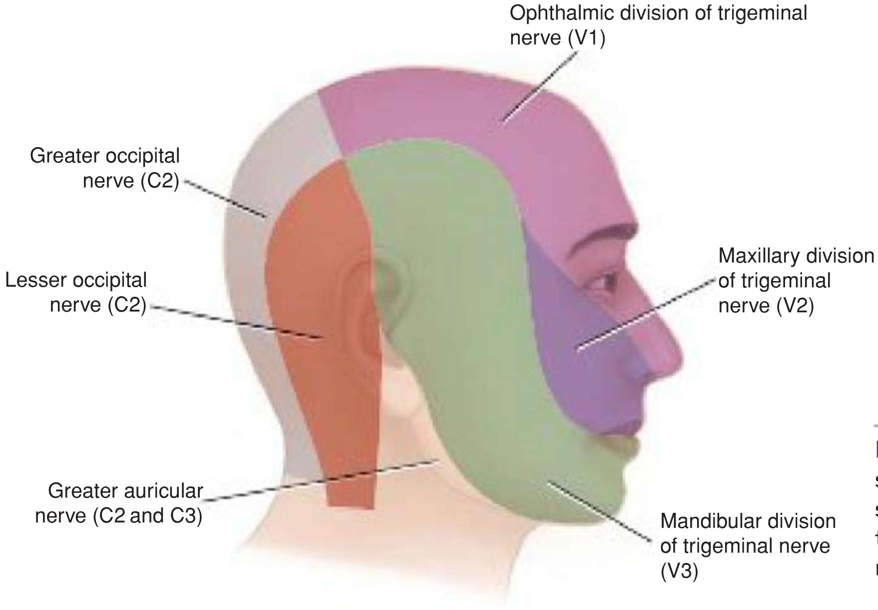
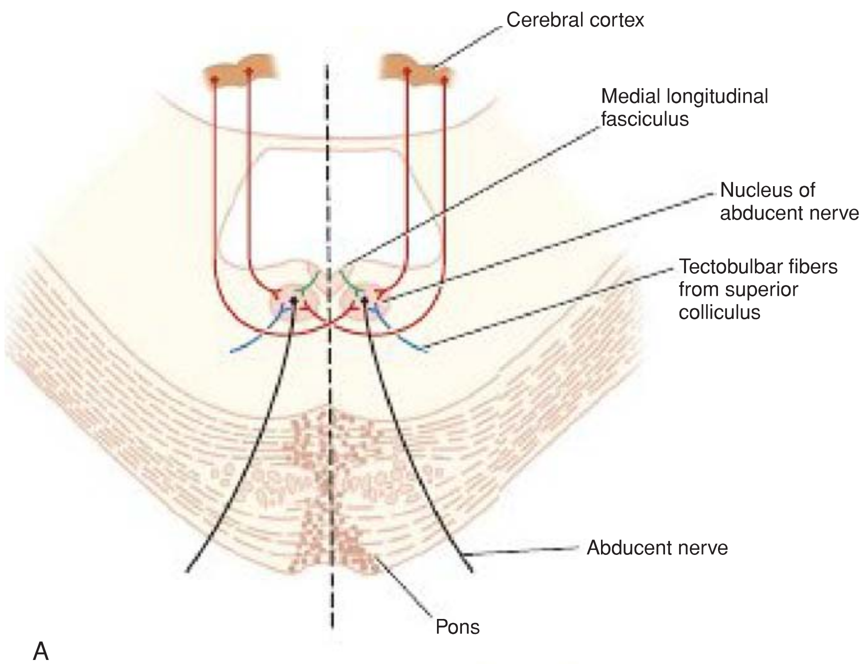


Figure 11-9 Sensory nerve supply to the skin of the head and neck. Note that the skin over the angle of the jaw is supplied by the great auricular nerve (C2 and C3) and not by branches of the trigeminal nerve.



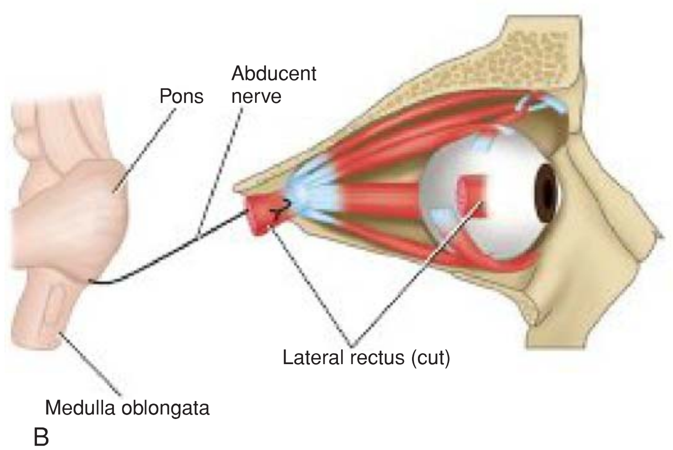


Figure 11-10 **A:** Abducens nerve nucleus and its central connections. **B:** Distribution of the abducens nerve.

Abducens Nerve Course

The fibers of the abducens nerve pass anteriorly through the pons and emerge in the groove between the lower border of the pons and the medulla oblongata (see Fig. 11-10B). It passes forward through the cavernous sinus, lying below and lateral to the internal carotid artery. The nerve then enters the orbit through the superior orbital fissure. The abducens nerve is entirely a motor nerve and supplies the lateral rectus muscle and, therefore, is responsible for turning the eye laterally.

FACIAL NERVE (CRANIAL NERVE VII)

The facial nerve is both a motor and a sensory nerve.

Facial Nerve Nuclei

The facial nerve has three nuclei: (1) the main motor nucleus, (2) the parasympathetic nuclei, and (3) the sensory nucleus.

Main Motor Nucleus

The main motor nucleus lies deep in the reticular formation of the lower part of the pons (Fig. 11-11). The part of the nucleus that supplies the muscles of the upper part of the face receives corticonuclear fibers from both cerebral hemispheres. The part of the nucleus that supplies the muscles of the lower part of the face receives only corticonuclear fibers from the opposite cerebral hemisphere.

These pathways explain the voluntary control of facial muscles. However, another involuntary pathway exists; it is separate and controls **mimetic** or **emotional changes in facial expression**. This other pathway forms part of the reticular formation (see p. 301).

Parasympathetic Nuclei

Parasympathetic nuclei lie posterolateral to the main motor nucleus. They are the **superior salivatory** and **lacrimal nuclei** (see Fig. 11-11). The superior salivatory nucleus receives afferent fibers from the hypothalamus through the **descending autonomic pathways**. Information concerning taste also is received from the **nucleus of the solitary tract** from the mouth cavity.

The lacrimal nucleus receives afferent fibers from the hypothalamus for emotional responses and from the sensory nuclei of the trigeminal nerve for reflex lacrimation secondary to irritation of the cornea or conjunctiva.

Sensory Nucleus

The sensory nucleus is the upper part of the **nucleus of the tractus solitarius** and lies close to the motor nucleus (see Fig. 11-11). Sensations of taste travel through the peripheral axons of nerve cells situated in the **geniculate ganglion** on the seventh cranial nerve. The central processes of these cells synapse on nerve cells in the nucleus. Efferent fibers cross the median plane and ascend to the ventral posteromedial nucleus of the opposite thalamus and to a number of hypothalamic nuclei. From the thalamus, the axons of the thalamic cells pass through the internal capsule and

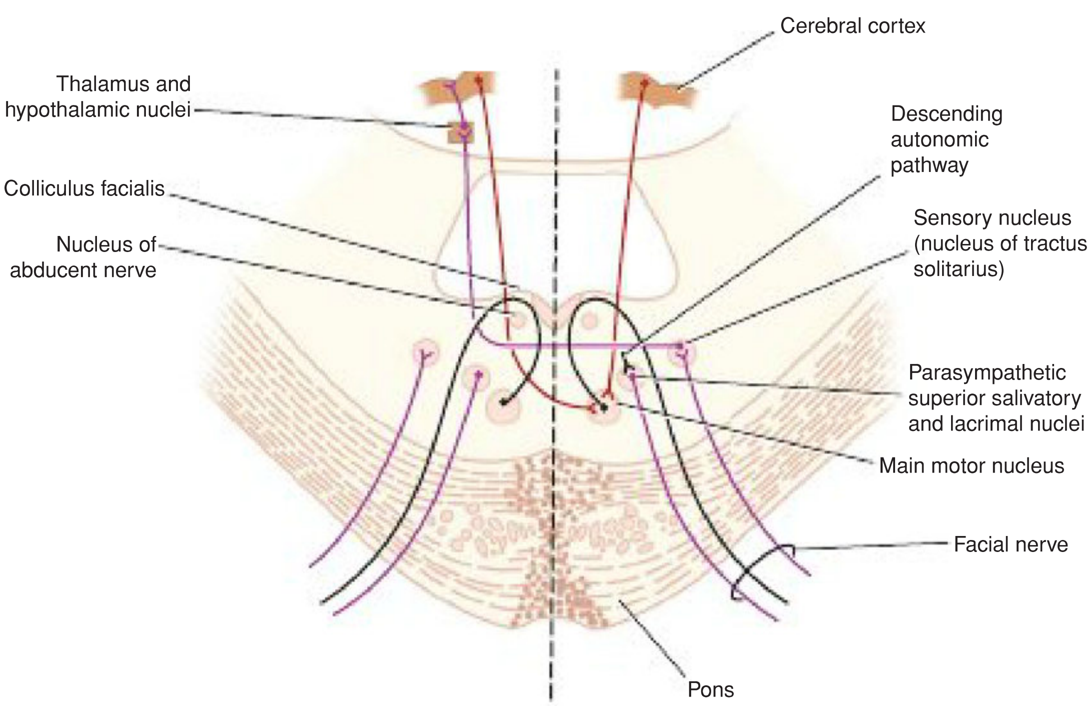


Figure 11-11 Facial nerve nuclei and their central connections.

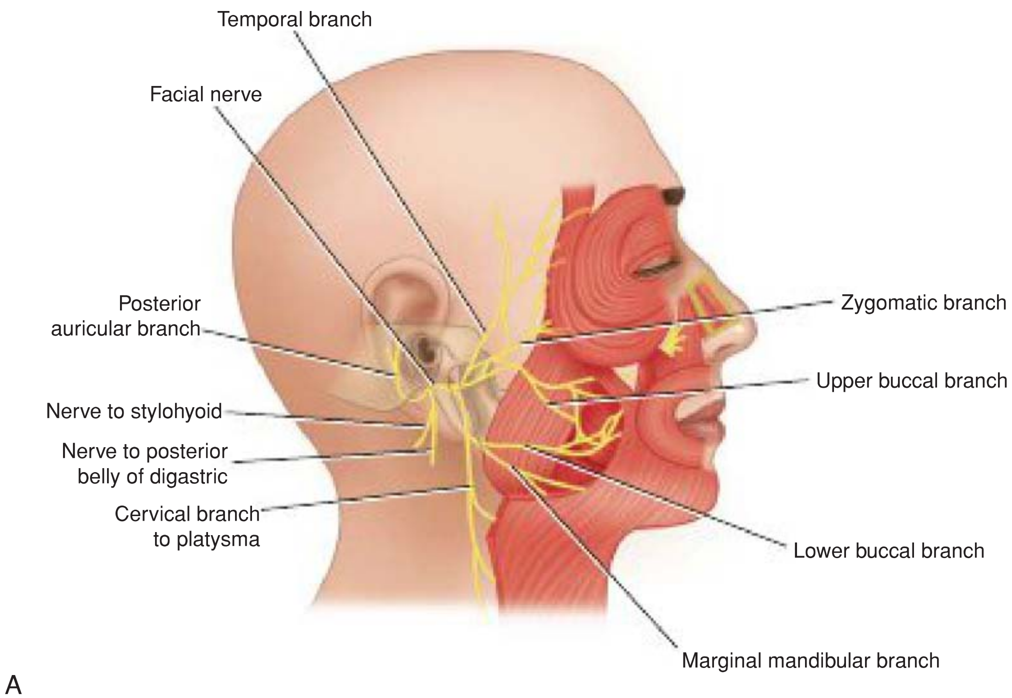
corona radiata to end in the taste area of the cortex in the lower part of the postcentral gyrus.

Facial Nerve Course

The facial nerve consists of a motor and a sensory root. The fibers of the motor root first travel posteriorly around the medial side of the abducens nucleus (see Fig. 11-11). They then pass around the nucleus beneath the **colliculus facialis** in the floor of the fourth ventricle and, finally, pass anteriorly to emerge from the brainstem.

The sensory root (**nervus intermedius**) is formed of the central processes of the unipolar cells of the geniculate ganglion. It also contains the efferent preganglionic parasympathetic fibers from the parasympathetic nuclei.

The two roots of the facial nerve emerge from the anterior surface of the brain between the pons and the medulla oblongata. They pass laterally in the posterior cranial fossa with the vestibulocochlear nerve and enter the internal acoustic meatus in the petrous part of the temporal bone. At the bottom of the meatus, the nerve enters the facial canal and runs laterally through the inner ear. On reaching the medial wall of the tympanic cavity, the nerve expands to form the sensory **geniculate ganglion** (Fig. 11-12) and turns sharply backward above the promontory. At the posterior wall of the tympanic cavity, the facial nerve turns downward on the medial side of the aditus to the mastoid antrum, descends behind the pyramid, and emerges from the stylomastoid foramen.



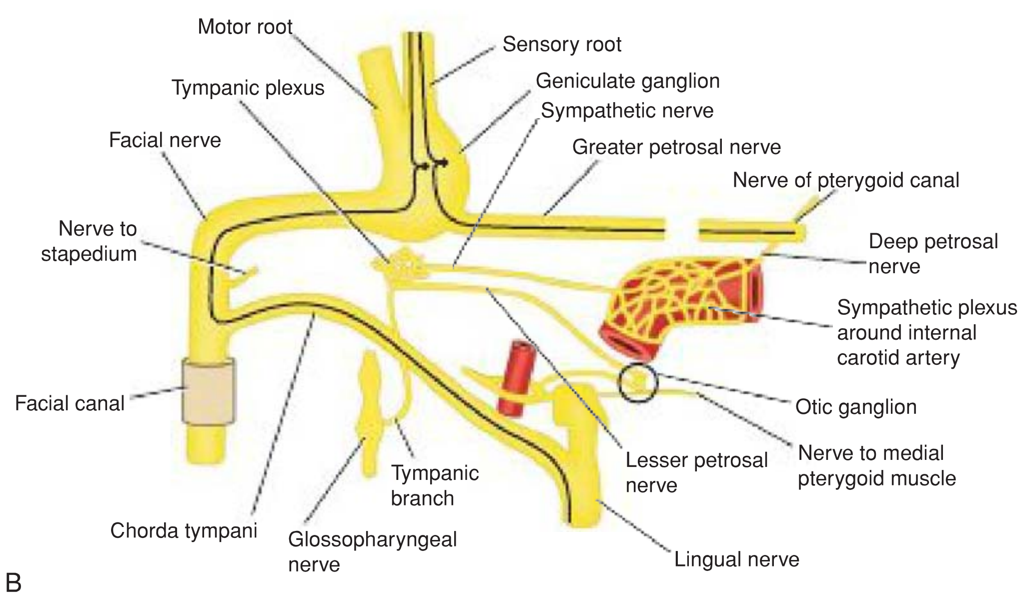


Figure 11-12 **A:** Distribution of the facial nerve. **B:** Branches of the facial nerve within the petrous part of the temporal bone; the taste fibers are shown in black. The glossopharyngeal nerve is also shown.

Facial Nerve Distribution

The **motor nucleus** supplies the muscles of facial expression, the auricular muscles, the stapedius, the posterior belly of the digastric, and the stylohyoid muscles (see Fig. 11-12).

The **superior salivatory nucleus** supplies the submandibular and sublingual salivary glands and the nasal and palatine glands. The **lacrimal nucleus** supplies the lacrimal gland.

The **sensory nucleus** receives taste fibers from the anterior two-thirds of the tongue, the floor of the mouth, and the palate.

VESTIBULOCOCHLEAR NERVE (CRANIAL NERVE VIII)

This nerve consists of two distinct parts, the **vestibular nerve** and the **cochlear nerve**, which are concerned with the transmission of afferent information from the internal ear to the central nervous system (Figs. 11-13 and 11-14).

Vestibular Nerve

The vestibular nerve conducts nerve impulses from the utricle and saccule that provide information concerning the position of the head; the nerve also conducts impulses from the semicircular canals that provide information concerning movements of the head.

The nerve fibers of the vestibular nerve are the central processes of nerve cells located in the **vestibular ganglion**, which is situated in the **internal acoustic meatus**. They enter the anterior surface of the brainstem in a groove between the lower border of the pons and the upper part of the medulla oblongata (see Fig. 11-13). When they enter the vestibular nuclear complex, the fibers divide into short ascending and long descending fibers; a small number of fibers pass directly to the cerebellum through the inferior cerebellar peduncle, bypassing the vestibular nuclei.

Vestibular Nuclear Complex

This complex consists of a group of nuclei situated beneath the floor of the fourth ventricle (see Fig. 11-13). Four nuclei may be recognized: (1) the **lateral** vestibular nucleus, (2) the **superior** vestibular nucleus, (3) the **medial** vestibular nucleus, and (4) the **inferior** vestibular nucleus (see Fig. 5-14).

The vestibular nuclei receive afferent fibers from the **utricle** and **saccule** and the **semicircular canals** through the vestibular nerve and fibers from the cerebellum through the inferior cerebellar peduncle (see Fig. 11-13). Efferent fibers from the nuclei pass to the

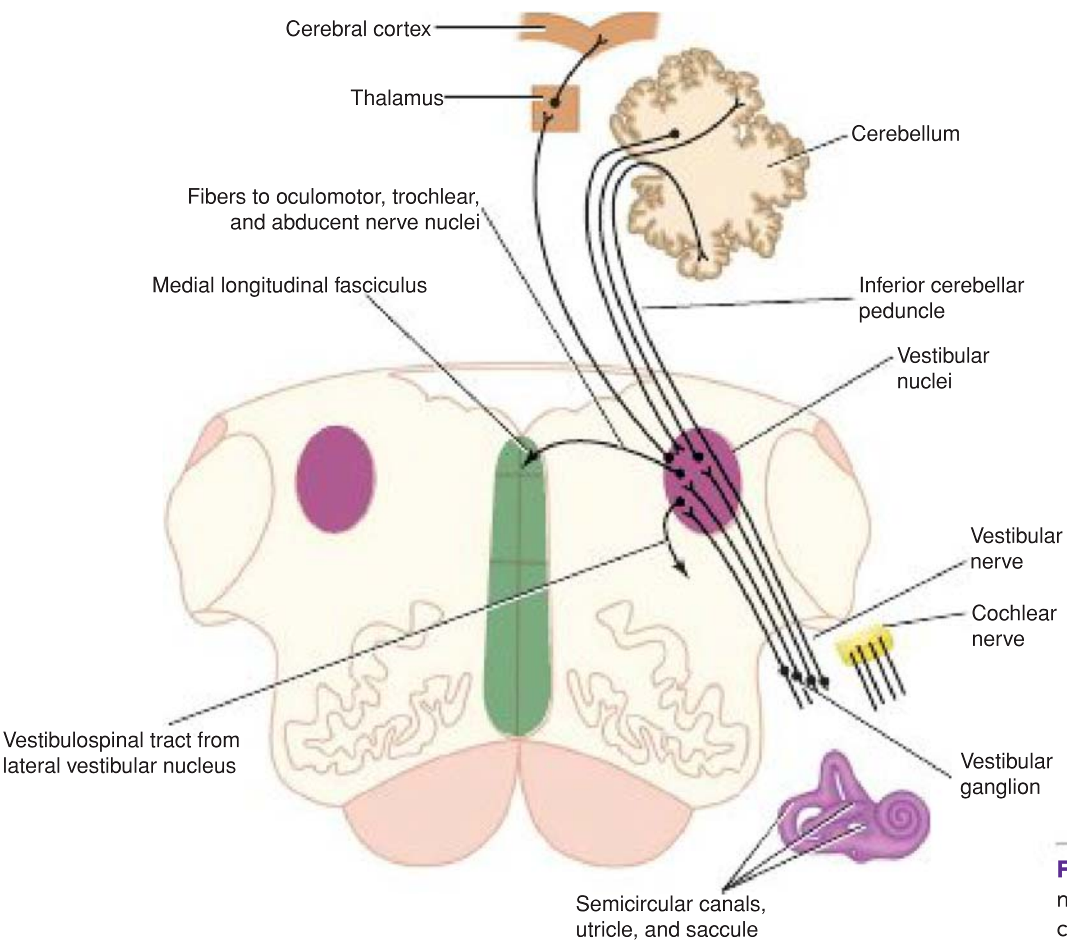


Figure 11-13 Vestibular nerve nuclei and their central connections.

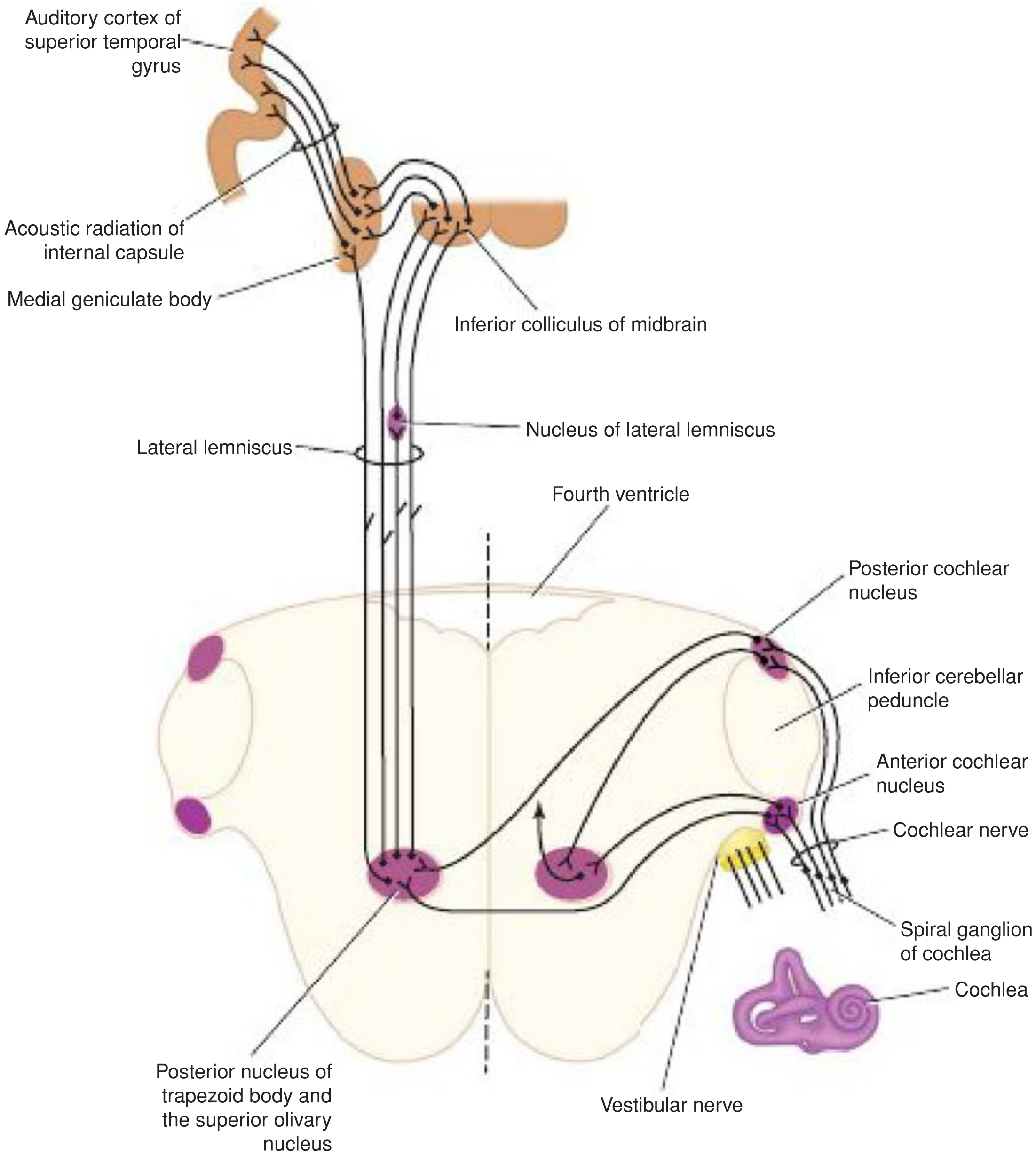


Figure 11-14 Cochlear nerve nuclei and their central connections. The descending pathways have been omitted.

cerebellum through the inferior cerebellar peduncle. Efferent fibers also descend uncrossed to the spinal cord from the lateral vestibular nucleus and form the **vestibulospinal tract**. In addition, efferent fibers pass to the nuclei of the oculomotor, trochlear, and abducens nerves through the medial longitudinal fasciculus.

These connections enable the movements of the head and the eyes to be coordinated so that visual fixation on an object can be maintained. In addition, information received from the internal ear can assist in maintaining balance by influencing the muscle tone of the limbs and trunk.

Ascending fibers also pass upward from the vestibular nuclei to the cerebral cortex, to the vestibular area in the postcentral gyrus just above the lateral fissure. These fibers are thought to relay in the ventral posterior nuclei of the thalamus. The cerebral cortex probably serves to orient the individual consciously in space.

Cochlear Nerve

The cochlear nerve conducts nerve impulses concerned with sound from the organ of Corti in the cochlea. The fibers of the cochlear nerve are the central processes of nerve cells located in the **spiral ganglion of the cochlea** (Fig. 11-15). They enter the anterior surface of the brainstem at the lower border of the pons on the lateral side of the emerging facial nerve by the vestibular nerve

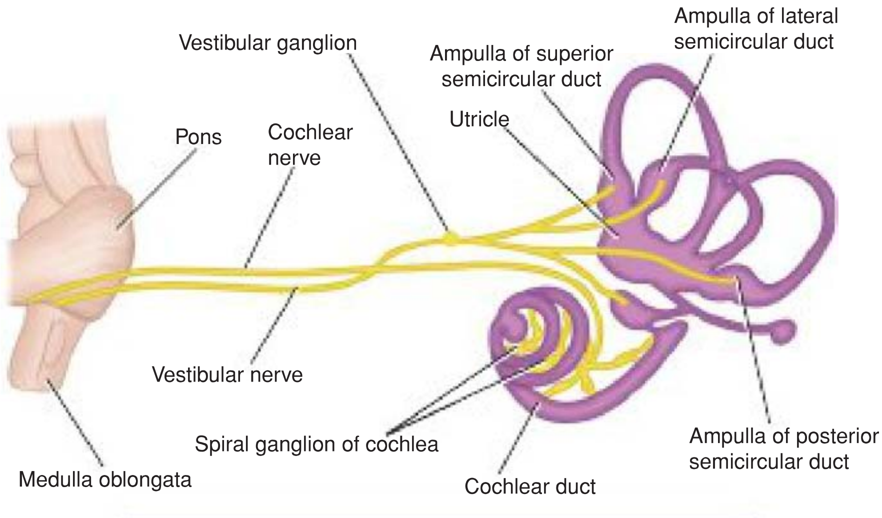


Figure 11-15 Distribution of the vestibulocochlear nerve.

(see Fig. 11-14). On entering the pons, the nerve fibers divide, with one branch entering the **posterior cochlear nucleus** and the other branch entering the **anterior cochlear nucleus**.

Cochlear Nuclei

The anterior and posterior cochlear nuclei are situated on the surface of the inferior cerebellar peduncle (see Fig. 11-14). They receive afferent fibers from the cochlea through the cochlear nerve. The cochlear nuclei send axons (second-order neuron fibers) that run medially through the pons to end in the **trapezoid body** and the olivary nucleus. Here, they are relayed in the **posterior nucleus of the trapezoid body** and the superior olivary nucleus on the same or the opposite side. The axons now ascend through the posterior part of the pons and midbrain and form a tract known as the **lateral lemniscus**. Each lateral lemniscus, therefore, consists of third-order neurons from both sides. As these fibers ascend, some of them relay in small groups of nerve cells, collectively known as the **nucleus of the lateral lemniscus**.

On reaching the midbrain, the fibers of the lateral lemniscus either terminate in the **nucleus of the inferior colliculus** or are relayed in the **medial geniculate body** and pass to the **auditory cortex** of the cerebral hemisphere through the **acoustic radiation of the internal capsule**.

The primary auditory cortex (areas 41 and 42) includes the gyrus of Heschl on the upper surface of the superior temporal gyrus. The recognition and interpretation of sounds, on the basis of past experience, take place in the secondary auditory area.

Nerve impulses from the ear are transmitted along auditory pathways on both sides of the brainstem, with more being projected along the contralateral pathway. Many collateral branches are given off to the reticular activating system of the brainstem (see p. 301). The tonotopic organization present in the organ of Corti is preserved within the cochlear nuclei, the inferior colliculi, and the primary auditory area.

Descending Auditory Pathways

Descending fibers originating in the auditory cortex and in other nuclei in the auditory pathway accompany the ascending pathway. These fibers are bilateral and end on nerve cells at different levels of the auditory pathway and on the hair cells of the organ of Corti. These fibers are believed to serve as a feedback mechanism and inhibit the reception of sound. They may also have a role in the process of auditory sharpening, suppressing some signals and enhancing others.

Vestibulocochlear Nerve Course

The vestibular and cochlear parts of the nerve leave the anterior surface of the brain between the lower border of the pons and the medulla oblongata (see Fig. 11-15). They run laterally in the posterior cranial fossa and enter the internal acoustic meatus with the facial nerve. The fibers are then distributed to the different parts of the internal ear.

GLOSSOPHARYNGEAL NERVE (CRANIAL NERVE IX)

The glossopharyngeal nerve is a motor and a sensory nerve.

Glossopharyngeal Nerve Nuclei

The glossopharyngeal nerve has three nuclei: (1) the main motor nucleus, (2) the parasympathetic nucleus, and (3) the sensory nucleus.

Main Motor Nucleus

The main motor nucleus lies deep in the reticular formation of the medulla oblongata and is formed by the superior end of the nucleus ambiguus (Fig. 11-16). It receives corticonuclear fibers from both cerebral

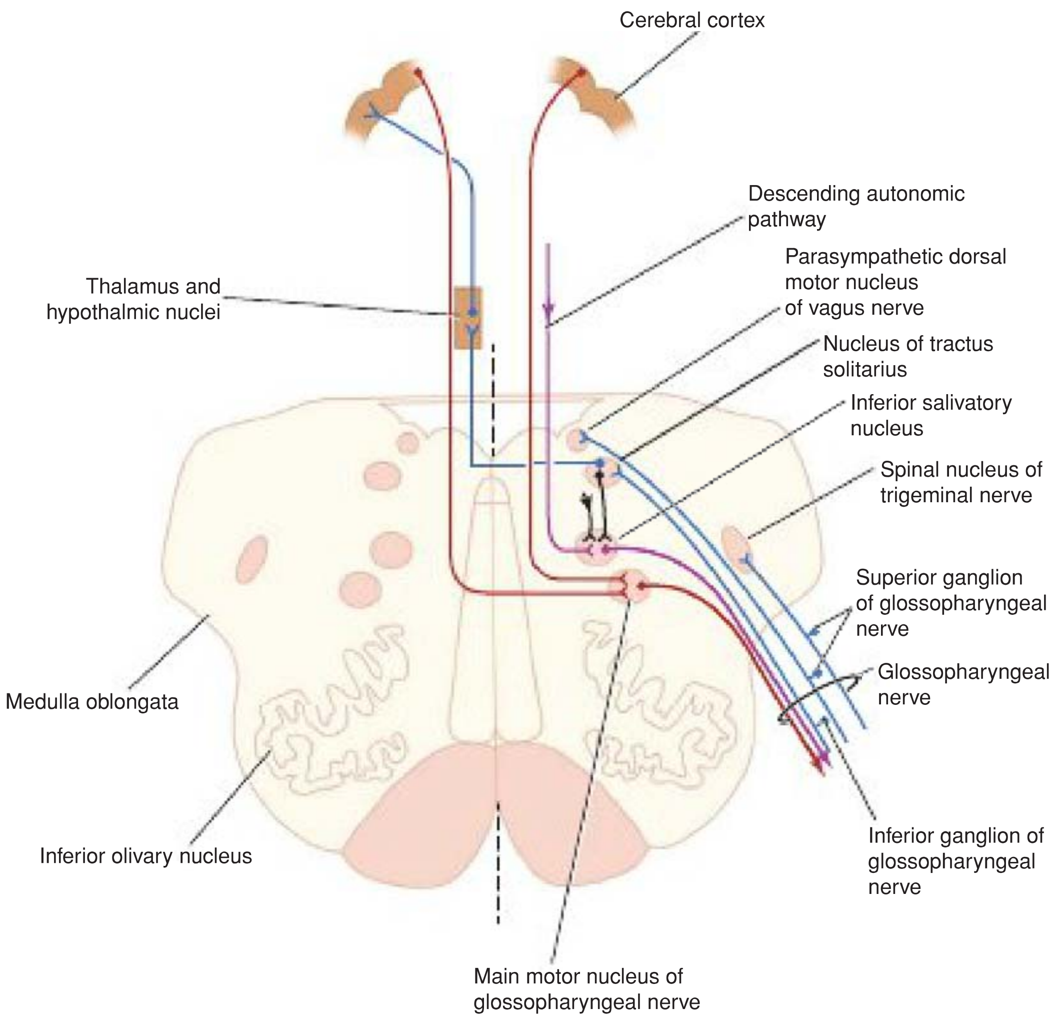


Figure 11-16 Glossopharyngeal nerve nuclei and their central connections.

hemispheres. The efferent fibers supply the **stylopharyngeus muscle**.

Parasympathetic Nucleus

The parasympathetic nucleus is also called the **inferior salivatory nucleus**. It receives afferent fibers from the hypothalamus through the **descending autonomic pathways**. It also is thought to receive information from the olfactory system through the reticular formation. Information concerning taste also is received from the nucleus of the solitary tract from the mouth cavity.

The efferent preganglionic parasympathetic fibers reach the otic ganglion through the **tympanic branch of the glossopharyngeal nerve**, the **tympanic plexus**, and the **lesser petrosal nerve** (Fig. 11-17). The postganglionic fibers pass to the **parotid salivary gland**.

Sensory Nucleus

The sensory nucleus is part of the **nucleus of the tractus solitarius** (see Fig. 11-16). Sensations of taste travel through the peripheral axons of nerve cells situated in the **ganglion** on the glossopharyngeal nerve. The central processes of these cells synapse on nerve cells in the nucleus. Efferent fibers cross the median plane and ascend to the ventral group of nuclei of the opposite thalamus and a number of hypothalamic nuclei. From the thalamus, the axons of the thalamic cells pass through the internal capsule and corona radiata to end in the lower part of the postcentral gyrus.

Afferent information that concerns common sensation enters the brainstem through the superior ganglion of the glossopharyngeal nerve but ends in the **spinal nucleus of the trigeminal nerve**. Afferent impulses from the **carotid sinus**, a baroreceptor situated at the bifurcation of the common carotid artery, also travel with the glossopharyngeal nerve. They terminate in the **nucleus of the tractus solitarius** and are connected to the **dorsal motor nucleus of the vagus nerve**. The carotid sinus reflex that involves the glossopharyngeal and vagus nerves assists in the regulation of arterial blood pressure.

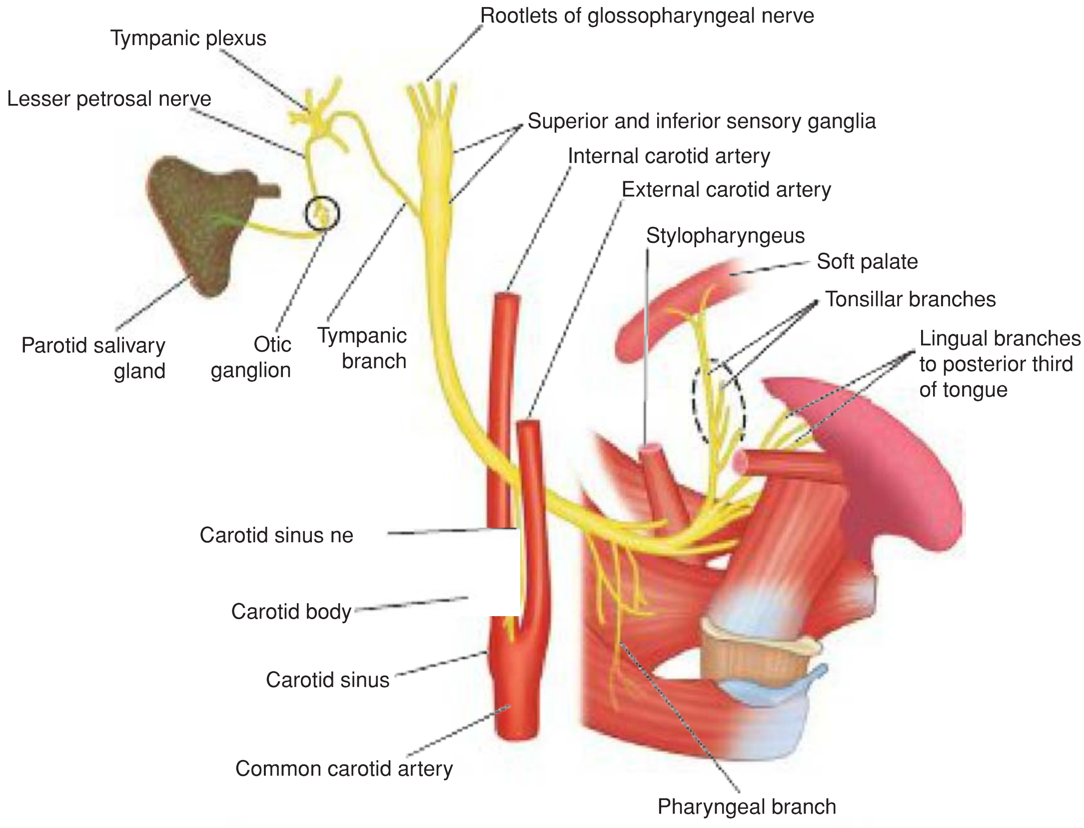


Figure 11-17 Distribution of the glossopharyngeal nerve.

Glossopharyngeal Nerve Course

The glossopharyngeal nerve leaves the anterolateral surface of the upper part of the medulla oblongata as a series of rootlets in a groove between the olive and the inferior cerebellar peduncle (see Fig. 11-16). It passes laterally in the posterior cranial fossa and leaves the skull through the jugular foramen. The superior and inferior glossopharyngeal sensory ganglia are situated on the nerve here. The nerve then descends through the upper part of the neck in company with the internal jugular vein and the internal carotid artery to reach the posterior border of the stylopharyngeus muscle, which it supplies. The nerve then passes forward between the superior and middle constrictor muscles of the pharynx to give sensory branches to the mucous membrane of the pharynx and the posterior third of the tongue (see Fig. 11-17).

VAGUS NERVE (CRANIAL NERVE X)

The vagus nerve is a motor and a sensory nerve.

Vagus Nerve Nuclei

The vagus nerve has three nuclei: (1) the main motor nucleus, (2) the parasympathetic nucleus, and (3) the sensory nucleus.

Main Motor Nucleus

The main motor nucleus lies deep in the reticular formation of the medulla oblongata and is formed by the nucleus ambiguus (Fig. 11-18). It receives corticonuclear fibers from both cerebral hemispheres. The efferent fibers supply the constrictor muscles of the pharynx and the intrinsic muscles of the larynx (Fig. 11-19).

Parasympathetic Nucleus

The parasympathetic nucleus forms the dorsal nucleus of the vagus and lies beneath the floor of the lower part of the fourth ventricle posterolateral to the hypoglossal nucleus (see Fig. 11-18). It receives afferent fibers from the hypothalamus through the descending autonomic pathways. It also receives other afferents, including those from the glossopharyngeal nerve (carotid sinus reflex). The efferent fibers are distributed to the involuntary muscle of the bronchi, heart, esophagus, stomach, small intestine, and large intestine as far as the distal third of the transverse colon (see Fig. 11-19).

Sensory Nucleus

The sensory nucleus is the lower part of the **nucleus of the tractus solitarius**. Sensations of taste travel through the peripheral axons of nerve cells situated in the **inferior ganglion on the vagus nerve**. The central

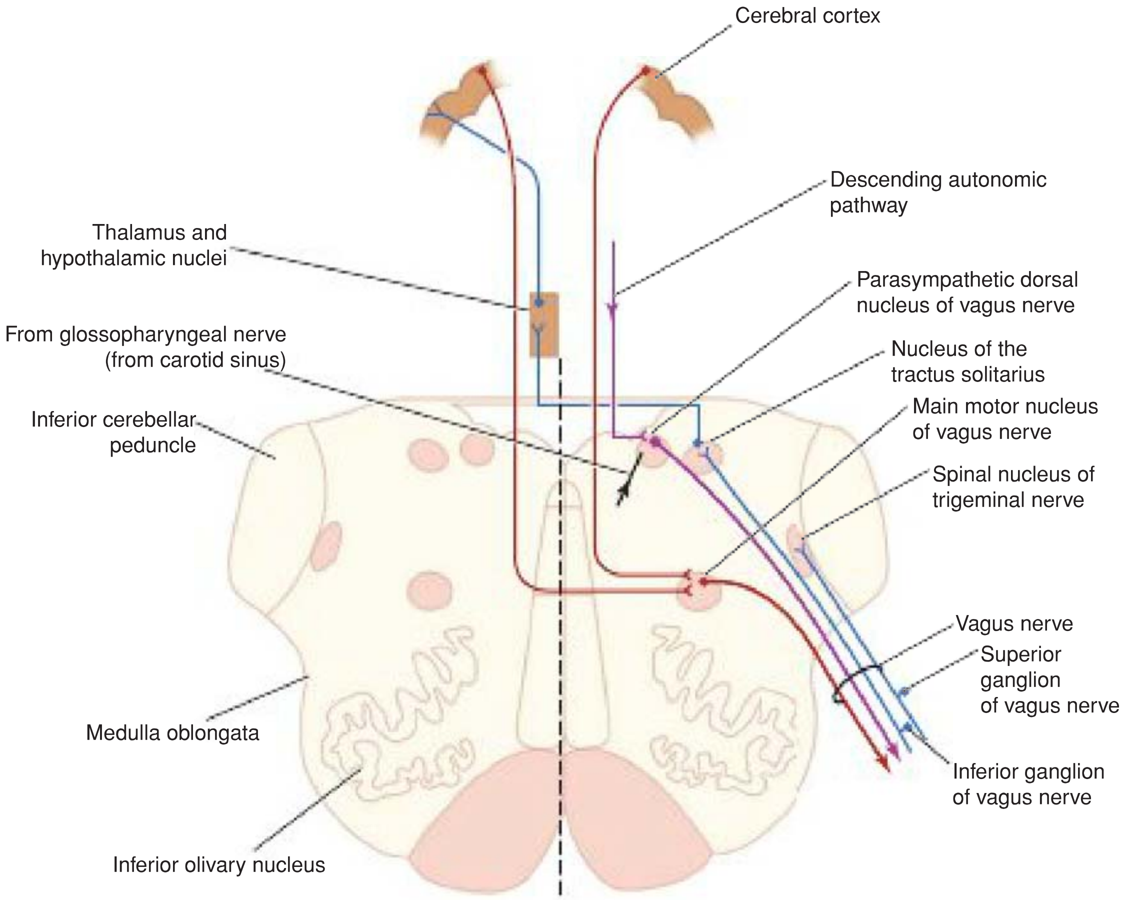


Figure 11-18 Vagus nerve nuclei and their central connections.

processes of those cells synapse on nerve cells in the nucleus (see Fig. 11-18). Efferent fibers cross the median plane and ascend to the ventral group of nuclei of the opposite thalamus as well as to a number of hypothalamic nuclei. From the thalamus, the axons of the thalamic cells pass through the internal capsule and corona radiata to end in the postcentral gyrus.

Afferent information concerning common sensation enters the brainstem through the superior ganglion of the vagus nerve but ends in the **spinal nucleus of the trigeminal nerve**.

Vagus Nerve Course

The vagus nerve leaves the anterolateral surface of the upper part of the medulla oblongata as a series of rootlets in a groove between the olive and the inferior cerebellar peduncle (see Fig. 11-18). The nerve passes laterally through the posterior cranial fossa and leaves the skull through the jugular foramen. The vagus nerve possesses two sensory ganglia, a rounded superior ganglion, situated on the nerve within the jugular foramen, and a cylindrical **inferior ganglion**, which lies on the nerve just below the foramen. Below the inferior ganglion, the cranial root of the accessory nerve joins the vagus nerve and is distributed mainly in its pharyngeal and recurrent laryngeal branches.

The vagus nerve descends vertically in the neck within the carotid sheath with the internal jugular vein and the internal and common carotid arteries.

The **right vagus nerve** enters the thorax and passes posterior to the root of the right lung, contributing to the pulmonary plexus. It then passes on to the posterior surface of the esophagus and contributes to the **esophageal plexus**. It enters the abdomen through the esophageal opening of the diaphragm. The posterior vagal trunk (which is the name now given to the right vagus) is distributed to the posterior surface of the stomach and, by a large celiac branch, to the duodenum, liver, kidneys, and small and large intestines as far as the distal third of the transverse colon. This wide distribution is accomplished through the celiac, superior mesenteric, and renal plexuses.

The **left vagus nerve** enters the thorax and crosses the left side of the aortic arch and descends behind the root of the left lung, contributing to the **pulmonary plexus**. The left vagus then descends on the anterior surface of the esophagus, contributing to the **esophageal plexus**. It enters the abdomen through the esophageal opening of the diaphragm. The anterior vagal trunk (which is the

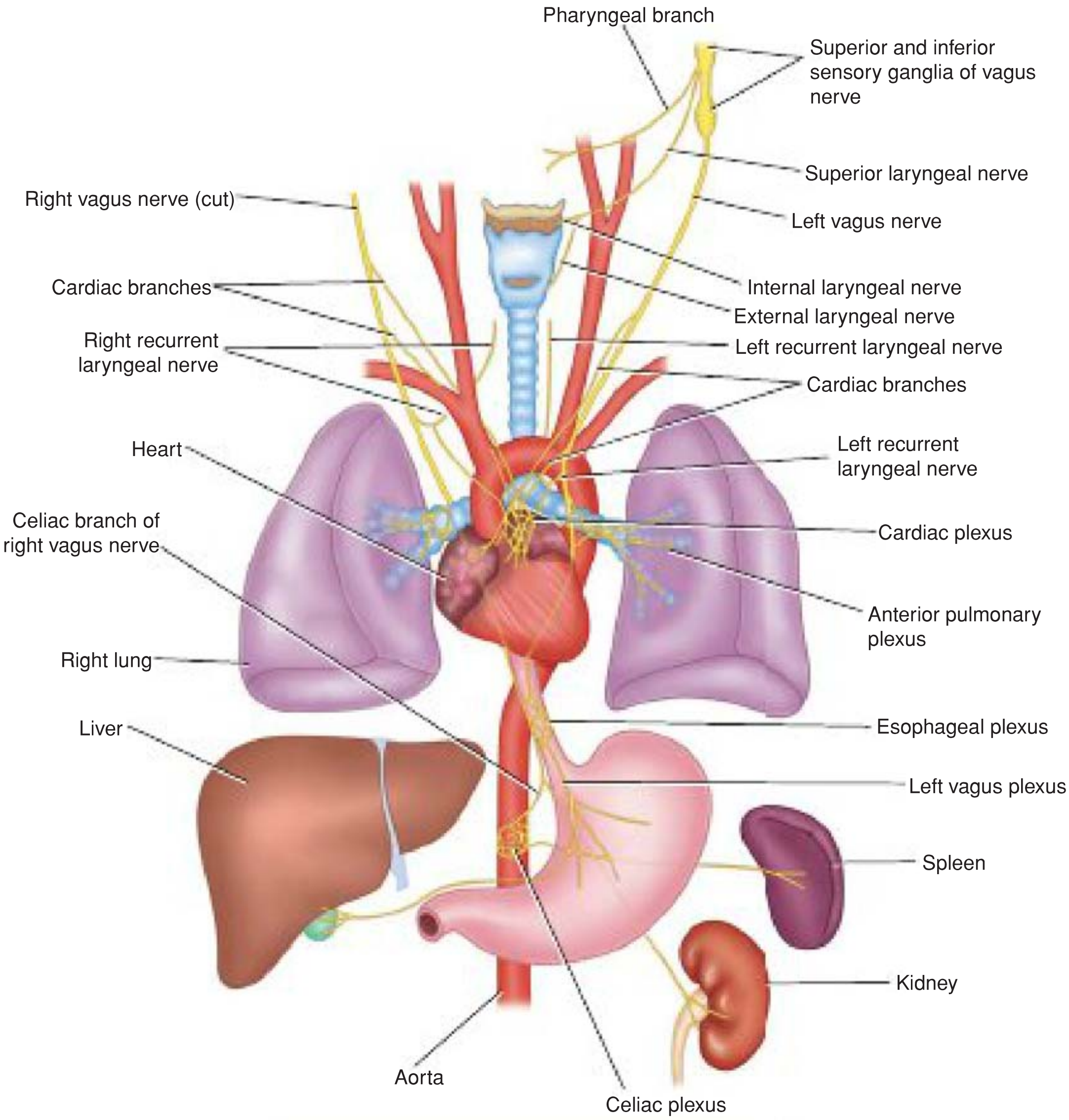


Figure 11-19 Distribution of the vagus nerve.

name now given to the left vagus) divides into several branches, which are distributed to the stomach, liver, upper part of the duodenum, and head of the pancreas.

ACCESSORY NERVE (CRANIAL NERVE XI)

The accessory nerve is a motor nerve that is formed by the union of a cranial and a spinal root.

Cranial Root

The cranial root (part) is formed from the axons of nerve cells of the nucleus ambiguus (Fig. 11-20). The nucleus receives corticonuclear fibers from both cerebral hemispheres. The efferent fibers of the nucleus emerge from the anterior surface of the medulla oblongata between the olive and the inferior cerebellar peduncle.

Cranial Root Course

The nerve runs laterally in the posterior cranial fossa and joins the spinal root. The two roots unite and leave the skull through the jugular foramen. The roots then separate, and the cranial root joins the vagus nerve and is distributed in its pharyngeal and recurrent laryngeal branches to the muscles of the soft palate, pharynx, and larynx.

Spinal Root

The spinal root (part) is formed from axons of nerve cells in the **spinal nucleus**, which is situated in the anterior gray column of the spinal cord in the upper five

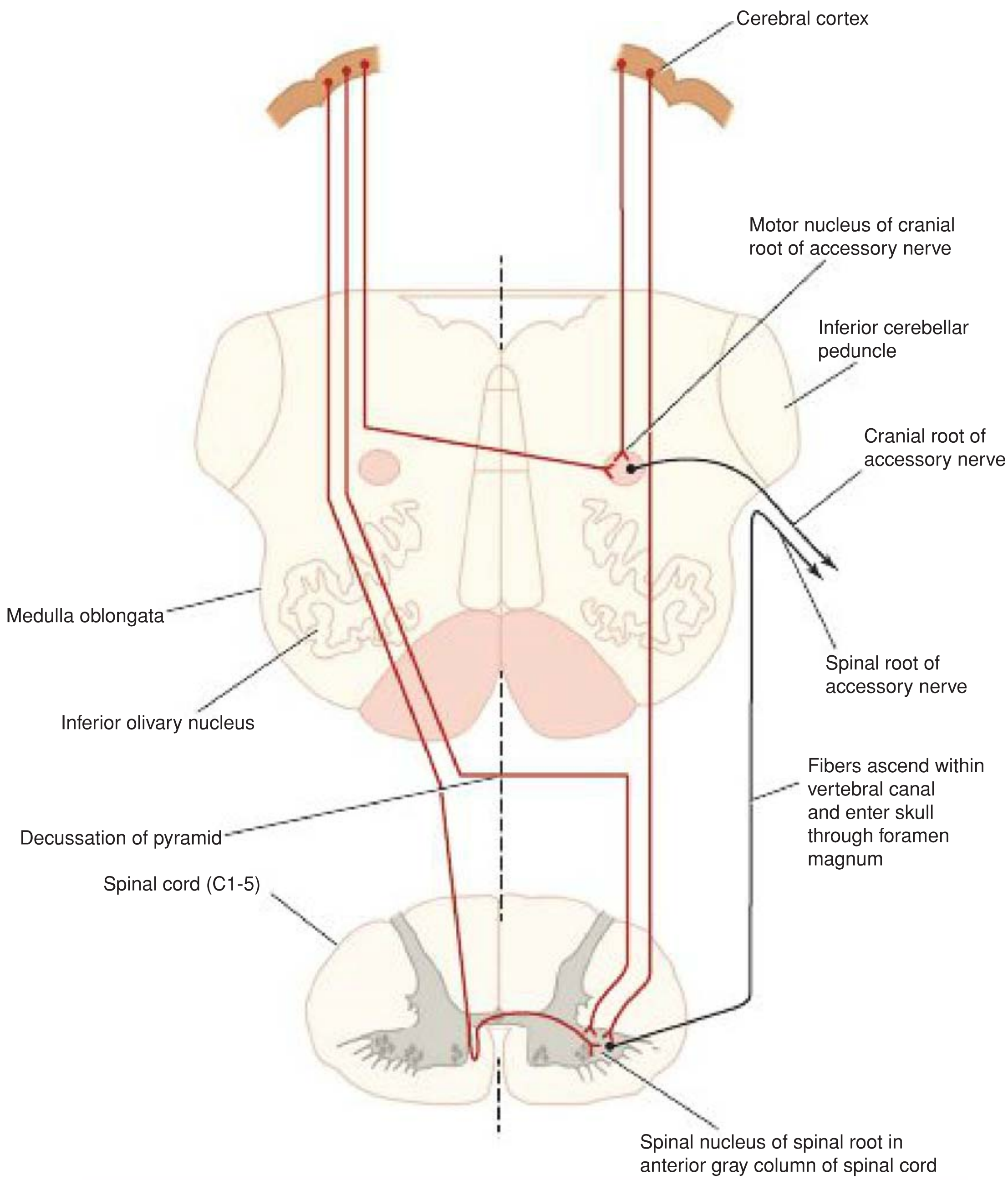


Figure 11-20 Cranial and spinal nuclei of the accessory nerve and their central connections.

cervical segments (see Fig. 11-20). The spinal nucleus is thought to receive corticospinal fibers from both cerebral hemispheres.

Spinal Root Course

The nerve fibers emerge from the spinal cord midway between the anterior and posterior nerve roots of the cervical spinal nerves. The fibers form a nerve trunk that ascends into the skull through the foramen magnum. The spinal root passes laterally and joins the cranial root as they pass through the jugular foramen. After a short distance, the spinal root separates from the cranial root and runs downward and laterally and enters the deep surface of the sternocleidomastoid (SCM) muscle, which it supplies (Fig. 11-21). The nerve then crosses the posterior triangle of the neck and passes beneath the trapezius muscle, which it supplies.

The accessory nerve thus brings about movements of the soft palate, pharynx, and larynx and controls the movement of two large muscles in the neck.

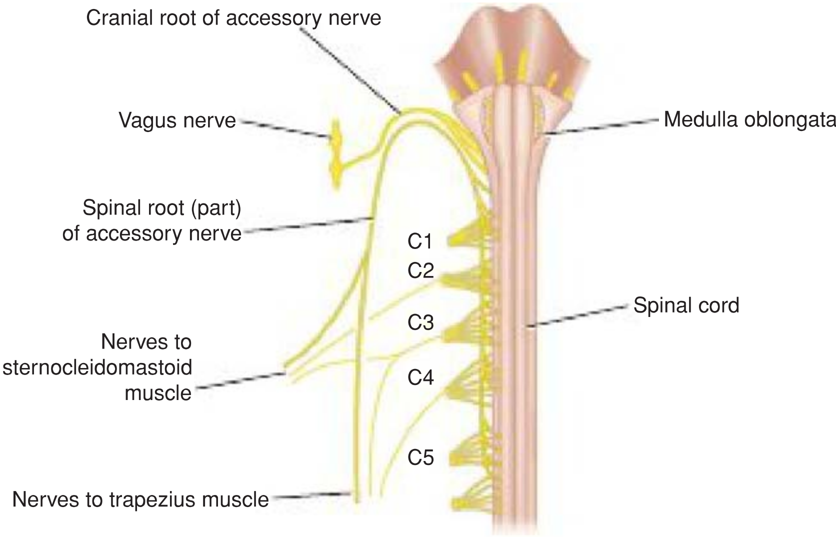


Figure 11-21 Distribution of the accessory nerve.

HYPOGLOSSAL NERVE (CRANIAL NERVE XII)

The hypoglossal nerve is a motor nerve that supplies all the intrinsic muscles of the tongue as well as the styloglossus, the hyoglossus, and the genioglossus muscles.

Hypoglossal Nucleus

The hypoglossal nucleus is situated close to the midline immediately beneath the floor of the lower part of the fourth ventricle (Fig. 11-22). It receives corticonuclear fibers from both cerebral hemispheres. However, the cells responsible for supplying the genioglossus muscle

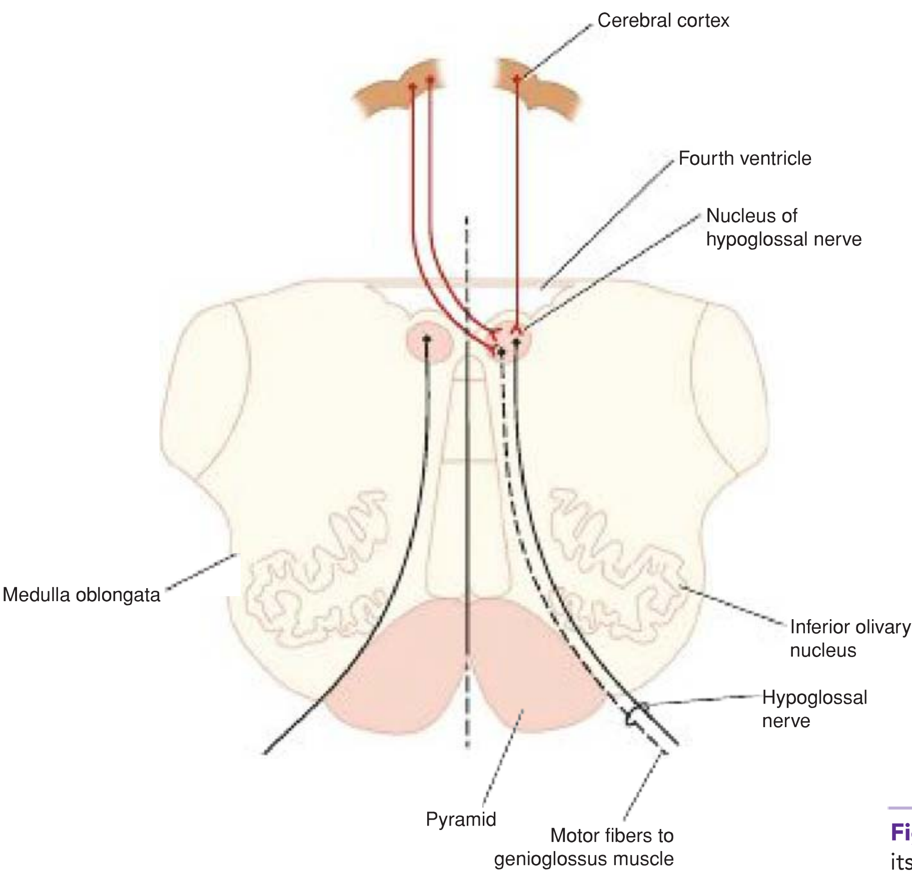


Figure 11-22 Hypoglossal nucleus and its central connections.

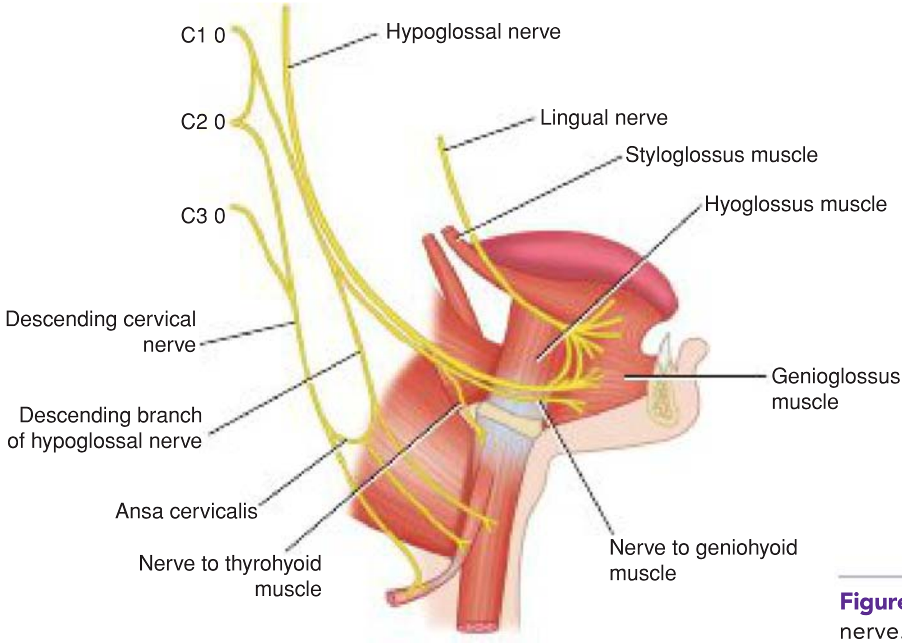


Figure 11-23 Distribution of the hypoglossal nerve.

(Fig. 11-23) only receive corticonuclear fibers from the opposite cerebral hemisphere.

The hypoglossal nerve fibers pass anteriorly through the medulla oblongata and emerge as a series of roots in the groove between the pyramid and the olive (see Fig. 11-22).

Hypoglossal Nerve Course

The hypoglossal nerve fibers emerge on the anterior surface of the medulla oblongata between the pyramid and the olive (see Fig. 11-22). The nerve crosses the posterior cranial fossa and leaves the skull through the hypoglossal canal. The nerve passes downward and forward in the neck between the internal carotid artery and the internal jugular vein until it reaches the lower border of the posterior belly of the digastric muscle. Here, it turns forward and crosses the internal and external carotid arteries and the loop of the lingual artery. It passes deep to the posterior margin of the mylohyoid muscle lying on the lateral surface of the hyoglossus muscle. The nerve then sends branches to the muscles of the tongue (see Fig. 11-23).

In the upper part of its course, the hypoglossal nerve is joined by C1 fibers from the cervical plexus. The delicate cervical nerve fibers merely run with the hypoglossal nerve for support and later leave it to supply muscles in the neck.

Thus, the hypoglossal nerve controls the movements and shape of the tongue.

Clinical Notes

General Considerations

The 12 pairs of cranial nerves supply information to the brain from outlying receptor organs and bring about changes in peripheral effector organs by means of appropriate motor nerves. Unfortunately for the student, the nerve cells are not arranged simply, as in the spinal cord, but are grouped together to form **nuclei** that are found in different situations at different levels of the brainstem. Moreover, whereas spinal nerves possess afferent somatic fibers, afferent visceral fibers, efferent somatic fibers, and efferent visceral fibers, cranial nerves, in addition, possess special somatic afferent fibers (e.g., visual and auditory) and special visceral afferent fibers (e.g., taste).

When the central connections of the different cranial nerve nuclei were discussed in the previous section, a simplified practical version was given, since many of the precise connections of the cranial nerve nuclei are still not known. Because the delicate movements of the eyes, the larynx, and the face require carefully integrated muscle action and the fine control of muscle tone, it must be assumed that the motor nuclei of the various cranial nerves receive input from the cerebellum, the red nucleus, the reticular formation, and the corpus striatum in the same manner as the lower motor neurons of the spinal cord.

Three points of clinical value should be remembered:

1. Bilateral corticonuclear connections are present for all the cranial motor nuclei **except** that part of the facial nucleus that supplies the muscles of the lower part of the face and that part of the hypoglossal nucleus that supplies the genioglossus muscle.
2. The cranial nerves that possess afferent sensory fibers have cell bodies that are found in ganglia along the course of the nerves; these are equivalent to the posterior root ganglia. In the case of the olfactory nerves, the cells are the olfactory receptors.
3. In situations in which the cranial nerve nuclei are close together, it is very rare for a disease process to affect one nucleus only. For example, the cell groups of the nucleus ambiguus serve the glossopharyngeal, the vagus, and the cranial root of the accessory nerve, and functional loss involving all three nerves is a common finding.

Clinical Examination

The systematic examination of the 12 cranial nerves is an important part of the examination of every neurologic patient. It may reveal a lesion of a cranial nerve nucleus or its central connections, or it may show an interruption of the lower motor neurons.

Olfactory Nerve

First, determine that the nasal passages are clear. Then, apply some easily recognizable aromatic substance, such as oil of peppermint, oil of clove, or tobacco, to each nostril in turn. Ask the patient whether he or she can smell anything; if so, ask the patient to identify the smell. It should be remembered that food flavors depend on the sense of smell and not on the sense of taste.

Bilateral anosmia can be caused by disease of the olfactory mucous membrane, such as the common cold or allergic rhinitis. **Unilateral anosmia** can result from disease affecting the olfactory nerves, bulb, or tract. A lesion of the olfactory cortex on one side is unlikely to produce complete anosmia, because fibers from each olfactory tract travel to both cerebral hemispheres. Fractures of the anterior cranial fossa involving the cribriform plate of the ethmoid could tear the olfactory nerves. Cerebral tumors of the frontal lobes or meningiomas of the anterior cranial fossa can produce anosmia by pressing on the olfactory bulb or tract.

Optic Nerve

First, ask the patient whether he or she has noted any change in eyesight. **Visual acuity** should be tested for near and distant vision. Near vision is tested by asking the patient to read a card with a standard size of type. Each eye is tested in turn, with or without spectacles. Distant vision is tested by asking the patient to read Snellen type at a distance of 20 ft.

The **visual fields** should then be tested. The patient and the examiner sit facing each other at a distance of 2 ft. The patient is asked to cover the right eye, and the examiner covers his own left eye. The patient is asked to look into the pupil of the examiner's right eye. A small object is then moved in an arc around the periphery of the field of vision, and the patient is asked whether he or she can see the object. The extent of the patient's field of vision is compared with the normal examiner's field. Then, the other eye is tested. The clinician must be careful not to miss loss or impairment of vision in the central area of the field (central scotoma).

VISUAL PATHWAY LESIONS

Lesions of the optic pathway may have many pathologic causes. Expanding tumors of the brain and neighboring structures, such as the pituitary gland and the meninges, and cerebrovascular accidents are commonly responsible. The most widespread effects on vision occur where the nerve fibers of the visual pathway are tightly packed together, such as in the optic nerve or the optic tract.

CIRCUMFERENTIAL BLINDNESS

Circumferential blindness may be caused by hysteria or optic neuritis (Fig. 11-24 [1]). Optic neuritis may occur following spread of infection from the sphenoid and ethmoid sinuses; the optic nerve is infected as it passes through the optic canal to enter the orbital cavity.

TOTAL BLINDNESS OF ONE EYE

Total blindness of one eye would follow complete section of one optic nerve (Fig. 11-24 [2]).

NASAL HEMIANOPIA

Nasal hemianopia would follow a partial lesion of the optic chiasma on its lateral side (Fig. 11-24 [3]).

BITEMPORAL HEMIANOPIA

Bitemporal hemianopia would follow a sagittal section of the optic chiasma (Fig. 11-24 [4]). This condition is most commonly produced by a tumor of the pituitary gland exerting pressure on the optic chiasma.

CONTRALATERAL HOMONYMOUS HEMIANOPIA

Contralateral homonymous hemianopia would follow division of the optic tract or optic radiation or destruction of the visual cortex on one side; the lesion would produce the same hemianopia for both eyes—that is, homonymous hemianopia (Fig. 11-24 [5–7]). If the right optic tract is divided, for example, a left temporal hemianopia and a right nasal hemianopia will occur.

FUNDUS EXAMINATION

The ocular fundus should be examined with an ophthalmoscope. The patient is asked to look at a distant object. When the right eye is examined, the physician should use his or her right eye and hold the ophthalmoscope in his or her right hand. The physician should systematically examine the fundus, looking first at the optic disc, then at the retina, then at the blood vessels, and finally at the macula.

The **optic disc** is creamy pink, and the lateral margin is seen clearly. The center of the disc is paler and hollowed out.

The **retina** is pinkish red, and there should be no hemorrhages or exudates.

The **blood vessels** should consist of four main arteries with their accompanying veins. Carefully examine the arteriovenous crossings. The veins should not be indented by the arteries.

The **macula** is examined by asking the patient to look directly at the light of the ophthalmoscope. It should look slightly darker than the surrounding retina.

EXTRAOCULAR MUSCLE EXAMINATION

To examine the extraocular muscles, the patient's head is fixed, and he or she is asked to move the eyes, in turn, to the

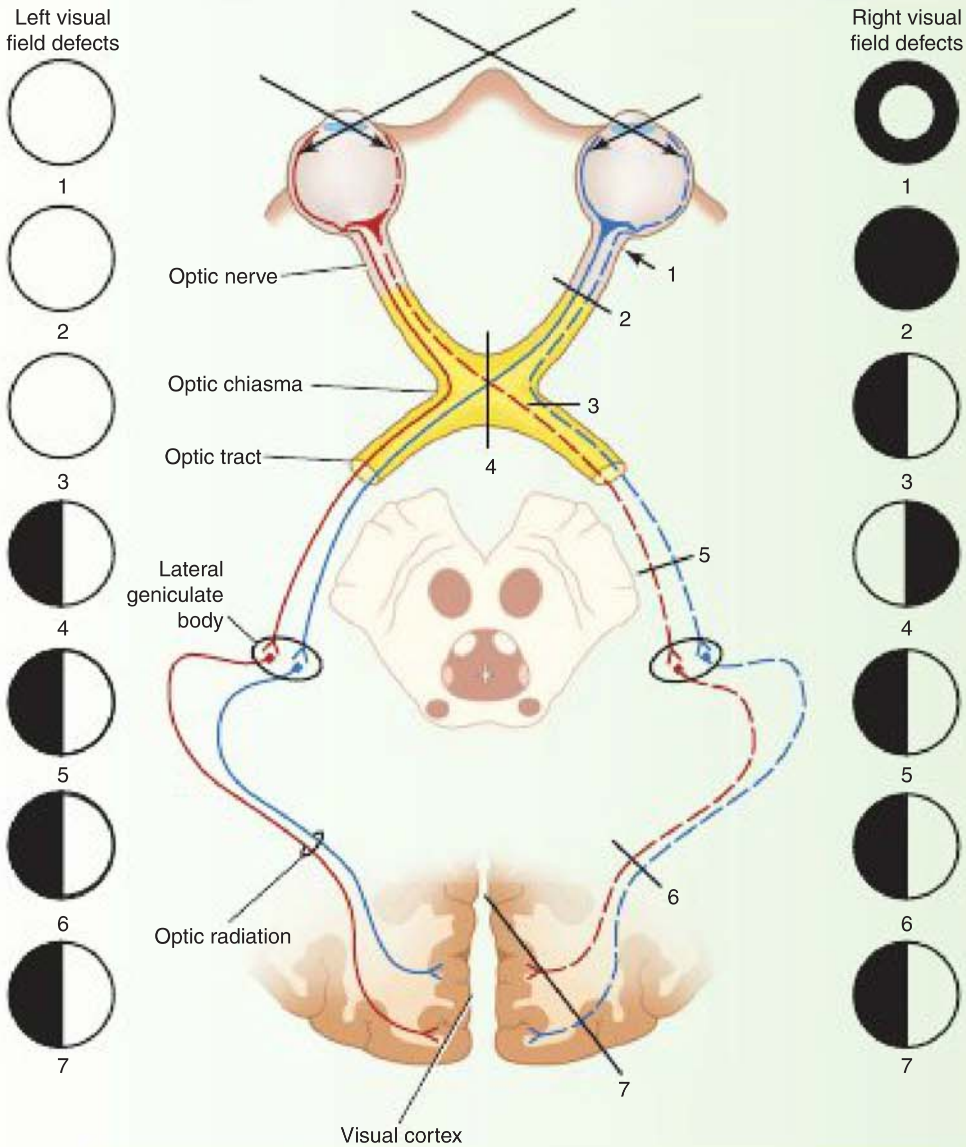


Figure 11-24 Visual field defects associated with lesions of the optic pathways. **1.** Right-sided circumferential blindness due to retrobulbar neuritis. **2.** Total blindness of the right eye due to division of the right optic nerve. **3.** Right nasal hemianopia due to a partial lesion of the right side of the optic chiasma. **4.** Bitemporal hemianopia due to a complete lesion of the optic chiasma. **5.** Left temporal hemianopia and right nasal hemianopia due to a lesion of the right optic tract. **6.** Left temporal and right nasal hemianopia due to a lesion of the right optic radiation. **7.** Left temporal and right nasal hemianopia due to a lesion of the right visual cortex.

left, to the right, upward, and downward, as far as possible in each direction. The patient should then be asked to look upward and laterally, upward and medially, downward and medially, and downward and laterally.

The pupillary reactions to convergence associated with accommodation and the direct and consensual pupillary reactions to light are tested. The nervous pathways involved in the pupillary reflexes are described on pages 328-329.

Oculomotor Nerve

The oculomotor nerve supplies all the extraocular muscles except the superior oblique and the lateral rectus. It also supplies the striated muscle of the levator palpebrae superioris and the smooth muscle concerned with accommodation, namely, the sphincter pupillae and the ciliary muscle.

In a complete lesion of the oculomotor nerve, the eye cannot be moved upward, downward, or inward. At rest, the eye looks laterally (external strabismus), owing to the activity of the lateral rectus, and downward, owing to the activity of the superior oblique. The patient sees double (diplopia). The upper eyelid droops (ptosis) due to paralysis of the levator palpebrae superioris. The pupil is widely dilated and nonreactive to light, owing to paralysis of the sphincter pupillae and unopposed action of the dilator (supplied by the sympathetic). Accommodation of the eye is paralyzed.

Incomplete lesions of the oculomotor nerve are common and may spare the extraocular muscles or the intraocular muscles. The condition in which the innervation of the extraocular muscles is spared with selective loss of the autonomic innervation of the sphincter pupillae and ciliary muscle is called **internal ophthalmoplegia**. The condition in which the sphincter pupillae and the ciliary muscle are spared with paralysis of the extraocular muscles is called **external ophthalmoplegia**.

The possible explanation for the involvement of the autonomic nerves and the sparing of the remaining fibers is that the parasympathetic autonomic fibers are superficially placed within the oculomotor nerve and are likely to be first affected by compression. The nature of the disease also plays a role. For example, in cases of diabetes with impaired nerve conduction (diabetic neuropathy), the autonomic fibers are unaffected, whereas the nerves to the extraocular muscles are paralyzed.

The conditions most commonly affecting the oculomotor nerve are diabetes, aneurysm, tumor, trauma, inflammation, and vascular disease. See lesions of the oculomotor nerve in the midbrain (Benedikt syndrome) on page 217.

Trochlear Nerve

The trochlear nerve supplies the superior oblique muscle, which rotates the eye downward and laterally.

In lesions of the trochlear nerve, the patient complains of double vision on looking straight downward, because the images of the two eyes are tilted relative to each other. This is because the superior oblique is paralyzed, and the eye turns medially as well as downward. In fact, the patient has great difficulty in turning the eye downward and laterally.

The conditions most often affecting the trochlear nerve include stretching or bruising as a complication of head injuries (the nerve is long and slender), cavernous sinus thrombosis, aneurysm of the internal carotid artery, and vascular lesions of the dorsal part of the midbrain. See lesions of the trochlear nerve in the midbrain on page 217.

Abducens Nerve

The abducens nerve supplies the lateral rectus muscle, which rotates the eye laterally. In a lesion of the abducens nerve, the patient cannot turn the eye laterally. When the patient is looking straight ahead, the lateral rectus is paralyzed, and the unopposed medial rectus pulls the eyeball medially, causing **internal strabismus**. Diplopia is also seen.

Lesions of the abducens nerve include damage due to head injuries (the nerve is long and slender), cavernous sinus thrombosis or aneurysm of the internal carotid artery, and vascular lesions of the pons.

INTERNUCLEAR OPHTHALMOPLEGIA

Lesions of the medial longitudinal fasciculus will disconnect the oculomotor nucleus that innervates the medial rectus muscle from the abducens nucleus that innervates the lateral rectus muscle. When the patient is asked to look laterally to the right or left, the ipsilateral lateral rectus contracts, turning the eye laterally, but the contralateral medial rectus fails to contract, and the eye looks straight forward.

Bilateral internuclear ophthalmoplegia can occur with multiple sclerosis, occlusive vascular disease, trauma, or brainstem tumors. Unilateral internuclear ophthalmoplegia can follow an infarct of a small branch of the basilar artery.

Trigeminal Nerve

The trigeminal nerve has sensory and motor roots. The sensory root passes to the trigeminal ganglion, from which emerge the ophthalmic (V_1), maxillary (V_2), and mandibular (V_3) divisions. The motor root joins the mandibular division.

The sensory function may be tested by using cotton and a pin over each area of the face supplied by the divisions of the trigeminal nerve (see Fig. 11-9). Note that the dermatomes overlap very little and that the skin covering the angle of the jaw is innervated by branches from the cervical plexus (C2 and C3). In lesions of the ophthalmic division, the cornea and conjunctiva will be insensitive to touch.

The motor function may be tested by asking the patient to clench his or her teeth. The masseter and the temporalis muscles can be palpated and felt to harden as they contract.

TRIGEMINAL NEURALGIA

In trigeminal neuralgia, the severe, stabbing pain over the face is of unknown cause and involves the pain fibers of the trigeminal nerve. Pain is felt most commonly over the skin areas innervated by the mandibular and maxillary divisions of the trigeminal nerve; only rarely is pain felt in the area supplied by the ophthalmic division.

Facial Nerve

The facial nerve supplies the muscles of facial expression, supplies the anterior two-thirds of the tongue with taste fibers, and is secretomotor to the lacrimal, submandibular, and sublingual glands.

To test the facial nerve, the patient is asked to show the teeth by separating the lips with the teeth clenched. Normally, equal areas of the upper and lower teeth are revealed on both sides. If a lesion of the facial nerve is present on one side, the mouth is distorted. A greater area of teeth is revealed on the side of the intact nerve, since the mouth is pulled up on that side. Another useful test is to ask the patient to close both eyes firmly. The examiner then attempts to open the eyes by gently raising the patient's upper lids. On the side of the lesion, the orbicularis oculi is paralyzed so that the eyelid on that side is easily raised.

The sensation of taste on each half of the anterior two-thirds of the tongue can be tested by placing small amounts of sugar, salt, vinegar, and quinine on the tongue for the sweet, salty, sour, and bitter sensations.

FACIAL NERVE LESIONS

The facial nerve may be injured or may become dysfunctional anywhere along its long course from the brainstem to the face. Its anatomical relationship to other structures greatly assists in the localization of the lesion. If the abducens nerve (supplies the lateral rectus muscle) and the facial nerve are not functioning, this would suggest a lesion in the pons of the brain. If the vestibulocochlear nerve (for balance and hearing) and the facial nerve are not functioning, this suggests a lesion in the internal acoustic meatus. If the patient is excessively sensitive to sound in one ear, the lesion probably involves the nerve to the stapedius muscle, which arises from the facial nerve in the facial canal.

Loss of taste over the anterior two-thirds of the tongue indicates that the facial nerve is damaged proximal to the point where it gives off the chorda tympani branch in the facial canal.

A firm swelling of the parotid salivary gland associated with impaired function of the facial nerve is strongly indicative of a cancer of the parotid gland with involvement of the nerve within the gland.

Deep lacerations of the face may involve branches of the facial nerve.

The part of the facial nucleus that controls the muscles of the upper part of the face receives corticonuclear fibers from both cerebral hemispheres. Therefore, it follows that with a lesion involving the upper motor neurons, only the muscles of the lower part of the face will be paralyzed (Fig. 11-25 [1]). However, in patients with a lesion of the facial nerve motor nucleus or the facial nerve itself—that is, a lower motor neuron lesion—all the muscles on the affected side of the face will be paralyzed (Fig. 11-25 [2]). The lower eyelid will droop, and the angle of the mouth will sag. Tears will flow over the lower eyelid, and saliva will dribble from the corner of the mouth. The patient will be unable to close the eye and will be unable to expose the teeth fully on the affected side.

In patients with hemiplegia, the emotional movements of the face are usually preserved. This indicates that the upper motor neurons controlling these **mimetic** movements have a course separate from that of the main corticobulbar fibers. A lesion involving this separate pathway alone results in a loss of emotional movements, but voluntary movements are preserved. A more extensive lesion will produce both mimetic and voluntary facial paralysis.

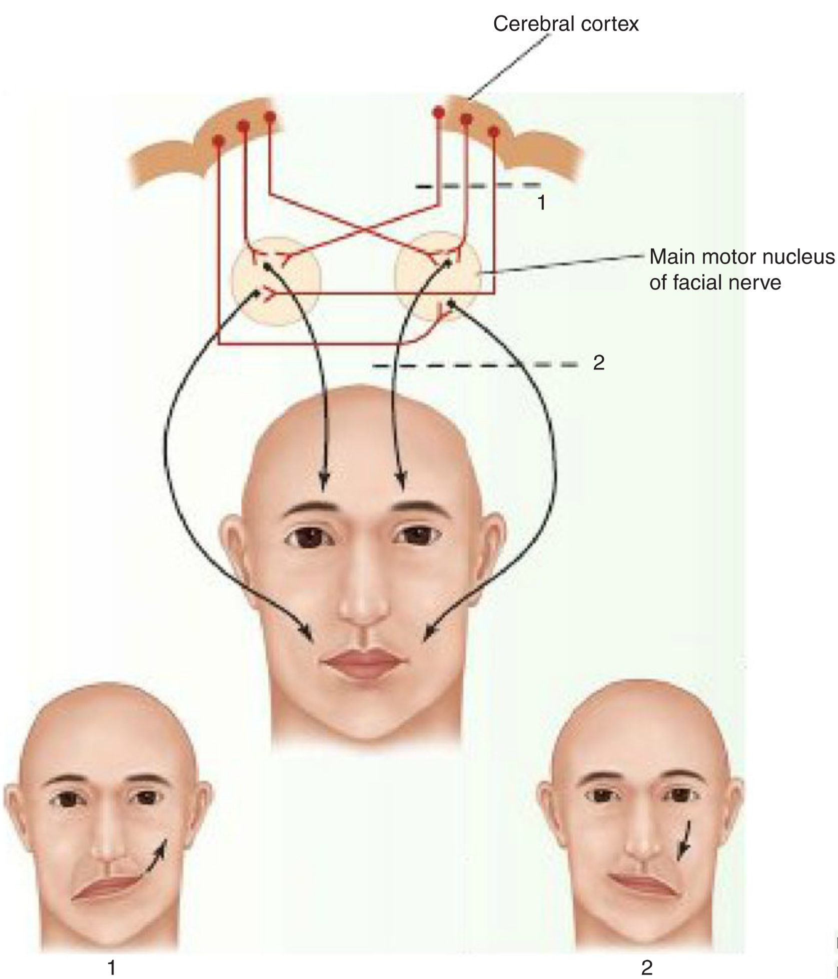
BELL PALSY

Bell palsy is a dysfunction of the facial nerve, as it lies within the facial canal; it is usually unilateral. The site of the dysfunction will determine the aspects of facial nerve function that do not work.

The swelling of the nerve within the bony canal causes pressure on the nerve fibers; this results in a temporary loss of function of the nerve, producing a lower motor neuron type of facial paralysis. The cause of Bell palsy is not known; it sometimes follows exposure of the face to a cold draft.

Vestibulocochlear Nerve

The vestibulocochlear nerve innervates the utricle and saccule, which are sensitive to static changes in equilibrium;



motor neurons (1) and lower motor neurons (2).

the semicircular canals, which are sensitive to changes in dynamic equilibrium; and the cochlea, which is sensitive to sound.

VESTIBULAR NERVE FUNCTION DISTURBANCE

Disturbances of vestibular nerve function include dizziness (**vertigo**) and **nystagmus** (see p. 242). Vestibular nystagmus is an uncontrollable rhythmic oscillation of the eyes, and the fast phase is away from the side of the lesion. This form of nystagmus is essentially a disturbance in the reflex control of the extraocular muscles, which is one of the functions of the semicircular canals. Normally, the nerve impulses pass reflexly from the canals through the vestibular nerve, the vestibular nuclei, and the medial longitudinal fasciculus, to the third, fourth, and sixth cranial nerve nuclei, which control the extraocular muscles; the cerebellum assists in coordinating the muscle movements.

Vestibular function can be investigated with **caloric tests**. These involve the raising and lowering of the temperature in the external auditory meatus, which induces convection currents in the endolymph of the semicircular canals (principally, the lateral semicircular canal) and stimulates the vestibular nerve endings.

The causes of vertigo include diseases of the labyrinth, such as Ménière disease. Lesions of the vestibular nerve, the vestibular nuclei, and the cerebellum can also be responsible. Multiple sclerosis, tumors, and vascular lesions of the brainstem also cause vertigo.

COCHLEAR NERVE FUNCTION DISTURBANCE

Disturbances of cochlear function are manifested as **deafness** and **tinnitus**. The patient's ability to hear a whispered voice or a vibrating tuning fork should be tested; each ear should be tested separately.

Loss of hearing may be due to a defect of the auditory-conducting mechanism in the middle ear, damage to the receptor cells in the spiral organ of Corti in the cochlea, a lesion of the cochlear nerve, a lesion of the central auditory pathways, or a lesion of the cortex of the temporal lobe.

Lesions of the internal ear include **Ménière disease**, **acute labyrinthitis**, and **trauma** following head injury. Lesions of the cochlear nerve include **tumor (acoustic neuroma)** and **trauma**. Lesions in the central nervous system include **tumors of the midbrain** and **multiple sclerosis**. Only bilateral temporal lobe lesions cause deafness.

Glossopharyngeal Nerve

The glossopharyngeal nerve supplies the stylopharyngeus muscle and sends secretomotor fibers to the parotid gland. Sensory fibers innervate the posterior third of the tongue for general sensation and taste.

The integrity of this nerve may be evaluated by testing the patient's general sensation and that of taste on the posterior third of the tongue.

Isolated lesions of the glossopharyngeal nerve are rare and usually also involve the vagus nerve.

Vagus Nerve

The vagus nerve innervates many important organs, but the examination of this nerve depends on testing the function of the branches to the pharynx, soft palate, and larynx. The **pharyngeal** or **gag reflex** may be tested by touching the lateral wall of the pharynx with a spatula. This should immediately cause the patient to gag; that is, the pharyngeal muscles will contract. The afferent neuron of the pharyngeal reflex runs in the glossopharyngeal nerve, and the efferent neurons run in the glossopharyngeal (to the stylopharyngeus muscle) and vagus nerves (pharyngeal constrictor muscles). Unilateral lesions of the vagus will show little or no gag reflex on that side.

The innervation of the soft palate may be tested by asking the patient to say "ah." Normally, the soft palate rises and the uvula moves backward in the midline.

All the muscles of the larynx are supplied by the recurrent laryngeal branch of the vagus, except the cricothyroid muscle, which is supplied by the external laryngeal branch of the superior laryngeal branch of the vagus. Hoarseness or absence of the voice may occur as a symptom of vagal nerve palsy. The movements of the vocal cords may be tested by means of a laryngoscopic examination. Lesions involving the vagus nerve in the posterior cranial fossa commonly involve the glossopharyngeal, accessory, and hypoglossal nerves as well.

Accessory Nerve

The accessory nerve supplies the SCM and the trapezius muscles by means of its spinal root. The patient should be asked to rotate the head to one side against resistance, causing the SCM of the opposite side to come into action. Then, the patient should be asked to shrug the shoulders, causing the trapezius muscles to come into action.

Lesions of the spinal part of the accessory nerve will result in paralysis of the SCM and trapezius muscles. The SCM muscle will atrophy, causing weakness in turning the head to the opposite side. The trapezius muscle will also atrophy, causing the shoulder to droop on that side as well as weakness and difficulty in raising the arm above the horizontal.

Lesions of the spinal part of the accessory nerve may occur anywhere along its course and may result from tumors or trauma from stab or gunshot wounds in the neck.

Hypoglossal Nerve

The hypoglossal nerve supplies the intrinsic muscles of the tongue and the styloglossus, hyoglossus, and genioglossus muscles. To test the integrity of the nerve, the patient is asked to put out the tongue; in the setting of a lower motor neuron lesion, the tongue will be observed to deviate toward the paralyzed side. The tongue will be smaller on the side of the lesion, owing to muscle atrophy, and fasciculation may accompany or precede the atrophy. Remember that the greater part of the hypoglossal nucleus receives corticonuclear fibers from both cerebral hemispheres. However, the part of the nucleus that supplies the genioglossus receives corticonuclear fibers only from the opposite cerebral hemisphere. If a patient has a lesion of the corticonuclear fibers, there will be no atrophy or fibrillation of the tongue, and on protrusion, the tongue will deviate to the side opposite the lesion. (Note that the genioglossus is the muscle that pulls the tongue forward.)

Lesions of the hypoglossal nerve may occur anywhere along its course and may result from tumor, demyelinating diseases, syringomyelia, and vascular accidents. Injury of the nerve in the neck may also follow stab and gunshot wounds.

Key Concepts

Cranial Nerve Organization

- The 12 pairs of cranial nerves leave the brain or superior spinal cord and pass through foramina and fissures in the skull. All nerves are distributed in the head and neck except for cranial nerve X, which also supplies structures in the thorax and abdomen.
- Olfactory, optic, and vestibulocochlear nerves are entirely sensory. Oculomotor, trochlear, abducens, accessory, and hypoglossal are entirely motor. All others cranial nerves are both sensory and motor.

Cranial Nerve I

- The olfactory nerves are a series of bipolar cells located in the mucous membrane of the nasal cavity roof. The projecting olfactory hairs react to odors in the air, stimulating the olfactory nerves.
- Nerves are myelinated by Schwann cells and project through the cribriform plate to synapse on mitral and tufted cells located in the olfactory bulb.
- Axons from the mitral and tufted cells form the olfactory tract and project to the primary olfactory cortex, accomplishing the function of smell.
- Secondary connections throughout the cortex are responsible for appreciation or triggering of emotional and autonomic responses to the detected smell.

Cranial Nerve II

- Fibers of the optic nerve are the axons of ganglion cells from the retina. The optic nerve leaves the orbital cavity through the optic canal and unites with the nerve of the opposite side to form the optic chiasma.
- The optic tract arises from the optic chiasma, carrying axons from the complementary half of each eye (i.e., ipsilateral nasal with contralateral temporal).
- Most fibers of optic tract synapse in the lateral geniculate body of the thalamus, which projects to the primary visual cortex via the optic radiations.
- A smaller number of fibers do not synapse in the lateral geniculate nucleus, but instead, project to the pretectal nucleus and the superior colliculus, and are concerned with light reflexes.

Cranial Nerve III

- Oculomotor nerve carries somatic and visceral motor fibers from the main oculomotor and Edinger–Westphal nuclei, respectively.
- This nerve controls the movement of extraocular muscles and the smooth muscle of the iris and ciliary muscles for the actions of constriction and accommodation.
- The nerve fibers exit the midbrain in the interpeduncular fossa and exit the cranial cavity through the superior orbital fissure.

Cranial Nerve IV

- The motor fibers from the trochlear nucleus exit the midbrain posteriorly and immediately decussate with the nerve on the opposite side.
- The trochlear nerves pass anteriorly around the midbrain and exit the cranial cavity via the superior orbital fissure to innervate the superior oblique muscle of the eyeball.

Cranial Nerve V

- The trigeminal nerve is the largest cranial nerve, carrying sensation to the head and motor control to the muscles of mastication.
- The trigeminal nerve has four nuclei: main (sensory), spinal (sensory), mesencephalic (sensory), and motor.
- Pain, temperature, touch, and pressure travel along axons whose cell bodies are located in the semilunar or trigeminal sensory ganglion.
  - The sensations of touch and pressure are conveyed by fibers that synapse in the main sensory nucleus.
  - The sensations of pain and temperature are conveyed by fibers that synapse in the spinal nucleus.
  - Proprioceptive fibers from the muscles of the face, orbit, mouth, and mastication, synapse in the mesencephalic nucleus
- The trigeminal nerve is formed from three major nerves: ophthalmic (V_1), maxillary (V_2), and mandibular (V_3).

Cranial Nerve VI

- The motor fibers from the abducens nerve nucleus exit the brainstem at the junction of the pons and medulla oblongata.
- The abducens nerve exits the cranial cavity through the superior orbital fissure, to the orbit, where it innervates the lateral rectus muscle of the eyeball.

Cranial Nerve VII

- The fibers of the facial nerve originate from the main motor nucleus, superior salivatory (parasympathetic) and lacrimal (parasympathetic), and nucleus of the tractus solitarious (sensory).
- The motor fibers exit the cranial cavity through the internal acoustic meatus where they join the sensory root stemming from the geniculate ganglion.
- The fibers from the motor nucleus innervate the muscles of facial expression, the stapedius, the posterior belly of the digastric, and the stylohyoid muscles.
- Fibers from the superior salivatory nucleus supply the submandibular and sublingual salivary glands. The lacrimal nucleus supplies the lacrimal gland.
- The sensory nucleus receives taste fibers from the anterior two-thirds of the tongue.

Cranial Nerve VIII

- The vestibulocochlear nerve consists of two parts, vestibular nerve and cochlear nerve.
- The vestibular nerve conducts head positioning information from the utricle, saccule, and semicircular canals.
- The cells bodies of these fibers are positioned in the vestibular ganglion and project to the vestibular nuclear complex, a group of nuclei that transmit vestibular information to the cortex and spinal cord.
- The cochlear nerve consists of bipolar cell bodies in the spiral nucleus of the cochlear, with fibers conducting cochlear sensations to the anterior and posterior cochlear nuclei.
- Second-order neurons from the cochlear nuclei communicate with the posterior nucleus of the trapezoid body, which sends a bundle of third-order fibers, called the lateral lemniscus, to the inferior colliculus and medial geniculate body. From here, axons project to the primary auditory cortex of the superior temporal gyrus.

Cranial Nerve IX

- The glossopharyngeal nerve has three nuclei: the main motor, inferior salivatory (parasympathetic), spinal trigeminal (sensory), and nucleus of the tractus solitarius (sensory).
- The motor fibers innervate the stylopharyngeus muscles.
- The parasympathetic fibers innervate the parotid salivary gland.
- The sensory fibers from the pharynx and posterior third of the tongue synapse in the spinal trigeminal nucleus, while the taste and carotid sinus and body reflexes synapse in the nucleus solitarius.
- The glossopharyngeal nerve exits the cranial cavity through the jugular foramen.

Cranial Nerve X

- The vagus has four nuclei: nucleus ambiguus (motor), dorsal nucleus (parasympathetic), spinal trigeminal (sensory), and nucleus of the tractus solitarius (sensory).
- The motor fibers from the nucleus ambiguus innervate the constrictor muscles of the pharynx and the intrinsic muscles of the larynx.
- The sensory fibers conveying taste from the epiglottis and visceral afferents from the organs synapse in the nucleus solitarius. Sensation from the mucosa of the larynx ends in the spinal nucleus of the trigeminal.
- Parasympathetic fibers from the dorsal nucleus of the vagus are distributed to the involuntary muscle of the bronchi, heart, esophagus, stomach, small intestine, and up to a third of the transverse colon.
- The vagus nerve exits the cranial cavity through the jugular foramen.

Cranial Nerve XI

- The accessory nerve is a motor nerve that receives efferent fibers from the nucleus ambiguus and the anterior gray column of the first five segments of the spinal cord.
- The fibers originating in the gray columns bring about movement of the SCM and trapezius muscles.
- Fibers from the nucleus ambiguus run with the vagus nerve and are usually attributed to the functions of CN X.
- The accessory nerve exits the cranial cavity through the jugular foramen.

Cranial Nerve XII

- The hypoglossal nerve is a motor nerve that receives its efferent fibers from the hypoglossal nucleus and innervates the muscles of the tongue.
- The hypoglossal nerve exits the medulla oblongata between the pyramid and the olive and traverses the hypoglossal canal to exit the cranial cavity.

Clinical Problem Solving

1. A 60-year-old woman is seen as an outpatient because she has suddenly developed double vision. She is watching her favorite television program when it suddenly occurs. She has no other symptoms. A complete physical examination shows that her right eye, when at rest, is turned medially, and she is unable to turn it laterally. A moderate amount of glucose is found in her urine, and she has an abnormally elevated blood glucose level. When closely questioned, she admits that recently she has noticed having to pass water more frequently, especially at night. She also says she often feels thirsty. She has lost 28 lb during the past 2 years. Using your knowledge of neuroanatomy, explain the problem in her right eye. Do you think a connection exists between her glucosuria, high blood glucose, polyuria, polydipsia, and weight loss and her eye condition?
2. An 18-year-old man is admitted to the hospital unconscious after a serious motorcycle accident. A complete physical examination is performed and lateral and anteroposterior radiographs of the skull taken, which show that the patient has a fracture involving the anterior cranial fossa. It also is noted that he has a slight but continuous blood-stained watery discharge from his left nostril. Three days later, he regains consciousness, and a further physical examination reveals that he can no longer smell. This is tested by asking him to recognize the smell of coffee, oil of clove, and oil of peppermint. Using your knowledge of neuroanatomy, diagnose what is wrong with this patient. Is it possible for normal individuals with an acute sense of smell to be unable to recognize common scents? Could a tumor that had destroyed the olfactory cortex of one cerebral hemisphere be responsible for the anosmia in this patient?
3. A 72-year-old man with a known history of cerebrovascular problems visits his physician because 3 days previously, he had begun to have trouble reading the paper. He complains that the print started to tilt and that he is beginning to see double. He also says that he finds it difficult to see the steps when he descends the staircase to the physician's office. On physical examination, the patient has weakness of movement of the right eye both downward and laterally. Using your knowledge of neuroanatomy, explain this patient's signs and symptoms. If we assume that a cranial nerve nucleus is the site of the lesion, is it the right one or the left one that is involved?
4. A 73-year-old man consults his physician because he is becoming deaf. His only other complaints are that he did not think he was as tall as he used to be, and he is annoyed to find that each year he has to buy a size larger hat. The physician diagnoses osteitis deformans (Paget disease) and explains to the medical students that this is a disease of bones involving bone absorption and new bone formation. These bony changes lead to enlargement of the skull, deformities of the vertebral column, and bowing of the long bones of the legs. The physician asks the students whether a connection exists between the bone disease and the patient's deafness and which other cranial nerve they would be particularly interested in testing. How would you have answered these questions?
5. A neurologist is visited by a 25-year-old man who complains of a feeling of heaviness in both legs and giddiness on walking. On examination, the patient has widely disseminated lesions involving the corticospinal tracts, the posterior white column, and the optic nerves. A diagnosis of multiple sclerosis is made. This disease of unknown origin primarily involves the white matter of the brain and spinal cord. Do you think this patient's symptoms of vertigo could be accounted for by this disease?
6. A 54-year-old woman with left-sided hemiplegia is examined by a fourth-year medical student. He very carefully tests each cranial nerve and notes any defects. During the examination, he stands behind the patient and gently grasps the trapezius muscles between his fingers and thumbs and asks the patient to shrug her shoulders against resistance. He is surprised to find no evidence of weakness in either trapezius muscle and no muscle wasting. Would you expect to find evidence of weakness or wasting in the trapezius muscles of a patient with hemiplegia?
7. A 35-year-old man is admitted to the hospital with a complaint of severe pain of the right side of the forehead and the right eye. The pain started 3 weeks previously and has progressively increased since then. One week ago, he started to see double, and this morning, his wife notices that his right eye is turning out laterally. The physician in charge makes a careful neurologic workup on this patient and finds a lateral deviation of the right eye, dilatation of the right pupil with loss of direct and consensual light reflexes, paralysis of accommodation on the right, and paralysis of all right-sided ocular movement, except laterally. He initially advises the patient to have computed tomography and magnetic resonance imaging scans of the skull and later orders a right-sided carotid arteriogram. The film shows an aneurysm of the internal carotid artery on the right side. Explain the signs and symptoms of this patient. Relate the signs and symptoms to the aneurysm.
8. During ward rounds, a neurologist demonstrates the signs and symptoms of neurosyphilis to a group of students. The patient is a 62-year-old man. The physician asks the students to note that both the patient's pupils are small and fixed and are not altered by shining a light in the eyes or shading the

eyes. However, the pupils narrow when the patient is asked to look from a distant object to the tip of his nose. Moreover, the pupils dilate again when he is looking into the distance. “This is a good example of the Argyll Robertson pupil,” said the physician. Using your knowledge of neuroanatomy, explain this curious pupillary reaction.

9. Describe the effects of a lesion at the following points along the visual pathway of the right eye:
   (a) Section of the right optic nerve
   (b) Midline section of the optic chiasma
   (c) Section of the right optic tract
   (d) Section of the right optic radiation
   (e) Destruction of the cortex of the right occipital pole
10. A 58-year-old woman is diagnosed as having an advanced carcinoma of the nasopharynx with neoplastic infiltration of the posterior cranial fossa. How do you test for the integrity of the 9th, 10th, and 11th cranial nerves?
11. A 32-year-old woman with syringomyelia is found on physical examination to have impairment of appreciation of pain and temperature of the face but preservation of light touch. Using your knowledge of neuroanatomy, explain this dissociated sensory loss in the face.
12. A 51-year-old man complaining of an agonizing, stabbing pain over the middle part of the right side of his face is seen in the emergency department. The stabs last a few seconds and are repeated several times. “The pain is the worst I have ever experienced,” he tells the physician. A draft of cold air on the right side of his face or the touching of a few hairs in the right temporal region of his scalp can trigger the pain. The patient has no other complaints and says he feels otherwise very fit. A complete physical examination of the cranial nerves reveals nothing abnormal. In particular, no evidence of sensory or motor loss of the right trigeminal nerve is seen. The patient indicates the area on the right side of his face in which he is experiencing the pain; it is seen to be in the distribution of the maxillary division of the trigeminal nerve. Using your knowledge of neuroanatomy, make the diagnosis.
13. A physician turned to a group of students and says, “I think this patient has an advanced neoplasm in the posterior cranial fossa with involvement of the medulla oblongata and in particular the nuclei of the vagus nerve.” What are the nuclei of the vagus nerve? Is it possible to have abnormal movements of the vocal cords in a patient with hemiplegia? Is it possible to have a solitary lesion of the vagal nuclei without involvement of other cranial nerve nuclei?

Answers and Explanations to Clinical Problem Solving

1. The medial strabismus of her right eye, the diplopia, and the inability to turn the right eye laterally were due to paralysis of the right lateral rectus muscle caused by a lesion of the abducens nerve. Yes, a connection exists between the eye condition and the other symptoms. The glucosuria, high blood glucose, polyuria, polydipsia, and weight loss are the classic signs and symptoms of diabetes mellitus. The lesion of the abducens nerve was an example of diabetic neuropathy, a complication of untreated or poorly treated diabetes. Once the patient’s diabetes was carefully controlled, the right lateral rectus palsy disappeared after 3 months.
2. This man suffered from anosmia secondary to a lesion involving both olfactory tracts. The watery discharge from the nose was due to a leak of cerebrospinal fluid through the fractured cribriform plate of the ethmoid bone. It was the fracture and the associated hemorrhage that had damaged both olfactory tracts. Yes, many normal persons with an acute sense of smell cannot name common scents. No, a lesion of one olfactory cortex cannot produce complete anosmia because both olfactory tracts communicate with each other through the anterior commissure.
3. This patient has a paralysis of the right superior oblique muscle resulting from a lesion of the trochlear nerve. Since the trochlear nerves decussate on emergence from the midbrain, the left trochlear nucleus is the site of the lesion. This patient had a thrombosis of a small artery supplying the left trochlear nucleus. The difficulty in reading, the diplopia, and the difficulty in walking down stairs were due to the paralysis of the right superior oblique muscle.
4. As the result of the great increase in the thickness of the bones due to new bone formation in osteitis deformans, mental deterioration may occur owing to compression of the cerebral hemispheres. Those cranial nerves that pass through relatively small foramina in the skull are likely to be compressed by the new bone growth. The nerves commonly involved are the vestibulocochlear and facial nerves, following narrowing of the internal acoustic meatus. The olfactory and optic nerves also may be compressed as they pass through the cribriform plate and the optic canal, respectively.
5. Yes. Multiple sclerosis may affect white matter in widely disseminated areas of the central nervous system. Although remissions may occur, it is inevitably progressive. Thirty years later, when this patient died, numerous areas of sclerosis were found throughout the brainstem and white matter of the spinal cord. It was noted that the region of the vestibular nuclei beneath the floor of the fourth ventricle was involved in the disease process.
6. No. The trapezius muscle is supplied by the spinal part of the accessory nerve. The spinal nucleus of this nerve in the upper five cervical segments of the spinal cord receives cortical fibers from both cerebral hemispheres. This would account for the absence of muscular weakness in this patient with

a left-sided hemiplegia. For a muscle to atrophy (except for disuse atrophy), the integrity of the monosynaptic reflex arc must be destroyed. This was not the case in this patient.

7. The severe pain over the forehead and the right eye was due to irritation of the ophthalmic division of the trigeminal nerve by the slowly expanding aneurysm of the internal carotid artery as it was lying in the cavernous sinus. The double vision (diplopia) and the lateral deviation of the right eye were due to the unopposed action of the lateral rectus muscle (supplied by the abducens nerve). The dilatation of the right pupil with loss of direct and consensual light reflexes, paralysis of accommodation, and paralysis of all right-sided ocular movement except laterally were due to pressure on the right oculomotor nerve by the aneurysm. The nerve at this point is situated in the lateral wall of the cavernous sinus. Note that the lateral movement of the eyeball was accomplished by contracting the lateral rectus muscle (abducens nerve) and that the inferolateral movement was due to the contraction of the superior oblique muscle (trochlear nerve).
8. The Argyll Robertson pupil is a common finding in neurosyphilis, although it may occur in other diseases. The lesion is believed to be located where the pretectal fibers pass to the parasympathetic oculomotor nuclei on both sides of the midbrain. This lesion effectively destroys the direct and consensual light reflexes of both eyes but leaves the pathway for the accommodation reflex intact. (For details of pathway, see p. 329.)
9. A lesion will have the following effects along the visual pathway of the right eye:
   (a) Complete blindness of the right eye
   (b) Bitemporal hemianopia
   (c) Left homonymous hemianopia
   (d) Left homonymous hemianopia
   (e) Left homonymous hemianopia, usually with some macular sparing owing to the very large area of the cortex allotted to the macula
10. The glossopharyngeal nerve supplies the posterior third of the tongue with fibers that subserve common sensations and taste. This may be tested easily. The vagus nerve, by means of its pharyngeal branch, supplies many muscles of the soft palate, and these may be tested by asking the patient to say “ah” and observing that normally the uvula is elevated in the midline. A lesion of the vagus nerve would result in the uvula being elevated to the opposite side. Additional tests may be carried out by observing the movements of the vocal cords through a laryngoscope.

    The spinal part of the accessory nerve may be tested by asking the patient to shrug her shoulders by using the trapezius muscles or to rotate her head so that she looks upward to the opposite side by contracting the sternocleidomastoid muscles. Both muscles are innervated by the spinal part of the accessory nerve.
11. The afferent fibers entering the central nervous system through the trigeminal nerve pass either to the main sensory nucleus in the pons or to the spinal nucleus situated in the medulla oblongata and the first two cervical segments of the spinal cord. The sensations of touch and pressure are served by the main sensory nucleus, while those of pain and temperature are served by the more inferiorly placed spinal nucleus. In this patient, the lesion of syringomyelia was situated in the medulla oblongata and the cervical part of the spinal cord, and the main sensory nucleus in the pons was intact.
12. This patient exhibited the classic history of right-sided trigeminal neuralgia involving the maxillary division of that cranial nerve. The temporal region of the scalp, supplied by the auriculotemporal branch of the mandibular division of that nerve, was the trigger area for the initiation of the intense pain. Clearly, knowledge of the distribution of the branches of the trigeminal nerve and the diseases that can affect this nerve is essential for a physician to be able to make the diagnosis.
13. The vagal nuclei are the (a) main motor nucleus, (b) parasympathetic nucleus, and (c) sensory nucleus. The main motor and parasympathetic nuclei are controlled by both cerebral hemispheres; thus, hemiplegia will have no effect on the movement of the vocal cords. The vagal nuclei are practically continuous with the nuclei of the glossopharyngeal and accessory nerves, and these usually are involved together in lesions of the medulla oblongata.

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 cranial nerve nuclei listed below have the following descending tracts terminating on them:
   (a) The inferior salivatory nucleus of the glossopharyngeal nerve receives descending tracts from the thalamus.
   (b) The nucleus of the abducens nerve receives only crossed corticobulbar tracts.
   (c) The nucleus of the facial nerve supplying the muscles of the lower part of the face receives only crossed corticobulbar tracts.
   (d) The trigeminal motor nucleus receives only uncrossed corticobulbar tracts.
   (e) The nucleus of the trochlear nerve receives only crossed corticobulbar tracts.

2. The nuclei associated with the facial nerve include the following:
   (a) Spinal nucleus
   (b) Inferior salivatory nucleus
   (c) Nucleus ambiguus
   (d) Main sensory nucleus
   (e) Lacrimal nucleus
3. A patient with unilateral upper motor neuron paralysis of the facial muscles can smile with both sides of his face in response to a joke but not voluntarily. This can be explained by the following facts:
   (a) The main corticobulbar fibers controlling voluntary movement of the facial muscles have been preserved.
   (b) Reticular fibers, possibly originating in the hypothalamus and descending to the motor nuclei of the facial nerves, are damaged.
   (c) The facial nerves are damaged.
   (d) The muscles producing mimetic movements of the face are innervated by corticobulbar fibers that have a course separate from the main corticobulbar fibers.
   (e) A lesion involving the lower motor neurons is present.

Directions: Each of the numbered items or incomplete statements in this section is followed by answers or by completions of the statement. Select the ONE lettered answer or completion that is BEST in each case.

4. Which of the following structures participates in the reception of sound?
   (a) Trapezoid body
   (b) Medial lemniscus
   (c) Nucleus of the trigeminal lemniscus
   (d) Inferior temporal gyrus
   (e) Lateral geniculate body
5. The cerebral cortex is necessary for which of the following visual reflexes?
   (a) Corneal reflex
   (b) Accommodation reflex
   (c) Consensual light reflex
   (d) Pupillary light reflex
   (e) Visual body reflex
6. The nasal field of the right eye is projected to the:
   (a) left lateral geniculate body.
   (b) both banks of the left calcarine fissure.
   (c) left optic tract.
   (d) temporal retina of the right eye.
   (e) left optic radiation.
7. Right pupillary constriction associated with light directed at the left eye requires the:
   (a) right optic radiation.
   (b) left optic nerve.
   (c) left Edinger–Westphal nucleus.
   (d) left oculomotor nerve.
   (e) right optic nerve.
8. Select the lettered statement concerning the hypoglossal nerve that is correct:
   (a) A lesion involving the hypoglossal nerve will result in deviation of the tongue toward the same side as the lesion when the tongue is protruded.
   (b) The hypoglossal nerve conducts taste impulses from the posterior third of the tongue.
   (c) The hypoglossal nerve emerges from the brainstem between the olive and the inferior cerebellar peduncle.
   (d) The hypoglossal nerve carries with it fibers from the third and fourth cervical nerves.
   (e) The fibers of the accessory nerve wind around the motor nucleus of the hypoglossal nerve beneath the floor of the fourth ventricle.
9. Select the lettered statement concerning the trigeminal nuclei that is correct:
   (a) The main sensory nucleus lies within the medulla oblongata.
   (b) The spinal nucleus extends inferiorly as far as the fifth cervical segment.
   (c) Proprioceptive impulses from the muscles of mastication reach the mesencephalic nucleus along fibers that are part of the unipolar neurons of the nucleus.
   (d) The sensations of pain and temperature terminate in the main sensory nucleus.
   (e) The trigeminal lemniscus contains only efferent fibers from the ipsilateral sensory nuclei of the trigeminal nerve.

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

10. The cranial nerves listed below are associated with the following functions:
    (a) The spinal part of the accessory nerve shrugs the shoulder.
    (b) The oculomotor nerve closes the eye.
    (c) The trigeminal nerve is responsible for swallowing.
    (d) The facial nerve receives the sensation of taste from the posterior two-thirds of the tongue.
    (e) The glossopharyngeal nerve receives the sensation of touch from the anterior third of the tongue.
11. The following statements concern the cranial nerves involved in the process of vision:
    (a) The nerve fibers of the optic nerve are surrounded by Schwann cells.
    (b) The optic nerve is surrounded by an extension of the subarachnoid space.
    (c) Internal ophthalmoplegia is a condition in which the oculomotor nerve supply to the dilator pupillae is lost, but the innervation of the extraocular muscles is spared.
    (d) External ophthalmoplegia is a condition in which the oculomotor nerve supply to the extraocular muscles is spared, but the innervation of the sphincter pupillae and the ciliary muscle is lost.
    (e) The optic nerve leaves the orbital cavity through the optic canal in the greater wing of the sphenoid bone.

12. The following statements concern the cranial nerves listed below:
    (a) The main sensory nucleus of the trigeminal nerve lies in the brainstem medial to the motor nucleus.
    (b) Proprioceptive impulses from the facial muscles end in the mesencephalic nucleus of the facial nerve.
    (c) The facial nerve leaves the posterior cranial fossa with the vestibulocochlear nerve by passing through the stylomastoid foramen.
    (d) The superior salivatory nucleus of the facial nerve innervates the parotid salivary gland.
    (e) The olfactory receptor cells are located in the mucous membrane of the nasal cavity above the level of the superior concha.

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

A 64-year-old man visited his physician because he had noticed a swelling on the right side of his neck. He mentioned that he had suffered from a chronic cough for 6 months and was rapidly losing weight.

13. On physical examination, the following possible signs emerged except:
    (a) The right half of his tongue was wrinkled and wasted.
    (b) When he was asked to protrude his tongue, it turned to the right.
    (c) The swelling on the right side of his neck was high up deep to the right sternocleidomastoid muscle and was hard and fixed.
    (d) A chest radiograph revealed an advanced bronchogenic carcinoma of the right lung.
    (e) The patient had no taste sensation on the anterior two-thirds of the tongue on the right side.
14. The physician made the following correct conclusions except:
    (a) The patient had numerous lung metastases in the deep cervical lymph nodes on the right side.
    (b) A lesion of the right hypoglossal nerve existed at some point between the nucleus in the medulla oblongata and the tongue muscles supplied.
    (c) One of the metastases had invaded the right hypoglossal nerve in the neck.
    (d) The loss of weight could be explained by the presence of the advanced carcinoma in the lung.
    (e) The tongue was wrinkled because the mucous membrane was atrophied.

Directions: Each of the numbered incomplete statements in this section is followed by completions of the statement. Select the ONE lettered completion that is BEST in each case. For questions 15 through 23, study Figure 11-26, showing the inferior view of the brain.

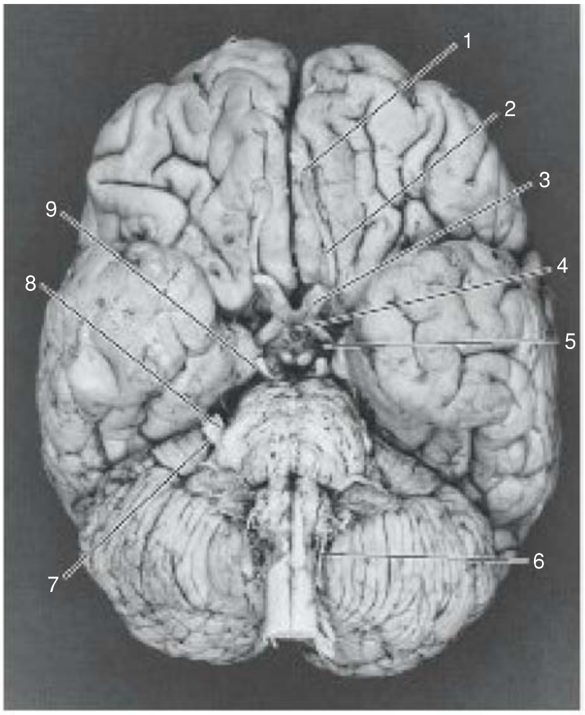


Figure 11-26 Inferior view of the brain.

15. Structure number 1 is the:
    (a) olfactory tract.
    (b) olfactory nerve.
    (c) anterior cerebral artery.
    (d) olfactory bulb.
    (e) inferior frontal gyrus.
16. Structure number 2 is the:
    (a) inferior frontal gyrus.
    (b) lateral olfactory stria.
    (c) olfactory nerve.
    (d) olfactory bulb.
    (e) olfactory tract.
17. Structure number 3 is the:
    (a) optic nerve.
    (b) optic chiasma.
    (c) anterior perforating substance.
    (d) optic tract.
    (e) oculomotor nerve.
18. Structure number 4 is the:
    (a) optic nerve.
    (b) optic tract.
    (c) optic chiasma.
    (d) hypophysis cerebri.
    (e) interpeduncular fossa.
19. Structure number 5 is the:
    (a) anterior perforated substance.
    (b) oculomotor nerve.
    (c) maxillary nerve.
    (d) middle cerebral artery.
    (e) optic tract.
20. Structure number 6 is the:
    (a) vertebral artery.
    (b) spinal part of the accessory nerve.
    (c) hypoglossal nerve.
    (d) glossopharyngeal nerve.
    (e) first cervical nerve.

21. Structure number 7 is the:
    (a) ophthalmic nerve.
    (b) motor root of the trigeminal nerve.
    (c) sensory root of the trigeminal nerve.
    (d) flocculus of the cerebellum.
    (e) vestibulocochlear nerve.
22. Structure number 8 is the:
    (a) motor root of the trigeminal nerve.
    (b) sensory root of the trigeminal nerve.
    (c) vestibular part of the eighth cranial nerve.
    (d) maxillary nerve.
    (e) abducens nerve.
23. Structure number 9 is the:
    (a) trochlear nerve.
    (b) abducens nerve.
    (c) facial nerve.
    (d) oculomotor nerve.
    (e) vestibulocochlear nerve.

For questions 24 through 29, study Figure 11-27, showing a medial view of the right side of the brain following a median sagittal section.

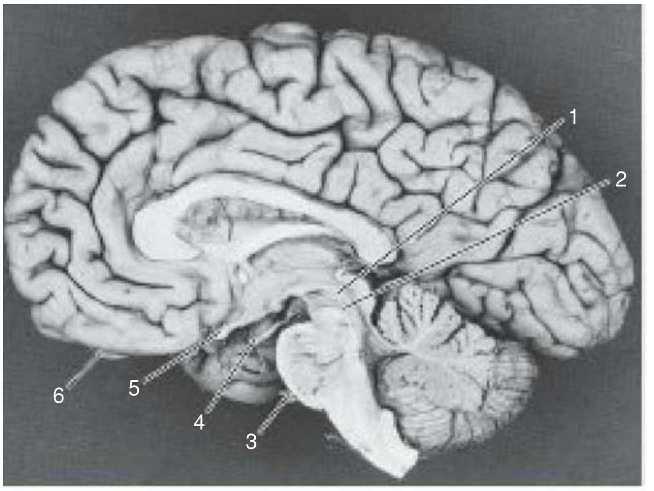


Figure 11-27 Medial view of the right side of the brain following a median sagittal section.

24. Structure number 1 is the location of the nucleus of the:
    (a) abducens nerve.
    (b) trochlear nerve.
    (c) trigeminal nerve.
    (d) facial nerve.
    (e) oculomotor nerve.
25. Structure number 2 is the location of the nucleus of the:
    (a) trigeminal nerve.
    (b) trochlear nerve.
    (c) abducens nerve.
    (d) oculomotor nerve.
    (e) vestibulocochlear nerve.
26. Structure number 3 is the:
    (a) oculomotor nerve.
    (b) trochlear nerve.
    (c) trigeminal nerve.
    (d) abducens nerve.
    (e) facial nerve.
27. Structure number 4 is the:
    (a) trochlear nerve.
    (b) oculomotor nerve.
    (c) trigeminal nerve.
    (d) facial nerve.
    (e) abducens nerve.
28. Structure number 5 is the:
    (a) lamina terminalis.
    (b) oculomotor nerve.
    (c) trochlear nerve.
    (d) abducens nerve.
    (e) optic chiasma.
29. Structure number 6 is the:
    (a) olfactory bulb.
    (b) crista galli.
    (c) olfactory stria.
    (d) anterior cerebral artery.
    (e) inferior frontal gyrus.

Answers and Explanations to Review Questions

1. C is correct. The nucleus of the facial nerve supplying the muscles of the lower part of the face receives only crossed corticobulbar tracts (see Fig. 11-25). A. The inferior salivatory nucleus of the glossopharyngeal nerve receives descending tracts from the hypothalamus. B. The nucleus of the abducens nerve receives crossed and uncrossed corticobulbar tracts. D. The trigeminal motor nucleus receives crossed and uncrossed corticobulbar tracts. E. The nucleus of the trochlear nerve receives crossed and uncrossed corticobulbar tracts.
2. E is correct. The lacrimal nucleus forms part of the group of facial nuclei. A. The trigeminal nerve has a spinal nucleus. B. The inferior salivatory nucleus forms part of the glossopharyngeal nuclei. C. The nucleus ambiguus is the motor nucleus associated with the 9th, 10th, and cranial part of the 11th cranial nerves. D. The facial nerve has a sensory nucleus for taste.
3. D is correct. In this patient, the muscles producing the mimetic movements of the face are innervated by corticobulbar fibers that have a course separate from that of the main corticobulbar fibers. A. The main corticobulbar fibers controlling the movements of the voluntary facial muscles in this patient have been destroyed. B. The reticular fibers, possibly originating in the hypothalamus and descending to the motor nuclei of the facial nerves, are intact. C. The facial nerves are intact since this patient is able to move the facial muscles.

E. The lower motor neurons of the facial nerve supplying the facial muscles are intact.

4. A is correct. The trapezoid body participates in the reception of sound.
5. B is correct. The cerebral cortex is necessary for the accommodation reflex.
6. D is correct. The nasal field of the right eye is projected to the temporal retina of the right eye. A. The nasal field of the right eye is projected to the right lateral geniculate body (see Fig. 11-2). B. The nasal field of the right eye is projected to both banks of the right calcarine fissure (see Fig. 11-2). C. The nasal field of the right eye is projected through the right optic tract (see Fig. 11-2). E. The nasal field of the right eye is projected through the right optic radiation (see Fig. 11-2).
7. B is correct. The right pupillary constriction associated with light directed at the left eye requires the left optic nerve (see Fig. 11-3). A. The right optic radiation is not required (see Fig. 11-3). C. The left Edinger–Westphal nucleus is not required (see Fig. 11-3). D. The right oculomotor nerve is required (see Fig. 11-3). E. The right optic nerve is not required (see Fig. 11-3).
8. A is correct.
9. C is correct.
10. A is correct. The spinal part of the accessory nerve supplies the trapezius muscle, which shrugs the shoulder. B. The facial nerve supplies the orbicularis oculi muscle, which closes the eye. C. The trigeminal nerve supplies the muscles of mastication responsible for chewing. D. The facial nerve receives the sensation of taste from the anterior two-thirds of the tongue. E. The glossopharyngeal nerve receives the sensation of touch from the posterior third of the tongue.
11. B is correct. The optic nerve is surrounded by an extension of the subarachnoid space. A. The nerve fibers of the optic nerve are surrounded by oligodendrocytes. C. Internal ophthalmoplegia is a condition in which the oculomotor nerve supply to the sphincter pupillae and the ciliary muscle is lost, but the innervation of the extraocular muscles is spared. D. External ophthalmoplegia is a condition in which the oculomotor nerve supply to the extraocular muscles is lost, but the innervation of the sphincter pupillae and the ciliary muscle is spared. E. The optic nerve leaves the orbital cavity through the optic canal in the lesser wing of the sphenoid bone.
12. E is correct. The olfactory receptor cells are located in the mucous membrane of the nasal cavity above the level of the superior concha. A. The main sensory nucleus of the trigeminal nerve lies in the brainstem lateral to the motor nucleus (see Fig. 11-7). B. Proprioceptive impulses from the facial muscles end in the mesencephalic nucleus of the trigeminal nerve. C. The facial nerve leaves the posterior cranial fossa with the vestibulocochlear nerve and enters the internal acoustic meatus. D. The superior salivatory nucleus of the facial nerve innervates the submandibular and sublingual salivary glands.
13. E is correct. The taste sensation from the mucous membrane covering the anterior two-thirds of the tongue is conducted in the facial nerves and the chorda tympani nerves, which are a considerable distance from the metastases in the deep cervical lymph nodes in the neck.
14. E is correct. The wasted right half of the tongue and the pointing of the protruded tongue to the right side indicated a lesion of the right hypoglossal nerve. The tongue muscles on the right side had atrophied and diminished in size, resulting in the wrinkling of the overlying normal mucous membrane.

The answers to questions 15 through 23 pertain to Figure 11-26, which shows the inferior view of the brain.

15. D is correct. Structure number 1 is the olfactory bulb.
16. E is correct. Structure number 2 is the olfactory tract.
17. A is correct. Structure number 3 is the optic nerve.
18. D is correct. Structure number 4 is the hypophysis cerebri.
19. E is correct. Structure number 5 is the optic tract.
20. B is correct. Structure number 6 is the spinal part of the accessory nerve.
21. C is correct. Structure number 7 is the sensory root of the trigeminal nerve.
22. A is correct. Structure number 8 is the motor root of the trigeminal nerve.
23. D is correct. Structure number 9 is the oculomotor nerve.

The answers to questions 24 through 29 pertain to Figure 11-27, showing a medial view of the right side of the brain following a median sagittal section.

24. E is correct. Structure number 1 is the nucleus of the oculomotor nerve in the tegmentum of the midbrain at the level of the superior colliculus.
25. B is correct. Structure number 2 is the nucleus of the trochlear nerve in the tegmentum of the midbrain at the level of the inferior colliculus.
26. C is correct. Structure number 3 is the trigeminal nerve emerging on the anterior surface of the pons.
27. B is correct. Structure number 4 is the oculomotor nerve emerging from the anterior surface of the midbrain in the interpeduncular fossa.
28. E is correct. Structure number 5 is the optic chiasma.
29. A is correct. Structure number 6 is the olfactory bulb.

12 Thalamus

CHAPTER OBJECTIVE

- To review the thalamus, a very complex area of the nervous system
- To emphasize that the thalamus lies at the center of many afferent and efferent neuronal loops to other parts of the nervous system
- To review some of the common clinical problems involving the thalamus

A 61-year-old man with hypertension is seen in the emergency department, having apparently suffered a stroke. A neurologist is called and makes a complete examination of the patient. The patient is conscious and is unable to feel any sensation down the right side of his body. No evidence of paralysis is noted on either side of the body, and the reflexes are normal. The patient is admitted to the hospital for observation.

Three days later, the patient appears to be improving, and return of sensation is evident on the right side of his body. The patient, however, seems to be excessively sensitive to testing for sensory loss. On light pinprick on the lateral side of the right leg, the patient suddenly shouts out because of excruciating burning pain, and he asks that the examination be stopped. Although the patient experiences very severe pain with the mildest stimulation, the threshold for pain sensitivity is raised, and the interval between applying the pinprick and the start of the pain is longer than normal; also, the pain persists after the stimulus has been removed. Moreover, the patient volunteers the information that the pain appears to be confined to the skin and does not involve deeper structures. Later, heat and cold stimulation are found to cause the same degree of discomfort.

The neurologist makes the diagnosis of analgesia dolorosa or Dejerine–Roussy syndrome involving the left thalamus. This condition of thalamic overreaction is most commonly caused by infarction of the lateral nuclei of the thalamus due to hypertensive vascular disease or thrombosis. Understanding the functional role of the thalamus in the sensory system and knowing the central connections of the thalamus are necessary in making a diagnosis of thalamic disease.

The thalamus is situated at the rostral end of the brainstem and functions as an important relay and integrative station for information passing to all areas of the cerebral cortex, the basal ganglia, the hypothalamus, and the brainstem.

GENERAL APPEARANCE

The thalamus is a large, egg-shaped mass of gray matter that forms the major part of the diencephalon. There are two thalami, and one is situated on each side of the third ventricle (Fig. 12-1; see also Fig. 7-3 and Atlas Plates 4, 5, and 8). The anterior end of the thalamus is narrow and rounded and forms the posterior boundary of the interventricular foramen. The posterior end is expanded to form the **pulvinar**, which overhangs the superior colliculus (Fig. 12-2). The inferior surface is continuous with the tegmentum of the midbrain. The medial surface of the thalamus forms 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).

SUBDIVISIONS

The thalamus is covered on its superior surface by a thin layer of white matter, called the **stratum zonale**, and on its lateral surface by another layer, the **external medullary lamina** (see Fig. 12-1). The gray matter of the thalamus is divided by a vertical sheet of white matter,

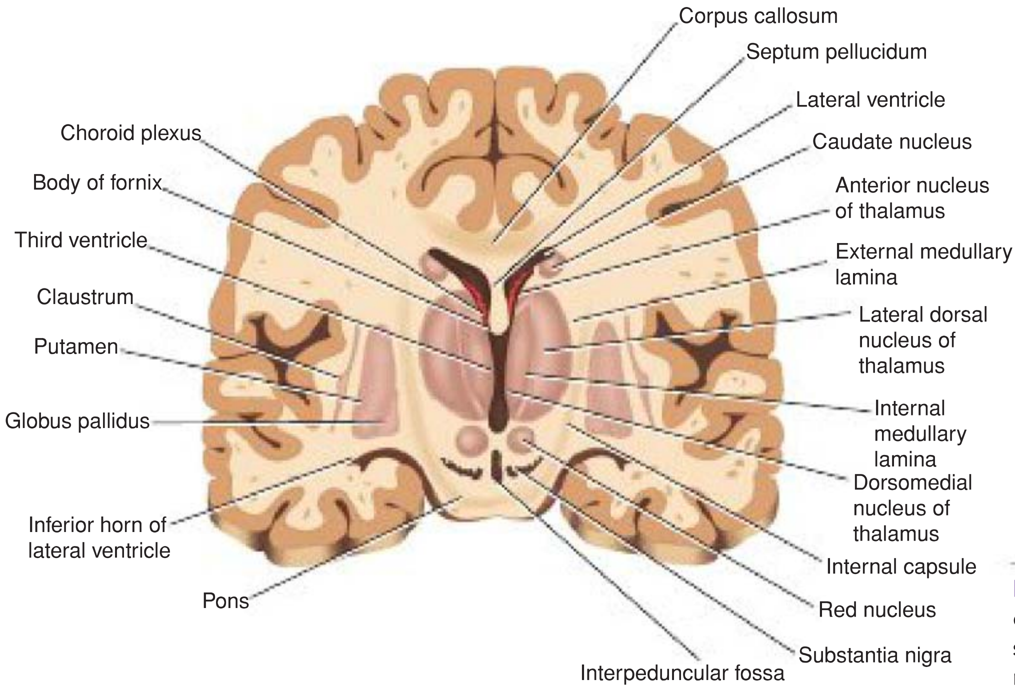


Figure 12-1 Coronal section of the cerebral hemispheres showing the position and relations of the thalamus.

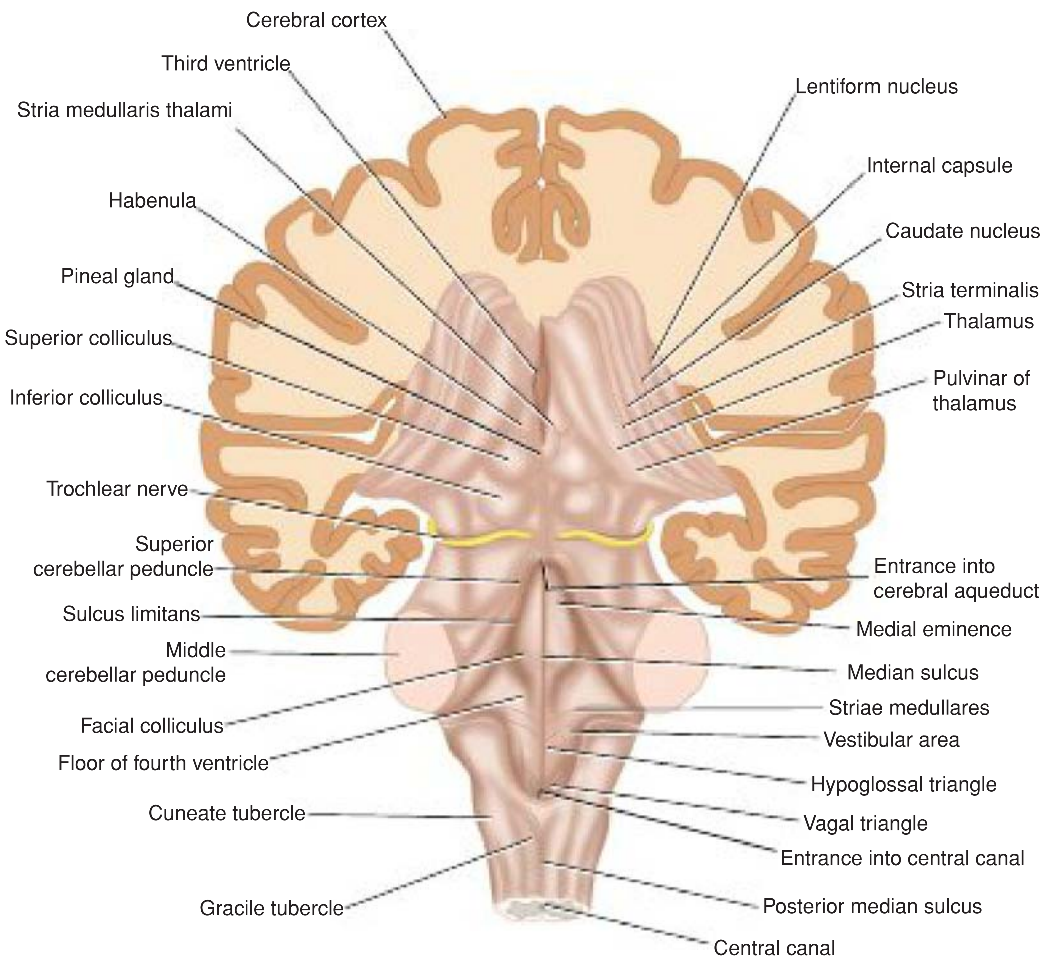


Figure 12-2 Posterior view of the brainstem showing the thalamus and the tectum of the midbrain.

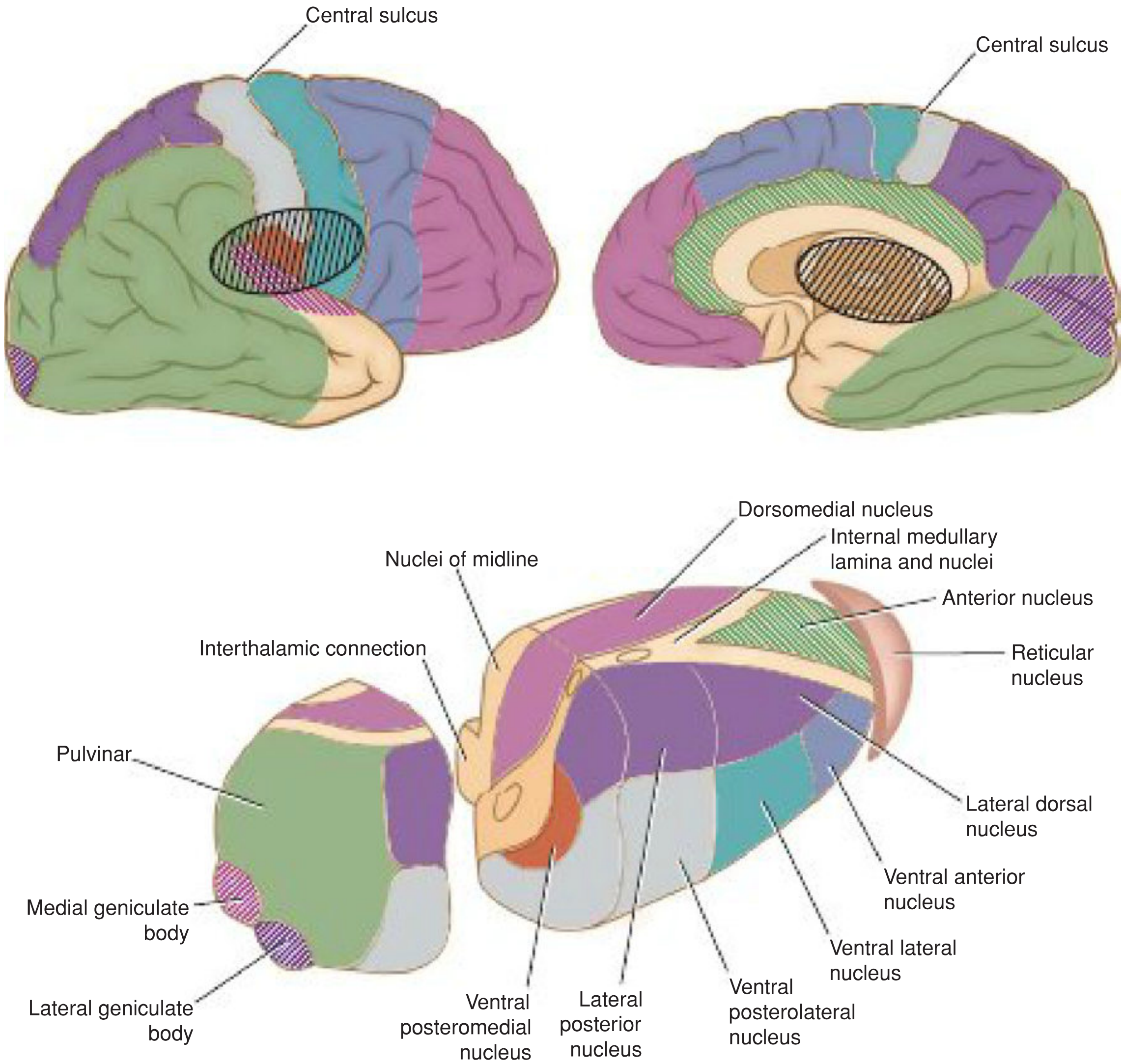


Figure 12-3 Important thalamocortical projections. (Adapted from an original painting by Netter, F. H. (1948). *The CIBA collection of medical illustrations*, copyright by CIBA Pharmaceutical Company, Division of CIBA-GEIGY Corporation.)

the **internal medullary lamina**, into medial and lateral halves (Fig. 12-3; also see Fig. 12-1). The internal medullary lamina consists of nerve fibers that pass from one thalamic nucleus to another. Anterosuperiorly, the internal medullary lamina splits, resembling a Y shape. The thalamus thus is subdivided into three main parts; the **anterior part** lies between the limbs of the Y, and the **medial** and **lateral parts** lie on the sides of the stem of the Y (see Fig. 12-3).

Each of the three parts of the thalamus contains a group of thalamic nuclei. Moreover, smaller nuclear groups are situated within the internal medullary lamina, and some are located on the medial and lateral surfaces of the thalamus.

Anterior Part

The anterior part of the thalamus contains the **anterior thalamic nuclei**. They receive the mammillothalamic tract from the mammillary nuclei. These anterior thalamic nuclei also receive reciprocal connections with the cingulate gyrus and hypothalamus. The function of the anterior thalamic nuclei is closely associated with that of the limbic system and is concerned with emotional tone and the mechanisms of recent memory.

Medial Part

The medial part of the thalamus contains the large **dorsomedial nucleus** and several smaller nuclei. The dorsomedial nucleus has two-way connections with the whole prefrontal cortex of the frontal lobe of the cerebral hemisphere. It also has similar connections with the hypothalamic nuclei. It is interconnected with all other groups of thalamic nuclei. The medial part of the thalamus is responsible for the integration of a large variety of sensory information, including somatic, visceral, and olfactory information, and the relation of this information to one's emotional feelings and subjective states.

Lateral Part

The nuclei are subdivided into a dorsal tier and a ventral tier.

Dorsal Tier

The dorsal tier includes the **lateral dorsal nucleus**, the **lateral posterior nucleus**, and the **pulvinar**. The details of the connections of these nuclei are not clear. They are known, however, to have interconnections with other thalamic nuclei and with the parietal lobe, cingulate gyrus, and occipital and temporal lobes.

Ventral Tier

The ventral tier consists of the following nuclei in a craniocaudal sequence:

1. **Ventral anterior nucleus.** This nucleus is connected to the reticular formation, the substantia nigra, the corpus striatum, and the premotor cortex as well as to many of the other thalamic nuclei. Since this nucleus lies on the pathway between the corpus striatum and the motor areas of the frontal cortex, it probably influences the activities of the motor cortex.
2. **Ventral lateral nucleus.** This nucleus has connections similar to those of the ventral anterior nucleus but, in addition, has a major input from the cerebellum and a minor input from the red nucleus. Its main projections pass to the motor and premotor regions of the cerebral cortex. Here again, this thalamic nucleus probably influences motor activity.
3. **Ventral posterior nucleus.** This nucleus is subdivided into the **ventral posteromedial nucleus** and the **ventral posterolateral nucleus**. The ventral posteromedial nucleus receives the ascending trigeminal and gustatory pathways, while the ventral posterolateral nucleus receives the important ascending sensory tracts, the medial and spinal lemnisci. The thalamocortical projections from these important nuclei pass through the posterior limb of the internal capsule and corona radiata to the primary somatic sensory areas of the cerebral cortex in the postcentral gyrus (areas 3, 1, and 2).

Other Nuclei

Other thalamic nuclei include the intralaminar nuclei, the midline nuclei, the reticular nucleus, and the medial and lateral geniculate bodies.

The **intralaminar nuclei** are small collections of nerve cells within the internal medullary lamina. They receive afferent fibers from the reticular formation as well as fibers from the spinothalamic and trigeminothalamic tracts; they send efferent fibers to other thalamic nuclei, which in turn project to the cerebral cortex, and fibers to the corpus striatum. The nuclei are believed to influence the levels of consciousness and alertness in an individual.

The **midline nuclei** consist of groups of nerve cells adjacent to the third ventricle and in the interthalamic connection. They receive afferent fibers from the reticular formation. Their precise functions are unknown.

The **reticular nucleus** is a thin layer of nerve cells sandwiched between the external medullary lamina and the posterior limb of the internal capsule. Afferent fibers converge on this nucleus from the cerebral cortex and the reticular formation, and its output is mainly to other thalamic nuclei. The function of this nucleus is not fully understood, but it may be concerned with a mechanism by which the cerebral cortex regulates thalamic activity.

The **medial geniculate body** forms part of the auditory pathway and is a swelling on the posterior surface of the thalamus beneath the pulvinar. Afferent fibers to the medial geniculate body form the **inferior brachium** and come from the inferior colliculus. It should be remembered that the inferior colliculus receives the termination of the fibers of the lateral lemniscus. The medial geniculate body receives auditory information from both ears but predominantly from the opposite ear.

The efferent fibers leave the medial geniculate body to form the auditory radiation, which passes to the auditory cortex of the superior temporal gyrus. The **lateral geniculate body** forms part of the visual pathway and is a swelling on the undersurface of the pulvinar of the thalamus. The nucleus consists of six layers of nerve cells and is the terminus of all but a few fibers of the optic tract (except the fibers passing to the pretectal nucleus). The fibers are the axons of the ganglion cell layer of the retina and come from the temporal half of the ipsilateral eye and from the nasal half of the contralateral eye, the latter's fibers crossing the midline in the optic chiasma. Each lateral geniculate body, therefore, receives visual information from the opposite field of vision.

The efferent fibers leave the lateral geniculate body to form the visual radiation, which passes to the visual cortex of the occipital lobe.

CONNECTIONS

The following important neuronal loops exist between the thalamic nuclei and other areas of the central nervous system:

1. Every thalamic nucleus (except the reticular nucleus) sends axons to specific parts of the cerebral cortex (see Fig. 12-3), and every part of the cerebral cortex sends reciprocal fibers back to the thalamic nuclei. This would indicate that information received by the thalamus is always shared with the cerebral cortex and that the cortex and thalamus can modify each other's activities.
2. The thalamus is an important relay station for two sensory motor axonal loops involving the cerebellum and the basal nuclei: (1) the cerebellar–rubro–thalamic–cortical–ponto–cerebellar loop and (2) the corticostriatal–pallidal–thalamic–cortical loop, both of which are necessary for normal voluntary movement.

A summary of the various thalamic nuclei, their nervous connections, and their functions is provided in Table 12-1. The main connections of the various thalamic nuclei are summarized in Figure 12-4.

Table 12-1 Thalamic Nuclei: Connections and Functions

Thalamic Nucleus	Afferent Neuronal Loop	Efferent Neuronal Loop	Function
Anterior	Mammillothalamic tract, cingulate gyrus, hypothalamus	Cingulate gyrus, hypothalamus	Emotional tone, mechanisms of recent memory
Dorsomedial	Prefrontal cortex, hypothalamus, other thalamic nuclei	Prefrontal cortex, hypothalamus, other thalamic nuclei	Integration of somatic, visceral, and olfactory information and relation to emotional feelings and subjective states
Lateral dorsal, lateral posterior, pulvinar	Cerebral cortex, other thalamic nuclei	Cerebral cortex, other thalamic nuclei	Unknown
Ventral anterior	Reticular formation, substantia nigra, corpus striatum, premotor cortex, other thalamic nuclei	Reticular formation, substantia nigra, corpus striatum, premotor cortex, other thalamic nuclei	Influences activity of motor cortex
Ventral lateral	As in ventral anterior nucleus but also major input from cerebellum and minor input from red nucleus		Influences motor activity of motor cortex
Ventral posteromedial (VPM)	Trigeminal lemniscus, gustatory fibers	Primary somatic sensory (areas 3, 1,and 2) cortex	Relays common sensations to consciousness
Ventral posterolateral (VPL)	Medial and spinal lemnisci	Primary somatic sensory (areas 3, 1, and 2) cortex	Relays common sensations to consciousness
Intralaminar	Reticular formation, spinothalamic and trigeminothalamic tracts	To cerebral cortex via other thalamic nuclei, corpus striatum	Influences levels of consciousness and alertness
Midline	Reticular formation	Unknown	Unknown
Reticular	Cerebral cortex, reticular formation	Other thalamic nuclei	Cerebral cortex regulates thalamus
Medial geniculate body	Inferior colliculus, lateral lemniscus from both ears but predominantly the contralateral ear	Auditory radiation to superior temporal gyrus	Hearing
Lateral geniculate body	Optic tract	Optic radiation to visual cortex of occipital lobe	Visual information from opposite field of vision

FUNCTION

A practicing physician does not need to have a detailed knowledge of *all* the thalamic nuclei and their connections. Although an enormous amount of research has been devoted to this area, we still know very little about the functional significance of many of the nuclei.

However, the following basic principles *should* be committed to memory:

1. The thalamus is made up of complicated collections of nerve cells that are centrally placed in the brain and are interconnected.
2. A vast amount of sensory information of all types (except smell) converges on the thalamus and presumably is integrated through the interconnections between the nuclei. The resulting information pattern is distributed to other parts of the central nervous system. Olfactory information is probably first integrated at a lower level with taste and other sensations and is relayed to the thalamus from the amygdaloid complex and hippocampus through the mammillothalamic tract.
3. Anatomically and functionally, the thalamus and the cerebral cortex are closely linked. The fiber connections have been established, and, following removal of the cortex, the thalamus can appreciate crude sensations. However, the cerebral cortex is required for the interpretation of sensations based on past experiences. For example, if the sensory cortex is destroyed, one can still appreciate the presence of a hot object in the hand; however, appreciation of the shape, weight, and exact temperature of the object would be impaired.
4. The thalamus possesses certain very important nuclei whose connections have been clearly established. These include the ventral posteromedial nucleus, the ventral posterolateral nucleus, the medial geniculate body, and the lateral geniculate body. Their positions and connections should be learned.

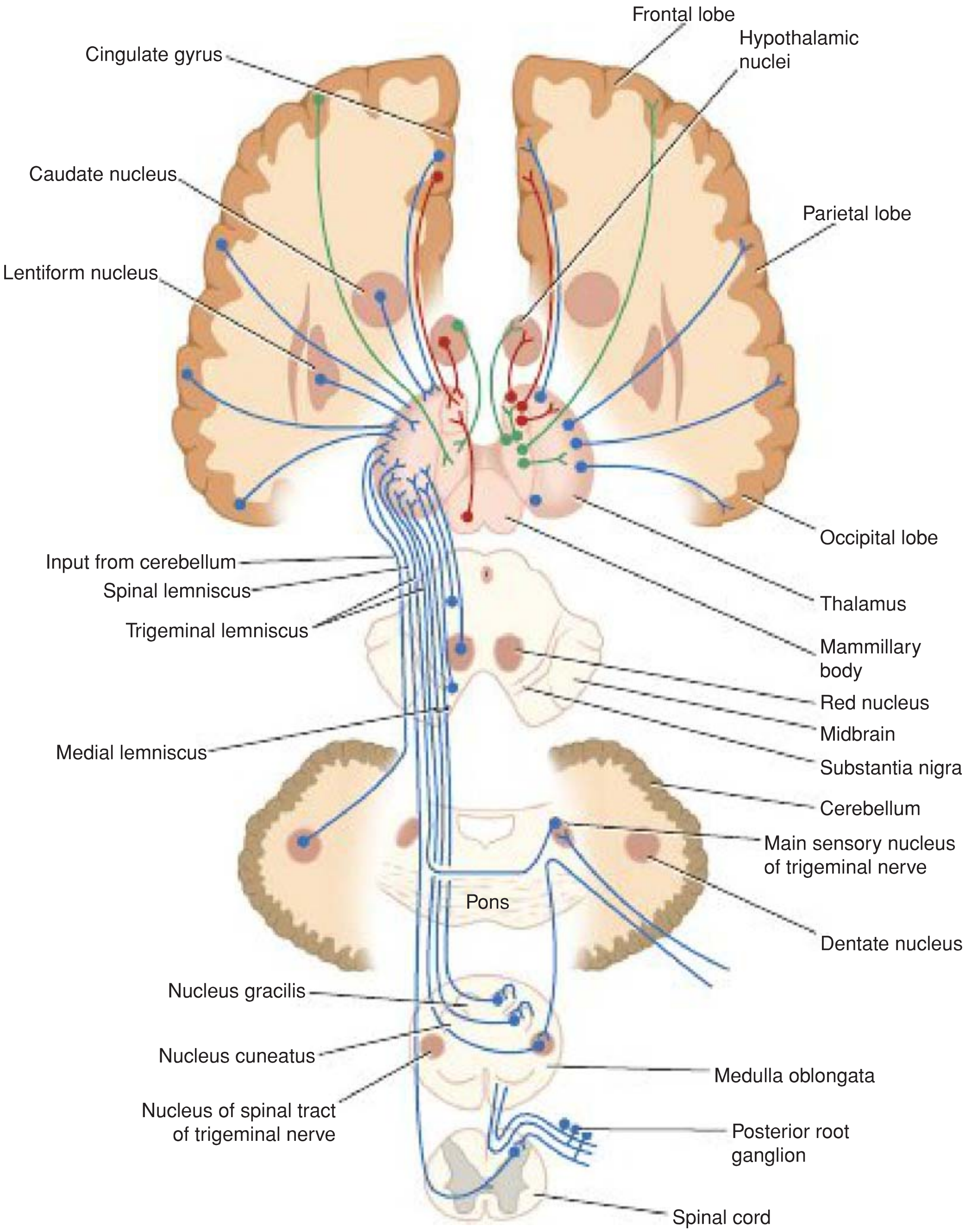


Figure 12-4 Main connections of the thalamus. Afferent fibers are shown on the left, and efferent fibers are shown on the right.

5. The ventroanterior and the ventrolateral nuclei of the thalamus form part of the basal nuclei circuit and thus are involved in the performance of voluntary movements. These nuclei receive input from the globus pallidus and send fibers to the prefrontal, supplemental, and premotor areas of the cerebral cortex.
6. The large dorsomedial nucleus has extensive connections with the frontal lobe cortex and hypothalamus. Considerable evidence suggests that this nucleus lies on the pathway that is concerned with subjective feeling states and the personality of the individual.
7. The intralaminar nuclei are closely connected with the activities of the reticular formation, and they receive much of their information from this source. Their strategic position enables them to control the level of overall activity of the cerebral cortex. The intralaminar nuclei are thus able to influence the levels of consciousness and alertness in an individual.

Clinical Notes

Lesions

Because the thalamus is such an important relay and integrative center, disease of this area of the central nervous system will have profound effects. The thalamus may be invaded by neoplasm, undergo degeneration following disease of its arterial supply, or be damaged by hemorrhage.

Sensory Loss

These lesions usually result from thrombosis or hemorrhage of one of the arteries supplying the thalamus. Damage to the ventral posteromedial nucleus and the ventral posterolateral nucleus will result in the loss of all forms of sensation, including light touch, tactile localization and discrimination, and muscle joint sense from the opposite side of the body.

The thalamus is centrally located among other important nervous structures. Usually, a thalamic lesion results in dysfunction of neighboring structures, producing symptoms and signs that overshadow those produced by the thalamic disease. For example, a vascular lesion of the thalamus may also involve the midbrain, with resulting coma, or a lateral extension of thalamic disease may involve the internal capsule and produce extensive motor and sensory deficits.

Surgical Relief of Pain by Thalamic Cauterization

The intralaminar nuclei of the thalamus are known to take part in the relay of pain to the cerebral cortex. Cauterization of these nuclei has been shown to relieve severe and intractable pain associated with terminal cancer.

Thalamic Pain

Thalamic pain may occur as the patient is recovering from a thalamic infarct. Spontaneous pain, which is often excessive (thalamic overreaction), occurs on the opposite side of the body. The painful sensation may be aroused by light touch or by cold and may fail to respond to powerful analgesic drugs.

ABNORMAL INVOLUNTARY MOVEMENTS

Choreoathetosis with ataxia may follow vascular lesions of the thalamus. Whether these signs in all cases are due to the loss of function of the thalamus or to involvement of the neighboring caudate and lentiform nuclei is not certain. The ataxia may arise as the result of the loss of appreciation of muscle and joint movement caused by a thalamic lesion.

THALAMIC HAND

The contralateral hand is held in an abnormal posture in some patients with thalamic lesions. The wrist is pronated and flexed, the metacarpophalangeal joints are flexed, and the interphalangeal joints are extended. The fingers can be moved actively, but the movements are slow. The condition is due to altered muscle tone in the different muscle groups.

Key Concepts

General Appearance

- The thalamus is a large egg-shaped mass that forms a major part of the diencephalon.
- It is located on either side of the third ventricle and attached by a band of gray matter called the interthalamic adhesion.
- The lateral thalamus contains the anterior thalamic nuclei, which are involved with the limbic system.
- The medial thalamus contains the large dorsomedial nucleus and two smaller nuclei, all of which are involved with somatic, visceral, and olfactory sensory information.
- The lateral thalamus is divided into dorsal and ventral tiers of nuclei.
  - The dorsal tier includes the lateral dorsal nucleus, lateral posterior nucleus, and the pulvinar.
  - The ventral tier includes the ventral anterior nucleus, ventral lateral nucleus, and the ventral posterior nuclei (posteromedial and posterolateral).

Functions

- A vast amount of sensory information converges on the thalamus and is distributed to other parts of the central nervous system.
- The thalamus is closely linked to the cortex but not for appreciation of sensation. For instance, upon removal of the cortex, the thalamus can still sense a hot object, but the interpretation of location, shape, weight, or temperature would be impaired.

Clinical Problem Solving

1. A 45-year-old man who has suddenly developed weakness of the left leg 12 hours previously is admitted to a medical ward. On examination, he is found to have paralysis of the left leg and weakness of the muscles of the left arm. The muscles of the affected limbs show increased tone, and tendon reflexes are exaggerated on the left side of the body. Also, considerable sensory loss on the left side of the body involves both the superficial and deep sensations. During the examination, the patient exhibits spontaneous jerking movements of the left leg. When asked to touch the tip of his nose with the left index finger, he demonstrates considerable intention tremor. The same test with the right arm shows nothing abnormal. Three days later, the patient starts to complain of agonizing pain down the left leg. The pain starts spontaneously or is initiated by the light touch of the bed sheet. What is your diagnosis? How can you explain the various signs and symptoms?

Answers and Explanations to Clinical Problem Solving

1. This man had a thrombosis of the thalamogeniculate branch of the right posterior cerebral artery. This resulted in a degenerative lesion within the right thalamus, causing the impairment of superficial and deep sensations on the left side of the body. The contralateral hemiparesis, involving the left leg and left arm with increased muscle tone, was produced by edema in the nearby posterior limb of the right internal capsule, causing blocking of the corticospinal fibers. As the edema resolved, the paralysis and spasticity improved. The choreoathetoid movements of the left leg and the intention tremor of the left arm were probably due to damage to the right thalamus or to the right dentatothalamic nerve fibers. The agonizing pain felt down the left leg was due to the lesion in the right thalamus.

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 thalamus:
   (a) All types of sensory information, with the exception of smell, reach the thalamic nuclei via afferent fibers.
   (b) Very few afferent fibers reach the thalamic nuclei from the cerebral cortex.
   (c) The intralaminar nuclei of the thalamus are not connected to the reticular formation.
   (d) The intralaminar nuclei cannot influence the levels of consciousness and alertness.
   (e) The thalamus is covered on its inferior surface by a thin layer of white matter called the stratum zonale.
2. The following statements concern the thalamus:
   (a) The external medullary lamina is an area of gray matter lying on the lateral surface of the thalamus.
   (b) The Y-shaped external medullary lamina subdivides the thalamus into three main parts.
   (c) The ventral posteromedial nucleus receives the descending trigeminal and gustatory pathways.
   (d) The cerebellar–rubro–thalamic–cortical–ponto–cerebellar neuron pathway is important in voluntary movement.
   (e) The mammillary body–thalamus–amygdaloid nucleus–dentate gyrus neuron pathway is important in maintaining posture.
3. The following statements concern the thalamic nuclei:
   (a) The intralaminar nuclei lie outside the internal medullary lamina.
   (b) The ventral posterolateral nucleus receives the descending sensory tracts of the medial and spinal lemnisci.
   (c) The projections of the anterolateral nucleus ascend to the postcentral gyrus.
   (d) The reticular nucleus is part of the reticular formation.
   (e) The projections of the ventral posterolateral nucleus ascend to the postcentral gyrus through the posterior limb of the internal capsule.

4. The following statements concern the medial geniculate body:
   (a) The medial geniculate body receives auditory information from the superior colliculus and from the lateral lemniscus.
   (b) Efferent fibers from the medial geniculate body form the inferior brachium.
   (c) The medial geniculate body receives auditory information from both ears but predominantly from the opposite ear.
   (d) The medial geniculate body projects to the auditory cortex of the inferior temporal gyrus.
   (e) The medial geniculate body is a swelling on the anterior surface of the thalamus.
5. The following statements concern the lateral geniculate body:
   (a) The lateral geniculate body receives most of the fibers of the optic nerve.
   (b) Each lateral geniculate body receives visual information from the opposite field of vision.
   (c) The lateral geniculate body has a nucleus made up of 12 layers of nerve cells.
   (d) The lateral geniculate body is part of the midbrain at the level of the red nucleus.
   (e) The afferent fibers to the lateral geniculate body are the axons of the rods and cones of the retina.

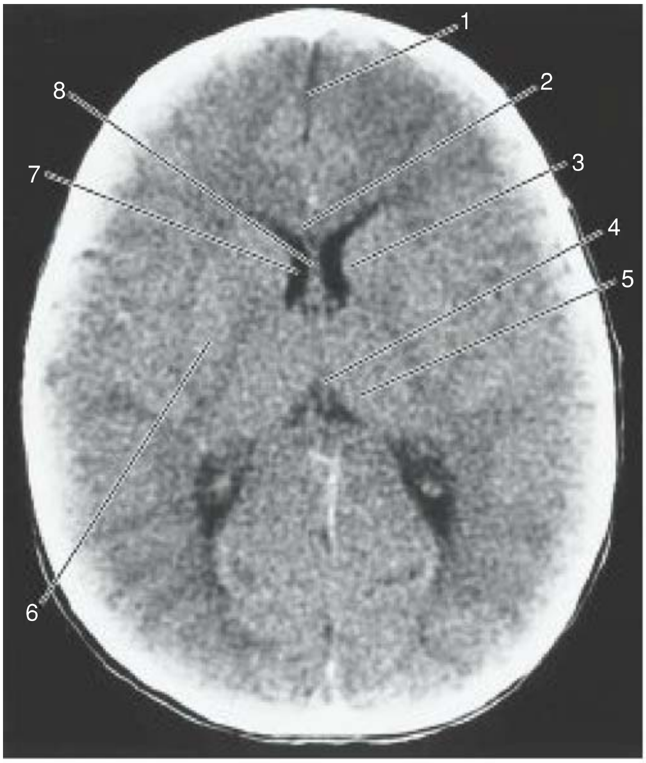


Figure 12-5 CT scan of the brain showing a horizontal (axial) cut.

Directions: Each of the numbered incomplete statements in this section is followed by completions of the statement. Select the ONE lettered completion that is BEST in each case. For questions 6 through 13, study Figure 12-5, showing a computed tomography (CT) scan of the brain (horizontal cut [axial] section).

6. Structure number 1 is the:
   (a) falx cerebelli.
   (b) anterior cerebral artery.
   (c) crest of frontal bone.
   (d) sagittal suture.
   (e) longitudinal fissure.
7. Structure number 2 is the:
   (a) genu of corpus callosum.
   (b) lamina terminalis.
   (c) septum pellucidum.
   (d) anterior column of fornix.
   (e) interthalamic connection.
8. Structure number 3 is the:
   (a) lentiform nucleus.
   (b) internal capsule.
   (c) putamen.
   (d) head of caudate nucleus.
   (e) globus pallidus.
9. Structure number 4 is the:
   (a) pineal body.
   (b) falx cerebri.
   (c) third ventricle.
   (d) septum pellucidum.
   (e) great cerebral vein.
10. Structure number 5 is the:
   (a) medial geniculate body.
   (b) thalamus.
   (c) choroid plexus of lateral ventricle.
   (d) body of caudate nucleus.
   (e) third ventricle.
11. Structure number 6 is the:
   (a) thalamus.
   (b) head of caudate nucleus.
   (c) internal capsule.
   (d) claustrum.
   (e) lentiform nucleus.
12. Structure number 7 is the:
   (a) body of lateral ventricle.
   (b) tail of lateral ventricle.
   (c) anterior horn of lateral ventricle.
   (d) third ventricle.
   (e) fourth ventricle.
13. Structure number 8 is the:
   (a) septum pellucidum.
   (b) falx cerebri.
   (c) anterior cerebral artery.
   (d) lamina terminalis.
   (e) interthalamic adhesion.

Answers and Explanations to Review Questions

1. A is correct. All types of sensory information, with the exception of smell, reach the thalamic nuclei via afferent fibers. B. Large numbers of afferent fibers reach the thalamic nuclei from the cerebral cortex. C. The intralaminar nuclei of the thalamus are closely connected with the reticular formation. D. The intralaminar nuclei of the thalamus do influence the levels of consciousness and alertness. E. The thalamus is covered on its superior surface by a thin layer of white matter called the stratum zonale (see Fig. 12-1).
2. D is correct. The cerebellar–rubro–thalamic–cortical–ponto–cerebellar neuron pathway is important in voluntary movement. A. The external medullary lamina is an area of white matter lying on the lateral surface of the thalamus (see Fig. 12-1). B. The Y-shaped internal medullary lamina subdivides the thalamus into three main parts. C. The ventral posteromedial nucleus receives the ascending trigeminal and gustatory pathways. E. The mammillary body–thalamus–amygdaloid nucleus–dentate gyrus neuron pathway is not important in maintaining posture.
3. E is correct. The projections of the ventral posterolateral nucleus ascend to the postcentral gyrus through the posterior limb of the internal capsule. A. The intralaminar nuclei lie within the internal medullary lamina (see Fig. 12-3). B. The ventral posterolateral nucleus receives the ascending sensory tracts of the medial and spinal lemnisci. C. The projections of the posterolateral nucleus ascend to the postcentral gyrus. D. The reticular nucleus is not part of the reticular formation, although it receives afferent fibers from the formation.
4. C is correct. The medial geniculate body receives auditory information from both ears but predominantly from the opposite ear. A. The medial geniculate body receives auditory information from the inferior colliculus and from the lateral lemniscus. B. Afferent fibers from the medial geniculate body form the inferior brachium. D. The medial geniculate body projects to the auditory cortex of the superior temporal gyrus. E. The medial geniculate body is a swelling on the posterior surface of the thalamus (see Fig. 12-3).
5. B is correct. Each lateral geniculate body receives visual information from the opposite field of vision. A. The lateral geniculate body receives most of the fibers of the optic tract. C. The lateral geniculate body has a nucleus made up of six layers of nerve cells. D. The lateral geniculate body is a swelling on the undersurface of the pulvinar of the thalamus (see Fig. 12-3). E. The afferent fibers to the lateral geniculate body are the axons of the ganglion cells of the retina.

The answers for Figure 12-5, which shows a CT scan of the brain (horizontal cut [axial] section), are as follows:

6. E is correct. Structure number 1 is the longitudinal fissure.
7. A is correct. Structure number 2 is the genu of the corpus callosum.
8. D is correct. Structure number 3 is the head of the caudate nucleus.
9. C is correct. Structure number 4 is the third ventricle.
10. B is correct. Structure number 5 is the thalamus.
11. E is correct. Structure number 6 is the lentiform nucleus.
12. C is correct. Structure number 7 is the anterior horn of the lateral ventricle.
13. A is correct. Structure number 8 is the septum pellucidum.