2. Aphasia if the left hemisphere is affected (rarely if the right hemisphere is affected)
3. Contralateral homonymous hemianopia (damage to the optic radiation)
4. Anosognosia if the right hemisphere is affected (rarely if the left hemisphere is affected)

POSTERIOR CEREBRAL ARTERY OCCLUSION

Occlusion of the posterior cerebral artery may produce the following signs and symptoms, but the clinical picture will vary according to the site of the occlusion and the availability of collateral anastomoses:

1. Contralateral homonymous hemianopia with some degree of macular sparing (damage to the calcarine cortex, macular sparing due to the occipital pole receiving collateral blood supply from the middle cerebral artery)
2. Visual agnosia (ischemia of the left occipital lobe)
3. Impairment of memory (possible damage to the medial aspect of the temporal lobe)

INTERNAL CAROTID ARTERY OCCLUSION

Occlusion of the internal carotid artery can occur without causing symptoms or signs or can cause massive cerebral ischemia depending on the degree of collateral anastomoses.

1. The symptoms and signs are those of middle cerebral artery occlusion, including contralateral hemiparesis and hemianesthesia.
2. Partial or complete loss of sight occurs on the same side, but permanent loss is rare (emboli dislodged from the internal carotid artery reach the retina through the ophthalmic artery).

VERTEBROBASILAR ARTERY OCCLUSION

The vertebral and basilar arteries supply all the parts of the central nervous system in the posterior cranial fossa, and through the posterior cerebral arteries, they supply the visual cortex on both sides. The clinical signs and symptoms are extremely varied and may include the following:

1. Ipsilateral pain and temperature sensory loss of the face and contralateral pain and temperature sensory loss of the body
2. Attacks of hemianopia or complete cortical blindness
3. Ipsilateral loss of the gag reflex, dysphagia, and hoarseness as the result of lesions of the nuclei of the glossopharyngeal and vagus nerves
4. Vertigo, nystagmus, nausea, and vomiting
5. Ipsilateral Horner syndrome
6. Ipsilateral ataxia and other cerebellar signs
7. Unilateral or bilateral hemiparesis
8. Coma

Cerebral Blood Flow Impairment

Impairment of cerebral blood flow can be caused by a large number of conditions, and the more important conditions can be considered under the following headings: (1) diseases that produce alteration in blood pressure, (2) diseases of arterial walls, and (3) diseases that result in blockage of the arterial lumen.

POSTURAL HYPOTENSION

Patients who get up after being confined to bed for several days, soldiers who stand at attention for long periods on a hot day, and worshipers kneeling in church may experience the accumulation of venous blood in the limbs or impaired venous return to the heart, with a consequent fall in the cardiac output and a lowered arterial blood pressure. The general arterial pressure has to be lowered considerably before the cerebral blood flow is diminished.

PHYSICAL AND PSYCHOLOGIC SHOCK

The profound and prolonged fall in blood pressure that may follow physical trauma, such as an automobile accident or extensive surgery, especially in older adults in whom the cerebral arteries are already narrowed by disease, may cause the patient to lose consciousness. Hyperventilation in anxiety states may reduce the cerebral blood flow by lowering the carbon dioxide content of the blood.

BLOOD VISCOSITY CHANGES

In polycythemia vera, the cerebral blood flow is considerably reduced as the result of an increase in the viscosity of the blood.

CAROTID SINUS SYNDROME

The carotid sinus, situated at the proximal end of the internal carotid artery, is extremely sensitive to changes in arterial blood pressure. Distention of the arterial wall causes a reflex slowing of the heart rate and a fall in blood pressure. This occurs as the result of an increased number of nervous impulses passing up the sinus nerve, a branch of the glossopharyngeal nerve, which connects with the cardioinhibitory and vasomotor centers. Hypersensitivity of the reflex or external pressure may cause the blood pressure to fall suddenly and produce cerebral ischemia and loss of consciousness.

HEART DISEASE

Any severe cardiac disease, such as coronary thrombosis, auricular fibrillation, or heart block, that results in a marked fall in cardiac output will result in a severe fall in general arterial blood pressure and reduction in cerebral blood flow.

ARTERIAL WALL DISEASE

The most common cause of narrowing of the lumen of the arteries that supply the brain is atheroma. This disease may affect the main arteries supplying the brain in their course through the neck as well as their course within the skull. Moreover, the impairment of the cerebral circulation may be worsened by an attack of coronary thrombosis with its associated hypotension, shock due to surgical procedures, severe anemia, or even rotation of the head with external pressure on the carotid arteries.

Atheromatous degeneration of the cerebral arteries occurs most commonly in middle or old age and often complicates diabetes and hypertension. When actual blockage of an artery occurs, the effect will depend on the size and location of the vessel. The nerve cells and their fibers will degenerate in the avascular area, and the surrounding neuroglia will proliferate and invade the area. In patients with generalized narrowing of the cerebral arteries without blockage of a single artery, the brain will undergo a diffuse atrophy. It should be remembered that a very narrow atheromatous artery may be blocked by a thrombus, thus totally closing the lumen.

DISEASES CAUSING ARTERIAL LUMEN BLOCKAGE

Embolism of a cerebral artery can occur in two forms: (1) a thrombus (by far the most common) and (2) fat globules. The thrombus may develop anywhere on the endothelial lining from the left side of the heart to the parent vessels of the cerebral arteries. A common site of origin is

an atheromatous plaque on the internal carotid, common carotid, or vertebral artery. Another area is the site of endocarditis on the mitral or aortic valve or the endocardial lining of a myocardial infarction following a coronary thrombosis. In women, cerebral thrombosis is more common among those taking oral contraceptives, especially those taking a high-dose estrogen–progesterone combination.

Fat embolism usually follows severe fractures of one of the long bones. Fat globules from the macerated yellow marrow enter the nutrient veins, pass through the pulmonary circulation, and end up blocking multiple small cerebral end arteries.

Cerebral Aneurysms

Congenital aneurysms occur most commonly at the site where two arteries join in the formation of the circle of Willis. At this point, the tunica media has a deficiency and this is complicated by the development of atheroma, which so weakens the arterial wall that a local dilatation occurs. The aneurysm may press on neighboring structures, such as the optic nerve or the third, fourth, or sixth cranial nerve, and produce signs or symptoms or may suddenly rupture into the subarachnoid space. In the latter case, a severe pain in the head suddenly develops, followed by mental confusion. Death may quickly occur, or the patient may survive the first bleeding only to die a few days or weeks later. Clipping or ligating the neck of the aneurysm offers the best chance of recovery.

Other than congenital aneurysms, aneurysms are rare and include those due to softening of the arterial wall following the lodging of an infected embolus; those due to damage of the internal carotid artery as it lies within the cavernous sinus following a fracture of the skull; and those that are associated with disease of the arterial wall, such as atheroma.

Intracranial Hemorrhage

Intracranial hemorrhage can result from trauma or cerebral vascular lesions. Four varieties are considered: (1) epidural, (2) subdural, (3) subarachnoid, and (4) cerebral. Epidural and subdural hemorrhages are described on pp. 429-430.

Subarachnoid Hemorrhage

Subarachnoid hemorrhage usually results from leakage or rupture of a congenital aneurysm on the cerebral arterial circle or, less commonly, from an angioma or contusion and laceration of the brain and meninges. The symptoms, which are sudden in onset, will include severe headache, stiffness of the neck, and loss of consciousness. The diagnosis is established by the use of computed tomography (CT). The dense areas of the blood in the subarachnoid space can be identified. The withdrawal of heavily blood-stained cerebrospinal fluid through a lumbar puncture is also diagnostic, but this method has been replaced by the use of CT.

Cerebral Hemorrhage

Cerebral hemorrhage generally is due to rupture of an atheromatous artery and is most common in patients with hypertension. It usually occurs in individuals of middle age and often involves a rupture of the thin-walled lenticulostriate artery, a branch of the middle cerebral artery. The important corticonuclear and corticospinal fibers in the internal capsule are damaged, producing hemiplegia on the opposite side of the body. The patient immediately loses consciousness, and the paralysis is evident when consciousness is regained. In some cases, the hemorrhage bursts into the lateral ventricle, resulting in deeper unconsciousness and corticospinal lesions on both sides of the body. Hemorrhage may also occur into the pons and cerebellum.

Computed Tomography, Magnetic Resonance Imaging, and Positron Emission Tomography

CT, magnetic resonance imaging (MRI), and PET are techniques that are indispensable in making the diagnosis of different forms of cerebrovascular disease. The diagnosis can usually be made with speed, accuracy, and safety. An intracranial blood clot can be recognized by its density. These techniques have largely replaced cerebral angiography (see below).

Cerebral Angiography

The technique of cerebral angiography is used for the detection of abnormalities of the blood vessels; the detection and localization of space-occupying lesions such as tumors, hematomas, or abscesses; or the determination of the vascular pattern of tumors to aid in the diagnosis of their pathology. With the patient under general anesthesia and in the supine position, the head is centered on a radiographic apparatus that will take repeated radiographs at 2-second intervals. Both anteroposterior and lateral projections are obtained. A radiopaque medium is injected rapidly into the lumen of the common carotid or vertebral artery or is indirectly introduced into one of these arteries through a catheter inserted into the radial or femoral artery. As the radiopaque material is rapidly introduced, a series of films is exposed. By this means, the cerebral arteries, the capillary flush, and the veins may be demonstrated. Examples of normal-appearing carotid and vertebral angiograms are shown in Figures 17-8 to 17-15.

Cerebral angiography is an invasive technique that unfortunately has a morbidity of 0.5% to 2.5%. CT and MRI should therefore be used whenever possible. PET is now also used extensively.

Spinal Cord Ischemia

The blood supply to the spinal cord is surprisingly meager considering the importance of this nervous tissue. The posterior and anterior spinal arteries are of small and variable diameter, and the reinforcing segmental arteries vary in number and size.

The posterior third of the spinal cord receives its arterial supply from the posterior spinal arteries. The anterior two-thirds of the spinal cord are supplied by the small, tenuous anterior spinal artery. This latter artery therefore supplies the anterior white column, the anterior gray horns, and the anterior part of the lateral white columns and the root of the posterior horns.

Occlusion of the anterior spinal artery may produce the following signs and symptoms (Fig. 17-16).

1. Loss of motor function (paraplegia) below the level of the lesion occurs due to bilateral damage to the corticospinal tracts.
2. Bilateral thermoanesthesia and analgesia occur below the level of the lesion due to bilateral damage to the spinothalamic tracts.
3. Weakness of the limb muscles may occur due to damage of the anterior gray horns in the cervical or lumbar regions of the cord.
4. Loss of bladder and bowel control occurs due to damage of the descending autonomic tracts.

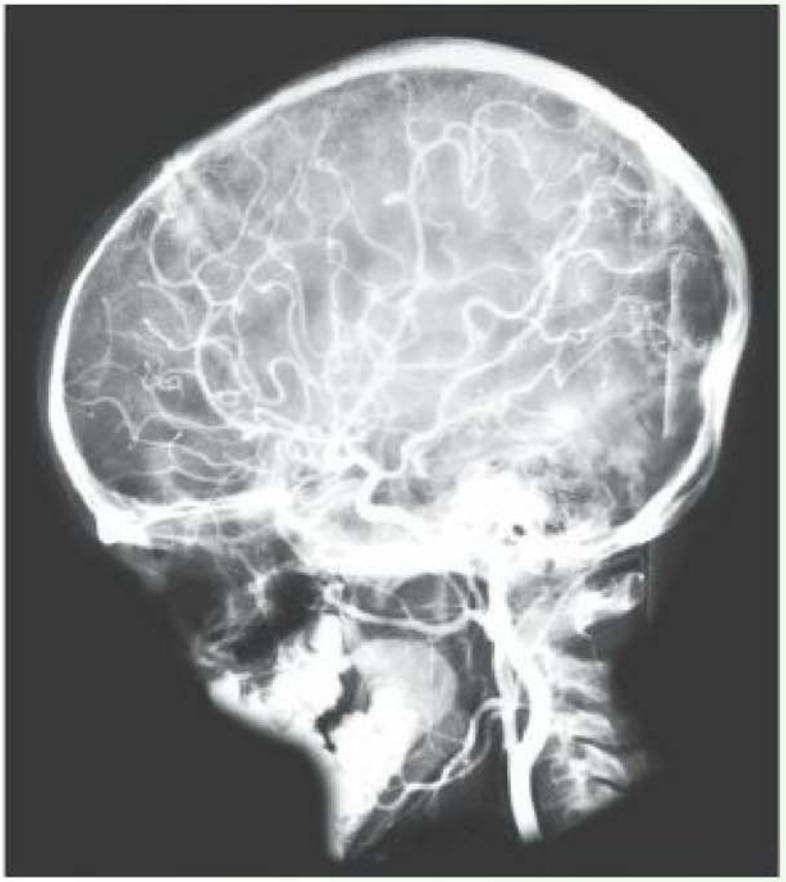

Figure 17-8 Lateral internal carotid arteriogram. Male aged 20 years.

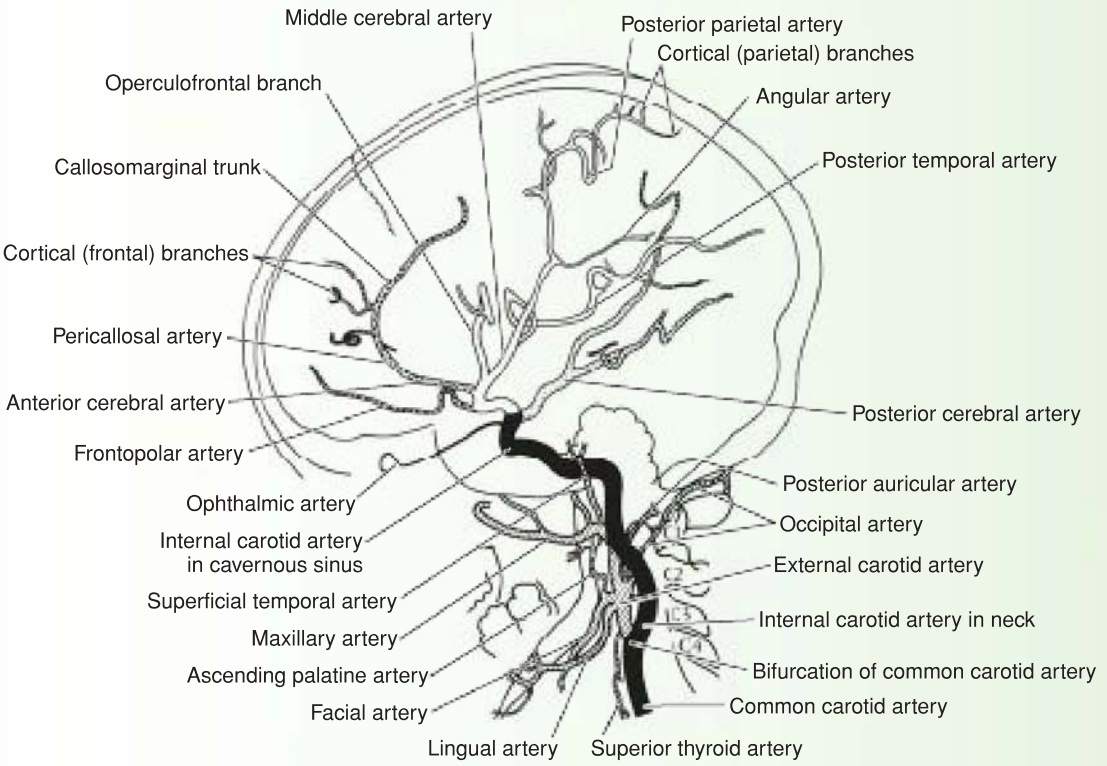

Figure 17-9 Main features seen in radiograph in Figure 17-8.

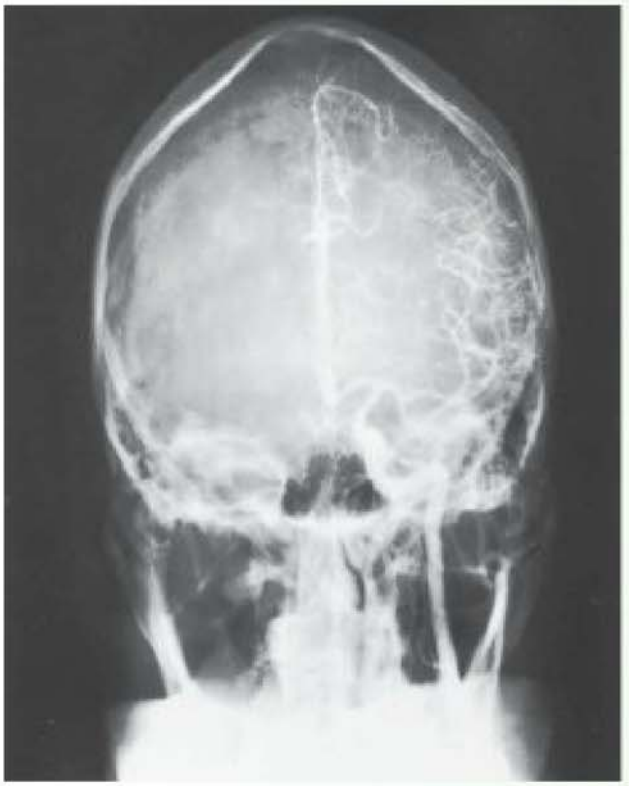

Figure 17-10 Anteroposterior internal carotid arteriogram. Male aged 20 years.

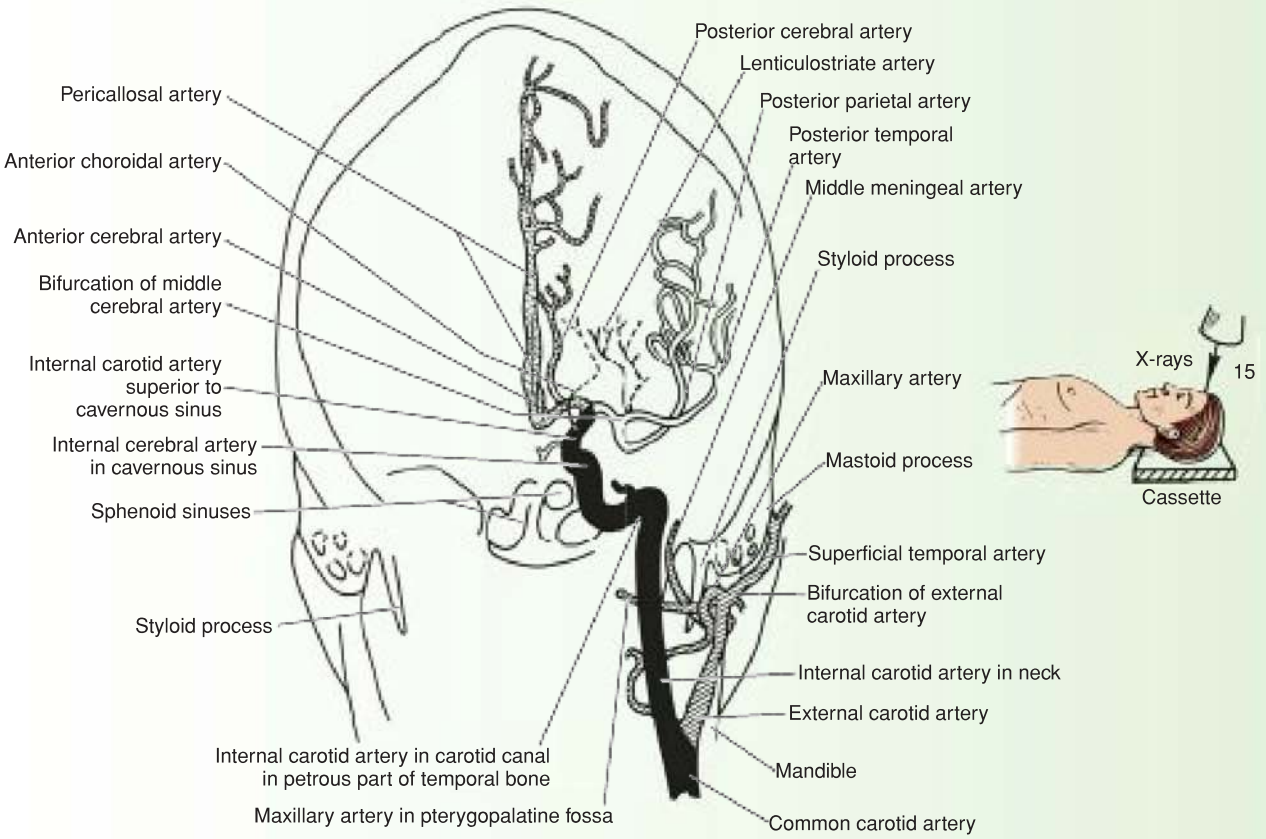

Figure 17-11 Main features seen in the radiograph in Figure 17-10.

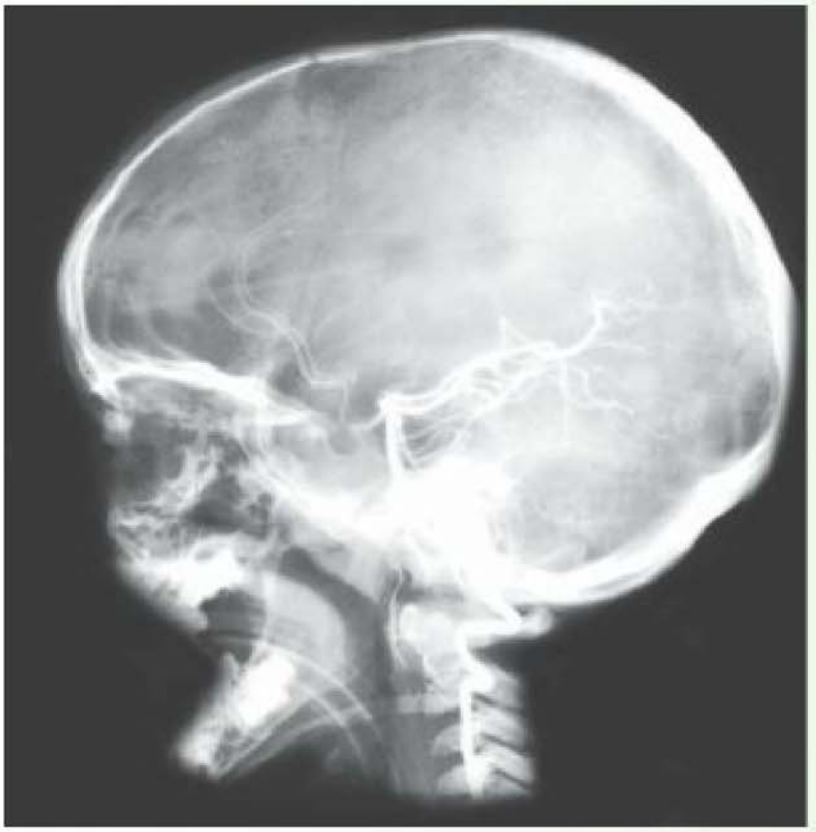

Figure 17-12 Lateral vertebral arteriogram. Male aged 20 years.

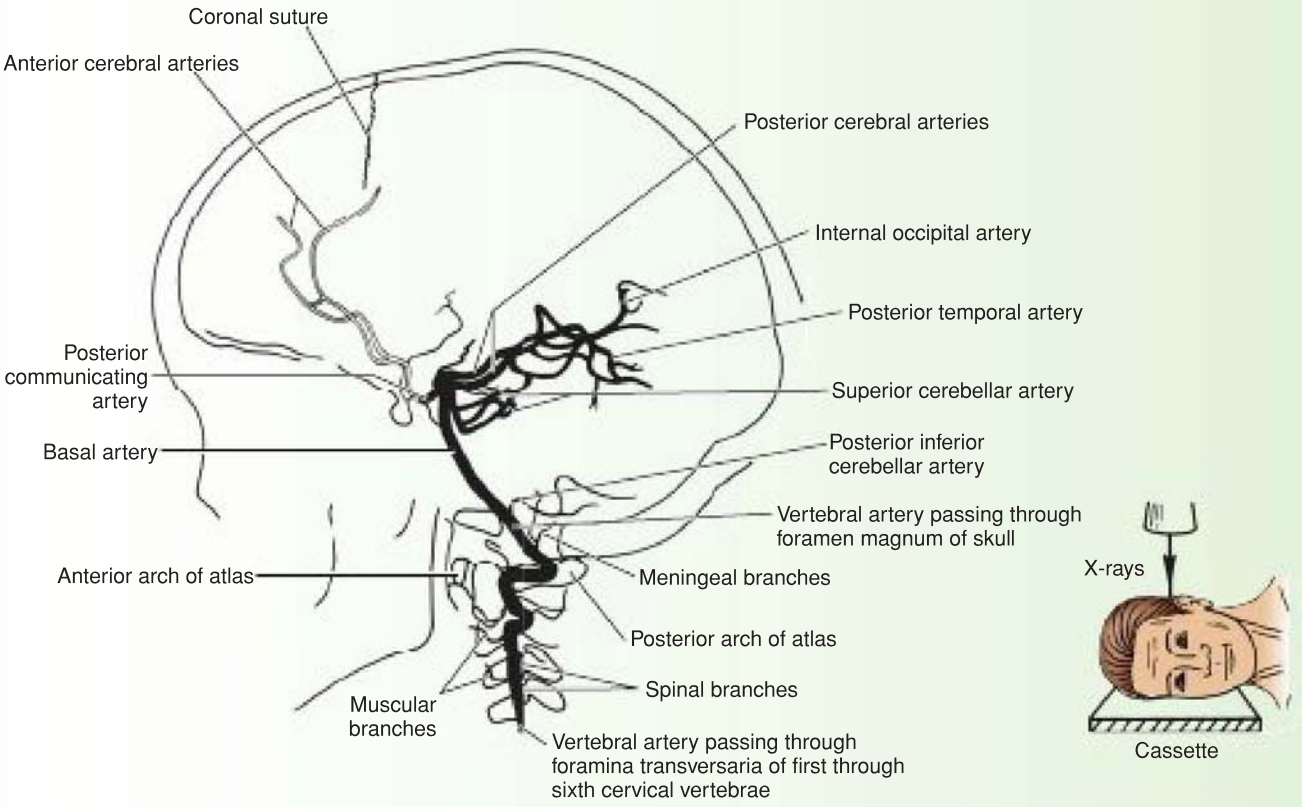

Figure 17-13 Main features shown in the radiograph in Figure 17-12.

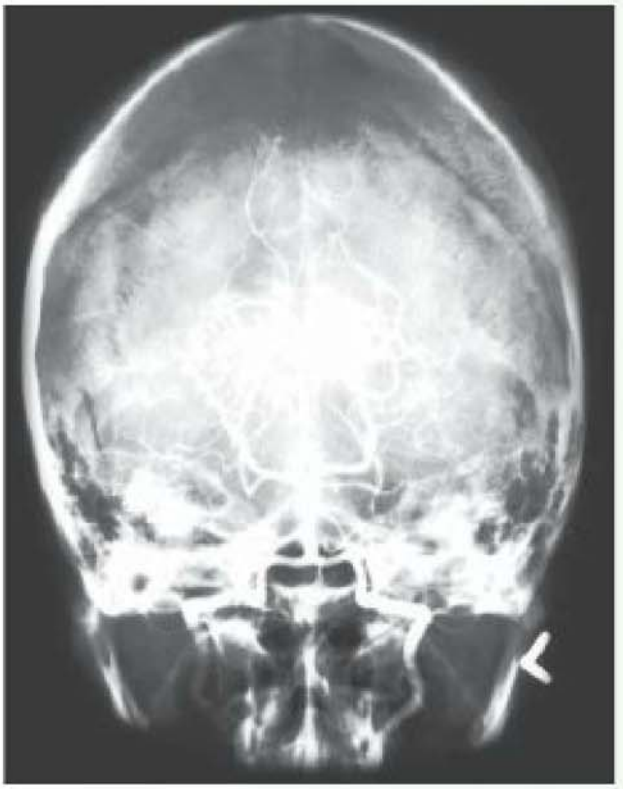

Figure 17-14 Anteroposterior (angled) vertebral arteriogram. Woman aged 35 years.

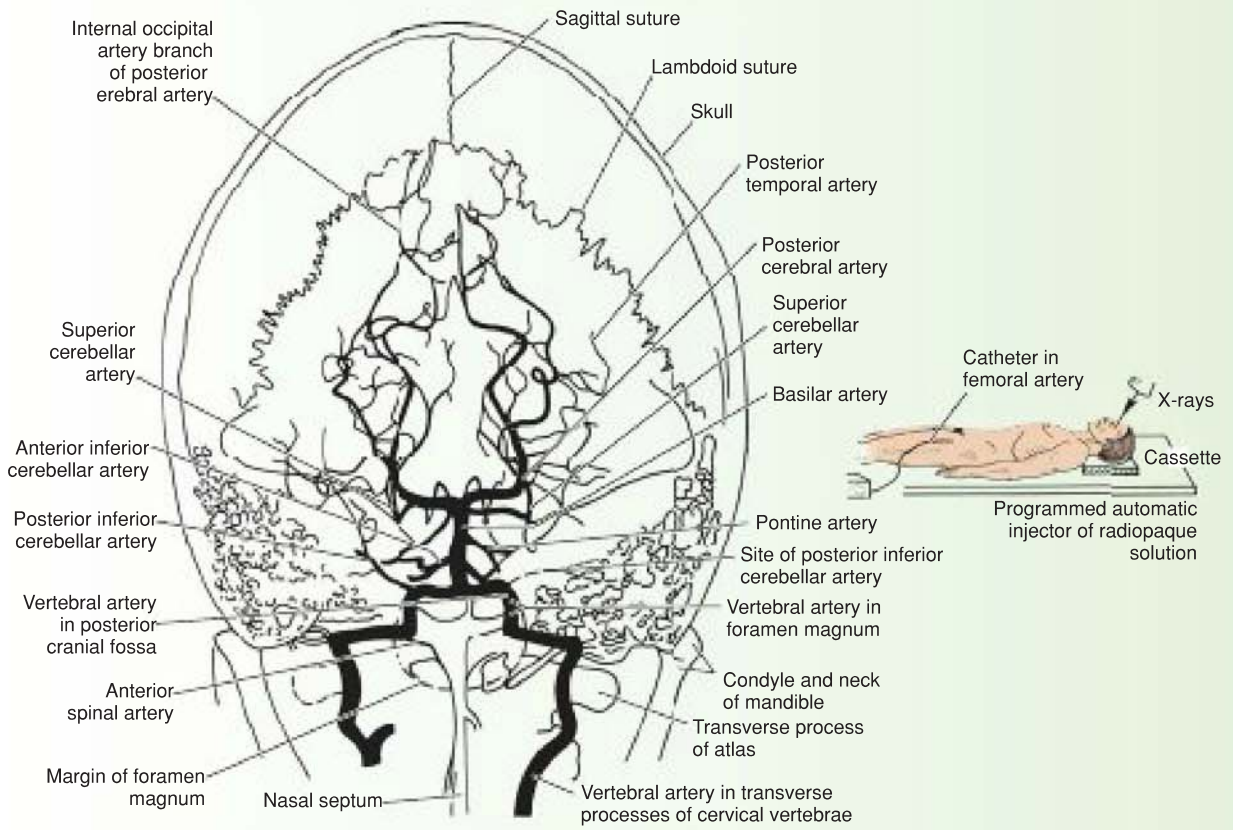

Figure 17-15 Main features shown in the radiograph in Figure 17-14.

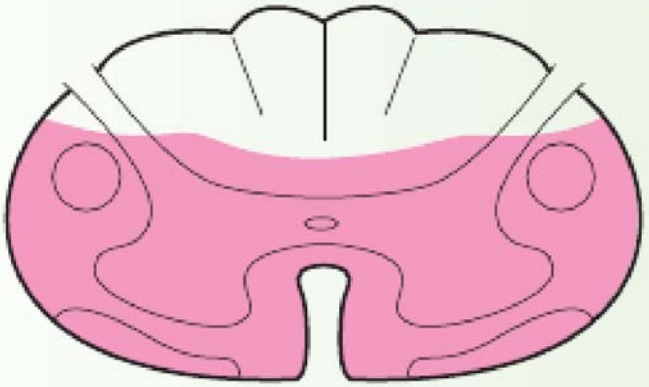

Figure 17-16 Anterior spinal artery occlusion. Pink area denotes region of spinal cord affected.

5. Position sense, vibration, and light touch are normal due to preservation of the posterior white columns that are supplied by the posterior spinal arteries.

Ischemia of the spinal cord can easily follow minor damage to the arterial supply as the result of nerve block procedures, aortic surgery, or any operation in which severe hypotension occurs. The fourth thoracic and first lumbar segments of the cord are particularly prone to ischemia.

Spinal Cord Ischemia and Thoracic Aortic Dissection

The thoracic region of the spinal cord receives its segmental arteries from the posterior intercostal arteries, which arise directly from the thoracic aorta. In thoracic aortic dissection, the expanding blood clot in the aortic wall can block the origins of the posterior intercostal arteries, causing ischemia of the spinal cord.

Spinal Cord Ischemia as a Complication of a Leaking Abdominal Aortic Aneurysm

The lumbar region of the spinal cord receives its segmental arteries from the lumbar arteries, which are branches of the abdominal aorta. The effect of direct pressure on the lumbar arteries by a leaking aneurysm can interfere with the blood supply to the spinal cord.

Key Concepts

Blood Supply of the Brain

- The brain is supplied by the two internal carotid and the two vertebral arteries that lie within cerebrospinal fluid of the subarachnoid space.
- The internal carotid begins at the bifurcation of the common carotid in the neck, where it possesses a local dilation called the carotid sinus.
- The internal carotid enters the cranial cavity through the carotid canal of the temporal bone.
- The internal carotid terminates as the anterior and middle cerebral arteries after giving off ophthalmic and posterior communicating arteries.
- The two vertebral arteries enter the cranial cavity through the foramen magnum after ascending through the transverse foramina of the cervical vertebrae.
- The cranial portion of the vertebral artery gives off the posterior spinal, anterior spinal, posterior inferior cerebellar, medullary, and meningeal arteries.
- The vertebral arteries merge to form the basilar artery on the anterior surface of the pons.
- The basilar artery branches into pontine, labyrinthine, anterior inferior cerebellar, superior cerebellar, and posterior cerebral arteries.
- The circle of Willis is formed by the anastomosis between the two internal carotid and vertebral blood supplies by communication of the anterior cerebral and anterior communicating arteries, internal carotid arteries, posterior communicating and posterior cerebral arteries, and the basilar artery.
- The corpus striatum and internal capsule are supplied by the medial and lateral striate branches of the middle cerebral artery.
- The thalamus is supplied by branches of the posterior communicating, basilar, and posterior cerebral arteries.
- The midbrain is supplied by the posterior cerebral, superior cerebellar, and basilar arteries.

- The pons is supplied by the basilar, anterior inferior, and superior cerebellar arteries.
- The medulla oblongata is supplied by the vertebral, anterior and posterior spinal, posterior inferior cerebellar, and basilar arteries.
- The cerebellum is supplied by the superior cerebellar, anterior inferior cerebellar, and posterior inferior cerebellar arteries.

Blood Supply of the Spinal Cord

- The spinal cord receives its arterial supply from three small arteries: two posterior spinal arteries and the anterior spinal artery.
- These longitudinally running arteries are reinforced by small segmentally arranged arteries that enter the vertebral column through the intervertebral foramina of the vertebral column.

Clinical Problem Solving

1. A distinguished neurosurgeon, while giving a lecture on cerebrovascular accidents, made the following statement: "It is generally agreed that there are no anastomoses of clinical importance between the terminal end arteries within the brain substance, but there are many important anastomoses between the large arteries, both within and outside the skull, and these may play a major role in determining the extent of brain damage in cerebral vascular disease." Comment on this statement, and name the sites at which important arterial anastomoses take place.
2. During examination of a carotid angiogram, the contrast medium had filled the anterior and middle cerebral arteries but had failed to fill the posterior cerebral artery. Careful following of the contrast medium showed it to enter the posterior communicating artery but to extend no farther. Explain this phenomenon in a normal person.
3. A 45-year-old man was admitted to the hospital after collapsing in his home 3 days previously. He was in a partial state of unconsciousness on the floor and was found by a friend. On physical examination, he had right-sided homonymous hemianopia, although careful examination of the fields of vision showed that the macular regions were normal. Right-sided hemianesthesia and hemianalgesia also were present, although the patient complained of severe burning pain in the right leg. During the first 24 hours in the hospital, the patient demonstrated mild right-sided hemiparesis of the flaccid type, which disappeared within 2 days. What is your diagnosis? Be specific in describing the branches of the artery that are involved.
4. During the course of an autopsy on a patient who had recently died of cerebrovascular disease, the pathologist made the comment that in atherosclerosis of the cerebral arteries, the atheromatous plaques tend to occur where the main arteries divide or where the arteries suddenly curve. At these sites, pressure flow changes may be a factor in the causation of the disease process. Using your knowledge of anatomy, name as many sites as you can where the main cerebral arteries divide or undergo abrupt change in their course.
5. Having carefully examined a male patient with cerebrovascular disease, the physician met with the family to discuss the nature of the illness, the course of treatment, and the prognosis. The daughter asked the physician what was meant by the term *stroke* as well as its common causes. He was also asked why the clinical findings vary so much from patient to patient. Using your knowledge of the anatomy and physiology of cerebral blood flow, explain why patients with cerebrovascular disease present such a variety of syndromes.
6. The classic sign of cerebrovascular disease is hemiplegia, yet we know that most patients also exhibit sensory deficits of different types. Using your knowledge of the anatomical distribution of the cerebral arteries, discuss the main types of sensory loss that you may find in such patients.
7. During the discussion of the symptoms and signs of a 70-year-old woman who had been admitted to the hospital for treatment of cerebrovascular disease, a fourth-year medical student made the comment that she was surprised to find that many of the signs and symptoms were bilateral in this patient. She said that the three previous patients she had examined had displayed only unilateral signs and symptoms. Using your knowledge of neuroanatomy, explain why some patients exhibit bilateral signs and symptoms, while in others the syndrome is clearly unilateral.
8. Neurologists speak frequently of the dominant hemisphere and if cerebrovascular disease should involve that hemisphere, one would expect the patient possibly to have global or total sensorimotor aphasia. Explain this phenomenon.
9. Explain why patients with a thrombosis of the middle cerebral artery often present with homonymous hemianopia as well as hemiplegia and hemianesthesia.

10. During the neurobiology course, the professor of neuroanatomy emphasized the importance of knowing the structure and blood supply of the internal capsule. He explained the arrangement of the ascending and descending tracts within the capsule and showed how they were concentrated into a small area between the thalamus and caudate nucleus medially and the lentiform nucleus laterally. Clearly, an interruption of the blood supply to this vital area would produce widespread neurologic defects. What is the blood supply to the internal capsule?
11. A 36-year-old man visited his physician with a complaint that on three occasions during the past 6 months, he had fainted at work. During careful questioning, the patient stated that on each occasion, he had fainted while sitting at his desk and while interviewing office personnel; he added that the person being interviewed sat in a chair immediately to the right of the desk. He said that before each fainting attack he felt dizzy; then, he lost consciousness only to recover within a few moments. The previous evening, he had a similar dizzy spell when he turned his head quickly to the right to talk to a friend in the street. The physician noted that the patient wore a stiff collar that was rather close fitting. When the physician commented on this, the patient stated that he always wore this type of collar to work. No abnormal physical signs were found. Using your knowledge of anatomy and physiology, what diagnosis would you make?
12. A 45-year-old man, a company director, rose to give his annual after-dinner speech to the board when he suddenly experienced an "agonizing, crushing" pain over the sternum. Feeling giddy and weak, he fell back in his chair. A few moments later, he lapsed into unconsciousness. An attendant at the dinner, who had received some training in cardiopulmonary resuscitation while a member of the armed forces, ran forward and noted that the patient had stopped breathing. He quickly started mouth-to-mouth resuscitation and cardiac compression and kept going until ambulance personnel arrived to take the patient to the hospital. The physician in the intensive care unit at the hospital later told the patient that his life had been saved by the alertness and competence of the attendant at the dinner. Using your knowledge of neurophysiology, state how long brain tissue can survive with complete cardiac arrest and when breathing has ceased.
13. A 62-year-old man with a history of hypertension visited his physician because the day before, he had temporarily lost the sight in his right eye. He explained that the sight loss was partial and lasted about half an hour. On close questioning, the patient admitted that he had had similar episodes of blindness in the same eye during the previous 6 months, but they had lasted only a few minutes. The patient also mentioned that there were days when he could not remember the names of people and things. He also had recently experienced severe right-sided headaches. When asked about his activities, he said that he could not walk as well as he used to and his left leg sometimes felt weak and numb. While performing a careful physical examination, the physician heard with his stethoscope a distinct systolic bruit over the right side of the neck. Given that the patient has vascular disease of the brain, which artery is likely to be involved in the disease process? What special clinical investigations could you perform to confirm the diagnosis?
14. A 39-year-old man was admitted to the hospital with a history of a sudden excruciating, generalized headache while gardening. This was followed, 10 minutes later, by the patient collapsing to the ground in a state of unconsciousness. After being carried indoors and placed on a settee, the patient regained consciousness but appeared confused. He complained of a severe headache and a stiff neck. Physical examination revealed some rigidity of the neck but nothing further. A careful neurologic examination 3 days later revealed some loss of tone in the muscles of the left leg. Using your knowledge of anatomy, make the diagnosis. What is the reason for the neck rigidity?
15. A 26-year-old man, on leaving a bar after a few drinks, stepped into the road at 1:00 AM and was struck by a passing car. Fortunately, the car was traveling slowly and struck the patient's head a glancing blow. One hour later, a policeman found the patient unconscious on the sidewalk. Physical examination at the local hospital found that the patient had recovered consciousness for a few minutes but then had quickly relapsed into an unconscious state. The right pupil was dilated, and the muscle tone of the left leg was found to be less than normal. A positive Babinski sign was obtained on the left side. Examination of the scalp showed a severe bruise over the right temple, and a lateral radiograph of the skull showed a fracture of the anterior inferior angle of the parietal bone. A CT scan showed a dense area extending from anterior to posterior along the inner table of the right parietal bone. What is the diagnosis? Let us suppose that the equipment for performing a CT scan was unavailable and that it was decided to perform a lumbar puncture; this test revealed a raised cerebrospinal fluid pressure, and the fluid was very slightly blood stained. Explain these additional findings.
16. A 50-year-old woman complaining of headaches, drowsiness, and mental confusion visited her physician. On close questioning, the patient distinctly remembered striking her head against a closet door when bending down 3 weeks previously. A CT scan revealed the presence of a large space-occupying lesion over the right frontal lobe of the brain. What is the possible diagnosis?
17. A 55-year-old man with a history of hypertension collapsed in the street while walking to work. He complained of a sudden severe headache. After 5 minutes, his face began to sag on the right side

and his speech became slurred. On admission to the hospital, his right arm and leg were found to be weaker than the left, and the muscles were hypotonic. The eyes were deviated to the left. Later, the right arm and leg showed complete paralysis and were insensitive to pinprick. A positive Babinski sign was present on the right side. Two hours later, the patient relapsed into a deep coma with bilateral dilated fixed pupils. Later, the respirations became deep and irregular, and the patient died 6 hours later. Using your knowledge of neuroanatomy, make the diagnosis.

18. What is the blood supply to the spinal cord? Which areas of the spinal cord are supplied by the anterior spinal artery? Which regions of the spinal cord are most susceptible to ischemia?

Answers and Explanations to Clinical Problem Solving

1. Once the terminal branches of the cerebral arteries enter the brain substance, no further anastomoses occur. Blockage of such end arteries by disease is quickly followed by neuronal death and necrosis. The surrounding neuroglia then usually proliferates and invades the area, producing a neuroglial scar or forming a cystic cavity. The following important anastomoses exist between the cerebral arteries: (a) the circle of Willis; (b) anastomoses between the branches of the cerebral arteries on the surface of the cerebral hemispheres and the cerebellar hemispheres; and (c) anastomoses between the branches of the internal and external carotid arteries: (i) at their origin at the common carotid artery, (ii) at the anastomosis between the branches of the ophthalmic artery within the orbit and the facial and maxillary arteries, and (iii) between the meningeal branches of the internal carotid artery and the middle meningeal artery.
2. The work of McDonald and Potter in 1951 showed that the posterior communicating artery is the site at which the streams of blood from the internal carotid and vertebral arteries on the same side come together, and since their pressures at this point are equal, they do not mix. Nevertheless, in clinical practice, good filling of the posterior cerebral artery with radiopaque material as shown by carotid angiography occurs in about 25% of patients. Slight filling also may be seen in other normal individuals. The variable results can be explained on the basis that the size of the arteries making up the arterial circle is subject to considerable variation, and consequently, the blood flow in different individuals may vary.
3. Occlusion of the cortical branches of the left posterior cerebral artery will give rise to right-sided homonymous hemianopia because of ischemia of the primary visual area in the calcarine fissure. The escape of the macular region could be accounted for by the overlapping of the arterial supply of this area of the occipital lobe by the left posterior and left middle cerebral arteries. The right-sided hemianesthesia and the severe burning pain in the right leg are referred to clinically as the thalamic syndrome and are due to occlusion of one of the central branches of the left posterior cerebral artery that supplies the sensory nuclei of the left thalamus. The presence of a mild fleeting right-sided hemiparesis could be explained by a temporary occlusion of a branch of the left posterior cerebral artery to the left cerebral peduncle.
4. Atheromatous plaques tend to occur at the following sites: (a) carotid sinus of the internal carotid artery at or just beyond the bifurcation of the common carotid artery, (b) the first main bifurcation of the middle cerebral artery, (c) where the vertebral arteries join to form the basilar artery, (d) where the anterior cerebral artery curves superiorly and posteriorly over the genu of the corpus callosum, and (e) where the posterior cerebral artery passes around the lateral side of the cerebral peduncle.
5. A stroke may be defined as a sudden development of a neurologic defect, usually associated with the development of some degree of hemiplegia and sometimes accompanied by unconsciousness; it is usually caused by a cerebrovascular accident. The symptoms and signs will depend on the cause of the interruption of cerebral blood flow and the size of the artery involved. For example, cerebral embolism or cerebral hemorrhage is a sudden event, whereas the development of atherosclerosis in a patient with hypertension is a slow process that suddenly may become worse when thrombosis occurs at the site of the atheromatous plaque. Hemiplegia is the most common sign, but many additional sensory defects may develop, depending on the artery blocked. Examples are hemianesthesia, hemianopia, dysphasia, and dysarthria.
6. Occlusion of the middle cerebral artery or its branches can produce, in addition to paralysis of the muscles of the opposite side of the body, contralateral hemianesthesia owing to ischemia of the postcentral gyrus and homonymous hemianopia owing to ischemia of the optic radiation. Occlusion of the anterior cerebral artery or its branches may produce contralateral sensory loss in the leg, foot, and toes owing to ischemia of the leg area of the cerebral cortex. Occlusion of the posterior cerebral artery or its branches may produce contralateral homonymous hemianopia owing to ischemia of the primary visual area in the region of the calcarine fissure. If the branches to the thalamus also are blocked, there will also be contralateral hemianesthesia and possibly the development of severe pain in the same areas.

These sensory deficits are the main ones seen. The degree of sensory involvement will depend on the size and number of branches of the artery occluded.

7. The internal carotid and the basilar arteries are equally affected by disease. The internal carotid artery supplies predominantly one cerebral hemisphere through the anterior cerebral and middle cerebral branches; therefore, occlusion of the internal carotid artery will produce contralateral hemiplegia, hemianesthesia, hemianopia, and aphasia and agnosia, depending on whether the dominant hemisphere is involved. On the other hand, the basilar artery contributes to the blood supply of both sides of the brain through the two posterior cerebral arteries and the many branches to both sides of the brainstem. Consequently, occlusion of the basilar artery will result in bilateral motor and sensory losses and involvement of the cranial nerves and cerebellum on both sides of the body.
8. The dominant hemisphere possesses the language function. In right-handed individuals (and in some left-handed persons), language is a function of the left hemisphere. A cerebrovascular accident involving the middle cerebral artery on the left side will therefore be more serious than one on the right side, since it will involve the cortical speech area and cause a total sensory motor aphasia. In persons who have a dominant right hemisphere, the reverse occurs.
9. The middle cerebral artery, in addition to giving off cortical branches, gives off central branches that supply part of the posterior limb of the internal capsule and the optic radiation. Occlusion of these branches will cause contralateral homonymous hemianopia.
10. Since so many important ascending and descending tracts travel in the internal capsule, an occlusion of its blood supply would produce a widespread neurologic deficit. The internal capsule is supplied by the medial and lateral striate central branches of the middle cerebral artery and by the central branches of the anterior cerebral artery.
11. This patient has the symptoms of the carotid sinus syndrome. For a full description of this syndrome, see page 473.
12. It has been estimated that irreversible changes start to occur in the cerebral nervous tissue about 4 minutes following the complete arrest of cerebral blood flow. (This figure may be higher if the patient's body has been cooled.)
13. The impairment of vision of the right eye with motor symptoms in the left leg strongly suggests partial occlusion of the right internal carotid artery. When these are coupled with impairment of memory and a systolic bruit over the right internal carotid artery, the diagnosis is almost certain. The right-sided headaches are also common symptoms in this condition. A right-sided carotid angiogram can confirm the presence of extreme narrowing of the internal carotid artery at its origin. Ophthalmodynamometric measurements can show diminished retinal arterial pressure on the right side owing to diminished pressure in the right ophthalmic artery.
14. This patient had a congenital aneurysm of the anterior communicating artery. The sudden onset of a severe headache, which is often so dramatic that the patient feels as though he or she has been hit on the head, is characteristic of rupture of a congenital aneurysm into the subarachnoid space. The stiff or rigid neck is due to meningeal irritation caused by the presence of blood in the subarachnoid space. This patient had no evidence of previous pressure on the optic nerve leading to unilateral visual defect, which sometimes occurs when the aneurysm is situated on the anterior part of the circle of Willis. The loss of tone in the left leg muscles is difficult to explain, although it may be due to the sudden hemorrhage into the subarachnoid space causing damage to the right cerebral hemisphere.
15. This patient had a right-sided extradural hemorrhage due to a fracture of the anterior part of the parietal bone, which tore the anterior division of the right middle meningeal artery. The history of the patient being found unconscious and then regaining consciousness for a period only to relapse into unconsciousness is a characteristic finding. The initial trauma usually is responsible for the initial loss of consciousness. The relapse into an unconscious state is due to the accumulation of a large blood clot under arterial pressure outside the meningeal layer of dura. This is responsible for the dilated pupil on the right side due to indirect pressure on the right oculomotor nerve. The pressure on the right precentral gyrus causes the hemiplegia and weakness of the left leg; it also causes the positive Babinski sign on the left side. The presence of a large blood clot in the intracranial cavity was easily recognized on a CT scan. The presence of the clot was also responsible for the raised cerebrospinal fluid pressure. The slight blood staining of the fluid obtained from a spinal tap was due to a small leakage of blood from the extradural space into the subarachnoid space at the fracture site.
16. This patient had a chronic subdural hematoma following trauma to the head 3 weeks previously. This resulted from one of the superior cerebral veins tearing at its point of entrance into the superior sagittal sinus. The blood accumulated under low pressure between the dura and the arachnoid. The headaches, drowsiness, and mental confusion were due to the raised intracranial pressure. The blood clot could be seen easily on the CT scan. The blood clot was successfully removed through a burr hole in the skull, and the patient had no further symptoms.
17. The history of hypertension, sudden onset of severe headache, slurring of speech, right lower facial weakness, right-sided hemiplegia, right positive Babinski sign, right-sided hemianesthesia, and deviation of the eyes to the left side are all diagnostic of a cerebrovascular accident involving the left cerebral hemisphere. The perforating central branches of the left middle cerebral artery were found at autopsy to be extensively affected by atherosclerosis. One of these arteries had ruptured, resulting in

a large hemorrhage into the left lentiform nucleus and left internal capsule. The combination of hypertension and atherosclerotic degeneration of the artery was responsible for the fatal hemorrhage. The dilated fixed pupils, the irregularity in breathing, and, finally, death were due to the raised pressure within the hemisphere causing downward pressure effects within the brainstem.

18. The blood supply to the spinal cord is fully described on pages 471-472. The anterior spinal artery supplies the anterior two-thirds of the spinal cord. The upper and lower thoracic segments of the spinal cord have a relatively poor supply of blood because the anterior spinal artery in this region may be extremely small; therefore, they are more susceptible to ischemia.

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 blood supply to the brain:
   (a) The brain receives its blood supply directly from the two external carotid arteries.
   (b) The circle of Willis is formed by the anterior cerebral, the internal carotid, the posterior cerebral, the basilar, and the anterior and posterior communicating arteries.
   (c) The cerebral arteries do not anastomose on the surface of the brain.
   (d) Numerous anastomoses occur between the branches of the cerebral arteries once they have entered the substance of the brain.
   (e) The main blood supply to the internal capsule is from the central branches of the anterior cerebral artery.
2. The areas of the cerebral cortex listed below receive their arterial supply as indicated:
   (a) The precentral gyrus (face area) is supplied by the middle cerebral artery.
   (b) The postcentral gyrus (face area) is supplied by the anterior cerebral artery.
   (c) The cuneus is supplied by the anterior cerebral artery.
   (d) The inferior temporal gyrus is supplied by the middle cerebral artery.
   (e) The Wernicke area is supplied by the posterior cerebral artery.
3. The arteries listed below arise from the main stem arteries as indicated:
   (a) The ophthalmic artery is a branch of the middle cerebral artery.
   (b) The pontine arteries are branches of the internal carotid artery.
   (c) The posterior communicating artery is a branch of the middle cerebral artery.
   (d) The posterior spinal artery arises from the vertebral artery.
   (e) The posterior inferior cerebellar artery is a branch of the basilar artery.
4. The veins listed below drain into the venous sinuses indicated:
   (a) The superior cerebral veins drain into the inferior sagittal sinus.
   (b) The great cerebral vein drains into the superior sagittal sinus.
   (c) The superior cerebellar veins drain only into the straight sinus.
   (d) The spinal veins drain into the external vertebral venous plexus.
   (e) The inferior sagittal sinus drains into the straight sinus.
5. The following statements concern the cerebral blood flow:
   (a) The sympathetic postganglionic fibers exert great control over the diameter of the cerebral blood vessels.
   (b) It varies greatly with changes in the general blood pressure.
   (c) Oxygen tension in the cerebral blood has no effect on the diameter of the cerebral blood vessels.
   (d) One of the most powerful vasodilators of cerebral blood vessels is carbon dioxide.
   (e) The blood flow for a particular area of nervous tissue following occlusion of a cerebral artery does not depend on the collateral circulation.
6. The following statements concern cerebral ischemia:
   (a) Atheromatous degeneration of a cerebral artery does not cause degeneration of the nerve cells in the avascular area due to the presence of cerebrospinal fluid.
   (b) Neuronal function ceases after the blood flow has stopped for about 10 seconds.
   (c) Irreversible cerebral damage starts to occur after the blood flow has ceased for about 4 minutes.
   (d) Shock occurring as the result of severe physical trauma does not result in cerebral ischemia.
   (e) Cooling of the patient's body following a cerebrovascular accident speeds up cerebral degeneration.

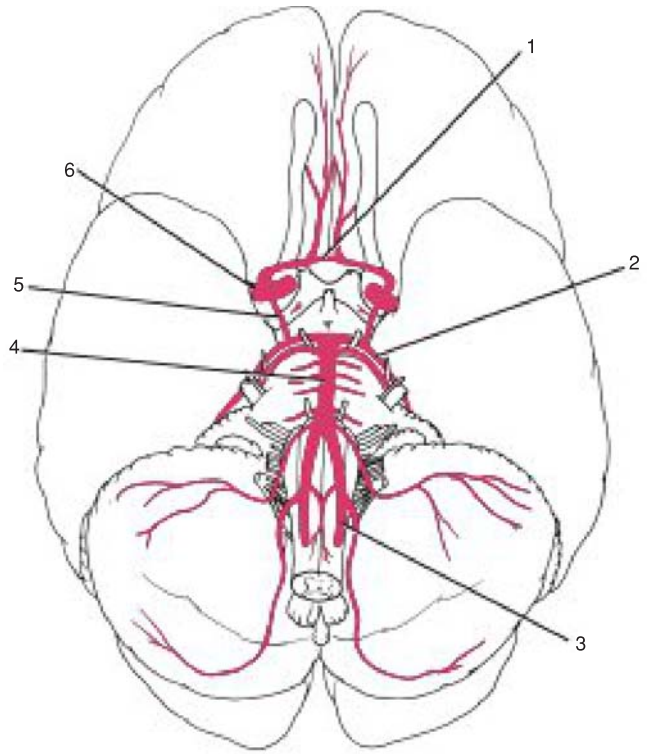

Figure 17-17 The arteries of the inferior surface of the brain.

Matching Questions. Directions: The following questions apply to Figure 17-17. Match the numbered arteries listed below with the appropriate lettered arteries. 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

(a) Middle cerebral artery
(b) Anterior communicating artery
(c) Posterior cerebral artery
(d) Basilar artery
(e) None of the above

Directions: In the next item, select the ONE lettered answer that is CORRECT.

13. The following statements concern the blood supply to the spinal cord:
    (a) The posterior spinal arteries supply the posterior third of the spinal cord.
    (b) The veins do not communicate with the veins of the brain and the venous sinuses.
    (c) The arteria radicularis magna (artery of Adamkiewicz) arises in the lower thoracic region from the arch of the aorta.
    (d) The anterior spinal artery is double but usually arises from one vertebral artery.
    (e) The spinal arteries are not reinforced by branches of local arteries.

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

A 58-year-old man, while eating his evening meal, suddenly complained of a severe headache. Moments later, he slumped forward and lost consciousness.

14. On being admitted to the hospital, the examining physician could have found the following physical signs **except:**
    (a) He was in a deep coma, and his breathing was deep and slow.
    (b) The patient's head was turned to the left.
    (c) The right side of his face was flattened, and saliva was drooling out of the right corner of his mouth.
    (d) The muscle tone of the limbs was less on the right side than on the left.
    (e) The right abdominal reflexes were absent, and there was a positive Babinski response on the left side.
15. Three days later, the patient regained consciousness, and the following additional signs could have become apparent **except:**
    (a) The right arm and, to a lesser extent, the right leg were paralyzed.
    (b) Movements of the left arm and leg and the left side of the face were normal.
    (c) The upper and lower parts of the right side of his face were paralyzed.
    (d) The patient had difficulty in swallowing.
    (e) The patient was unable to speak.
16. During the next 2 weeks, the following signs could have developed **except:**
    (a) The muscles of the limbs on the right side became hypertonic.
    (b) The tendon reflexes on the right side became hyperactive.
    (c) The patient had some sensory loss on the right side.
    (d) The patient was suffering from urinary incontinence.
    (e) The muscles on the left side exhibited hypotonia.
17. The neurologist in charge of this patient interpreted the findings as follows. All his interpretations were likely to be correct **except:**
    (a) The sudden onset of a severe headache followed by loss of consciousness is a common finding in patients with a blockage of a cerebral artery.
    (b) The depth of coma is unrelated to the extent of the arterial blockage.
    (c) Paralysis of the face on the right side indicated the presence of a lesion on the left side of the brain.
    (d) The patient's head and eyes were turned to the left (i.e., to the side of the lesion).
    (e) The loss of right-sided abdominal reflexes indicated the presence of a lesion on the left side of the brain.

18. The following physical signs and known anatomical data strongly suggested the involvement of the left middle cerebral artery **except:**
    (a) Paralysis of the right side of the face and the right arm was more severe than that of the right leg.
    (b) The presence of aphasia.
    (c) The central branches of the middle cerebral artery do not supply the lentiform nucleus, the caudate nucleus, and the internal capsule.
    (d) The left middle cerebral artery supplies the entire lateral surface of the cerebral hemisphere except for the narrow strip supplied by the anterior cerebral artery.
    (e) The left posterior cerebral artery supplies the occipital pole and the inferolateral surface of the cerebral hemisphere.

A 60-year-old man was admitted to the emergency department, complaining of the sudden onset of excruciating, sharp, tearing pain localized to the back of the chest and the back. After a thorough physical and radiologic examination, a diagnosis of dissection of the descending thoracic aorta was made. Within a few hours, the patient started to experience "girdle" pain involving the fourth thoracic dermatome on both sides. Later, he was found to have bilateral thermoanesthesia and analgesia below the level of the fourth thoracic dermatome. Position sense, vibration, and light touch remained normal. Complete spastic paralysis of both legs quickly developed.

19. The sudden onset of "girdle" pain in this patient was **most likely caused by:**
    (a) Pressure on the fourth thoracic spinal nerves
    (b) Blockage of the origins of the posterior intercostal arteries that give rise to the segmental spinal arteries by the aortic dissection
    (c) Discomfort caused by the expanding aneurysm
    (d) Osteoarthritis of the vertebral column
20. The development of bilateral thermoanesthesia and analgesia below the level of the fourth thoracic segment of the cord and the later development of paraplegia **could be caused by:**
    (a) Absent circulation in the posterior spinal arteries
    (b) Cerebral hemorrhage
    (c) Absent circulation in the anterior spinal artery
    (d) Collapse of the fourth thoracic vertebral body

Answers and Explanations to Review Questions

1. B is correct. The circle of Willis is formed by the anterior cerebral, the internal carotid, the posterior cerebral, the basilar, and the anterior and posterior communicating arteries (see Fig. 17-6). A. The brain receives its blood supply directly and indirectly from the two internal carotid and the two vertebral arteries that lie within the subarachnoid space. C. The cerebral arteries anastomose on the surface of the brain. D. No anastomoses exist between the branches of the cerebral arteries once they have entered the substance of the brain. E. The main blood supply to the internal capsule is from the central branches of the middle cerebral artery.
2. A is correct. The precentral gyrus (face area) is supplied by the middle cerebral artery (see Figs. 8-5 and 17-3). B. The face area of the postcentral gyrus is supplied by the middle cerebral artery. C. The cuneus is supplied by the posterior cerebral artery (see Fig. 17-3). D. The inferior temporal gyrus is supplied by the posterior cerebral artery (see Fig. 17-3). E. The Wernicke area is supplied by the middle cerebral artery.
3. D is correct. The posterior spinal artery arises from the vertebral artery (see Fig. 17-7). A. The ophthalmic artery is a branch of the cerebral portion of the internal carotid artery. B. The pontine arteries are branches of the basilar artery (see Fig. 17-2). C. The posterior communicating artery is a branch of the internal carotid artery (see Fig. 17-2). E. The posterior inferior cerebellar artery is a branch of the vertebral artery (see Fig. 17-2).
4. E is correct. The inferior sagittal sinus drains into the straight sinus (see Fig. 17-5). A. The superior cerebral veins drain into the superior sagittal sinus (see Fig. 17-5). B. The great cerebral vein drains into the straight sinus (see Fig. 17-5). C. The superior cerebellar veins drain into the straight sinus, the transverse sinus, and the occipital sinus (see Fig. 17-5). D. The spinal veins drain into the internal vertebral venous plexus.
5. D is correct. One of the most powerful vasodilators of cerebral blood vessels is carbon dioxide. A. The sympathetic postganglionic fibers exert very little control over the diameter of the cerebral blood vessels. B. The cerebral blood flow varies only slightly with changes in the general blood pressure. C. Low oxygen tension in the cerebral blood causes vasodilation of the cerebral blood vessels. E. The blood flow for a particular area of nervous tissue following occlusion of a cerebral artery depends on the adequacy of the collateral circulation.
6. C is correct. Irreversible cerebral damage starts to occur after blood flow has ceased for about 4 minutes. A. Atheromatous degeneration of a cerebral artery may cause degeneration of the nerve cells in the avascular area and proliferation of the microglial cells in the surrounding area. B. Neuronal function ceases after blood flow has stopped for about 1 minute. D. Shock occurring as the result of severe physical trauma can result in cerebral ischemia. E. Cooling of the patient's body following a cerebrovascular accident slows down cerebral degeneration.

For answers to Questions 7 to 12, study Figure 17-17 which shows the arteries of the inferior surface of the brain.

7. B is correct; 1 is the anterior communicating artery.
8. C is correct; 2 is the posterior cerebral artery.
9. E is correct; 3 is the left vertebral artery.
10. D is correct; 4 is the basilar artery.
11. E is correct; 5 is the (right) posterior communicating artery.
12. A is correct; 6 is the (right) middle cerebral artery.
13. A is correct. The posterior spinal arteries supply the posterior third of the spinal cord (see p. 471). B. The spinal cord veins communicate with the veins of the brain and the venous sinuses. C. The arteria radicularis magna (artery of Adamkiewicz) arises from the aorta in the lower thoracic or upper lumbar vertebral levels. D. The anterior spinal artery is single but usually arises from both vertebral arteries. E. The spinal arteries are reinforced by radicular arteries, which are branches of local arteries.
14. E is the exception. A positive Babinski sign was present on the right side.
15. C is the exception. The muscles of the upper part of the face on the right side are not affected by a lesion involving the upper motor neurons on the left side of the brain. This is due to the fact that the part of the facial nucleus of the seventh cranial nerve that controls the muscles of the upper part of the face receives corticonuclear fibers from both cerebral hemispheres.
16. E is the exception. The cerebral lesion was on the left side of the brain, and the muscles of the left leg were completely unaffected by the vascular accident.
17. B is the exception. The depth of coma is related to the extent of the arterial blockage.
18. C is the exception. The central branches of the right middle cerebral artery do supply the right lentiform and caudate nuclei and the right internal capsule.
19. B is correct. In the thoracic region, the posterior intercostal arteries arise directly from the thoracic aorta and can be blocked by a blood clot as the aortic dissection progresses. The segmental spinal arteries, which are branches of the posterior intercostal arteries, give origin to the radicular arteries that supply the spinal nerves and their roots. If these arteries are compromised, severe pain is experienced in the distribution of the spinal nerves involved and, hence, the “girdle” pain.
20. C is correct. The blood supply to the spinal cord is meager and if the segmental arteries that reinforce the anterior and posterior spinal arteries are compromised, ischemia of the spinal cord could follow. In this patient, the circulation in the anterior spinal artery ceased and the blood supply to the anterior two-thirds of the spinal cord was cut off. This would explain the sudden development of bilateral thermoanesthesia and analgesia (spinothalamic tracts in both lateral white columns) and the paraplegia (corticospinal tracts in both lateral white columns). The sparing of the sensations of position, vibration, and light touch, which travel in the fasciculus gracilis and fasciculus cuneatus, can be explained by the fact that the posterior white columns are supplied by the posterior spinal arteries in which the circulation is adequate.

18 Nervous System Development

CHAPTER OBJECTIVES

- To review the development of the nervous system
- To visualize the relationship of different parts of the nervous system to one another
- To understand how the different nerve tracts insinuate themselves between the central masses of gray matter
- To review common congenital anomalies of the nervous system

A pediatrician examines a newborn baby boy after a difficult delivery and finds a soft, fluctuant swelling over the vertebral column in the lumbosacral region. The swelling measures about 3 in (7.5 cm) in diameter and is covered with a thin layer of intact skin. Transillumination of the sac reveals what appears to be solid nervous tissue. Any neurologic deficit is carefully looked for, and the baby is noted to move both legs normally and appears to respond normally to painful stimulation of the leg skin. Examination of the anal sphincter shows normal tone. Careful examination for other congenital anomalies, especially hydrocephalus, is also made, but nothing abnormal is detected.

A diagnosis of meningomyelocele is made. In this condition, vertebral arches fail to develop, with herniation of the meninges and nervous tissue through the defect. The child must be operated on; the lower end of the spinal cord and the cauda equina are returned to the vertebral canal, and the vertebral defect is repaired. The child will make an uneventful recovery.

In Chapter 1, the early development of the nervous system was considered to give the reader some insight into how the brain and spinal cord came into existence (see p. 14). In this chapter, the process of development continues, and the different parts of the nervous system followed as they evolve. An embryologic explanation for some of the more common congenital anomalies will be discussed.

SPINAL CORD

In early development, the neural tube is seen to dilate at the cephalic end into the **forebrain vesicle**, the **midbrain vesicle**, and the **hindbrain vesicle** (see Fig. 1-18A). The rest of the tube elongates and remains smaller in diameter; it will form the **spinal cord**.

The wall of the neural tube consists of a single layer of pseudostratified columnar epithelial cells, called the **matrix cells**. This thick zone of epithelium, which extends from the cavity of the tube to the exterior, is referred to as the **ventricular zone**. The nuclei of these cells move in toward the cavity of the tube to divide, and out toward the periphery during the intermitotic phases of the cell cycle (see Fig. 1-18C). Repeated division of the matrix cells results in an increase in length and diameter of the neural tube. Eventually, the early **neuroblasts** are formed and are incapable of further division. These cells migrate peripherally to form the **intermediate zone**. The intermediate zone will form the **gray matter** of the spinal cord. The neuroblasts now give rise to nerve fibers that grow peripherally and form a layer external to the intermediate zone called the **marginal zone**. The nerve fibers in the marginal zone become myelinated and form the **white matter** of the spinal cord.

While the neuroblasts are being formed, the matrix cells also give rise to the **astrocytes** and the **oligodendrocytes** of the neuroglia. Later, the **microglial cells**, which are derived from the surrounding mesenchyme, migrate into the developing spinal cord along with blood vessels. The **ependymal cells** are formed from the matrix cells that line the neural tube.

The cavity of the neural tube now becomes narrowed to form a dorsiventral cleft with thick lateral walls and thin **floor** and **roof plates** (Fig. 18-1A). The intermediate zone of the lateral wall of the tube forms a large anterior thickening known as the **basal plate** and a smaller

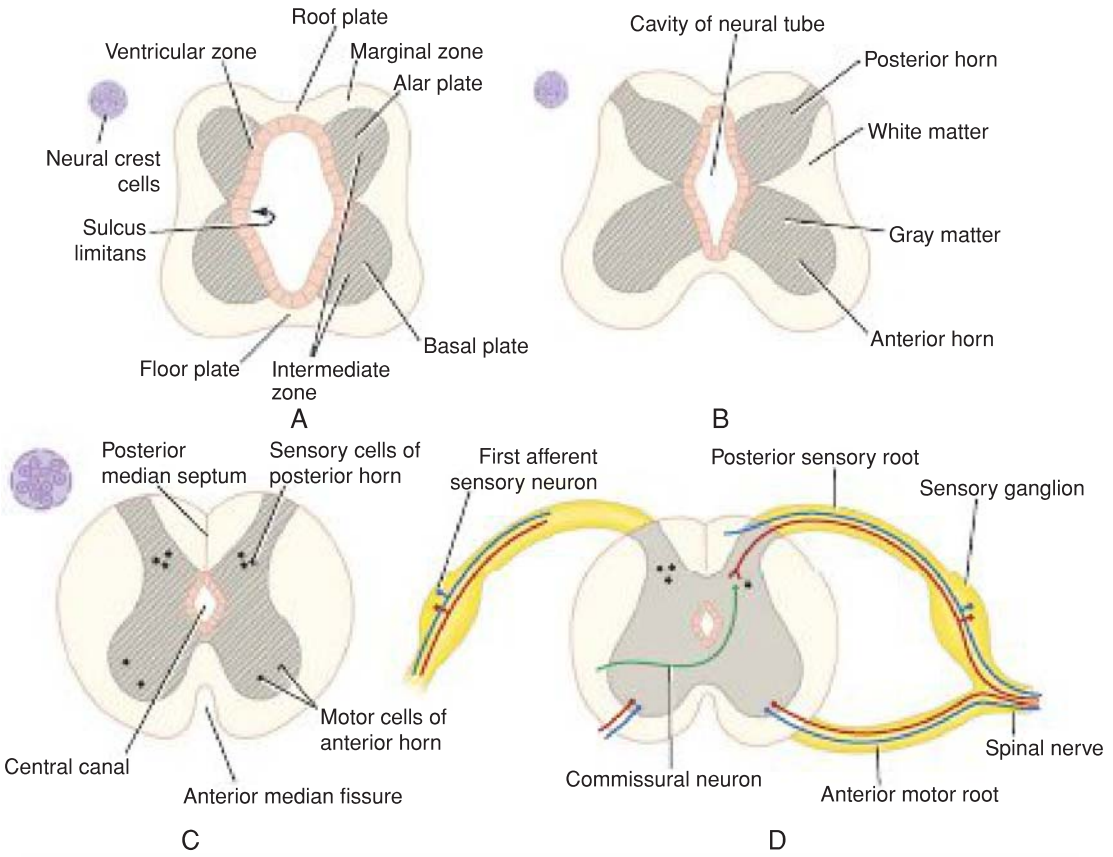

Figure 18-1 Different stages in the development of the spinal cord showing the neural crest cells, which will form the first afferent neurons in the sensory pathway.

posterior thickening known as the **alar plate**. The neuroblasts in the basal plate will form the motor cells of the anterior column (horn), while the neuroblasts in the alar plate will become the sensory cells of the posterior column. The motor basal plate and the sensory alar plate are separated on each side by the **sulcus limitans**. The roof and floor plates remain thin, and the cells contribute to the ependyma.

Continued growth of the basal plates on each side of the midline forms a deep longitudinal groove called the **anterior median fissure** (see Fig. 18-1C). The alar plates also increase in size and extend medially, compressing the posterior part of the lumen of the neural tube. Ultimately, the walls of the posterior portion of the tube fuse, forming the **posterior median septum**. The lumen of the neural tube becomes the **central canal**.

Further Development of the Motor Neurons

The medial group of motor neurons forms large multipolar cells whose axons will leave the anterior surface of the spinal cord to supply the musculature of the body. Currently occupying the minds of researchers is how the axons from a developing neuron are guided from their points of origin to a specific target. The growing end of the axon is believed to possess numerous receptors that respond to chemical cues along the way.

The lateral group of neurons gives rise to axons that will leave the anterior surface of the spinal cord as autonomic preganglionic fibers. Between the first thoracic and second or third lumbar segments of the mature spinal cord, the lateral group of neurons will form the **lateral gray column** (**horn**), that is, the **sympathetic outflow**. Collectively, the axons leaving the anterior surface of the spinal cord will form the **anterior roots of the spinal nerves** (see Fig. 18-1D).

Afferent Neuron Development in the Sensory Pathway

The first neurons in the sensory pathway have their cell bodies situated outside the spinal cord and are derived from the neural crest (see Figs. 1-16 and 18-1D). The neural crest cells migrate to a posterolateral position on either side of the developing spinal cord and become segmented into cell clusters. Some of the cells in each cluster now differentiate into neuroblasts. Each neuroblast develops two processes: a peripheral process and a central process. The peripheral processes grow out laterally to become typical axons of sensory nerve fibers. The central processes, also axons, grow into the

posterior part of the developing spinal cord and either end in the posterior gray column or ascend through the marginal zone (white matter) to one of the higher brain centers. These central processes are referred to collectively as the **posterior root of the spinal nerve** (see Fig. 18-1D). The peripheral processes join the anterior root to form the **spinal nerve**.

Some of the neural crest cells form the **capsular** or **satellite cells**, which surround the unipolar nerve cell bodies in a ganglion. Each **posterior root ganglion** is thus formed of the unipolar neurons and the capsular cells.

Further Development of Posterior Gray Column Sensory Neurons

The neuroblasts that have entered the alar plates now develop processes that enter the marginal zone (white matter) of the cord on the same side and either ascend or descend to a higher or lower level. Other nerve cells send processes to the opposite side of the cord through the floor plate, where they ascend or descend for variable distances (see Fig. 18-1A).

Development of the Meninges and Spinal Cord Relationship to Vertebral Column

The **pia mater**, **arachnoid mater**, and **dura mater** are formed from the mesenchyme (sclerotome) that surrounds the neural tube. The **subarachnoid space** develops as a cavity in the mesenchyme, which becomes filled with **cerebrospinal fluid** (**CSF**). The **ligamentum denticulatum** is formed from areas of condensation of the mesenchyme.

During the first 2 months of intrauterine life, the spinal cord is the same length as the vertebral column. Thereafter, the developing vertebral column grows more rapidly than the spinal cord; thus, at birth, the coccygeal end of the cord lies at the level of the third lumbar vertebra. In the adult, the lower end of the spinal cord lies at the level of the lower border of the body of the first lumbar vertebra. As a result of this disproportion in the rate of growth of the vertebral column and spinal cord, the anterior and posterior roots of the spinal nerves below the first lumbar segment of the spinal cord descend within the vertebral canal until they reach their appropriate exits through the intervertebral foramina. Moreover, the pia mater, which attached the coccygeal end of the spinal cord to the coccyx, now extends down as a slender fibrous strand from the lower end of the cord to the coccyx and forms the **filum terminale**. The obliquely coursing anterior and posterior roots of the spinal nerves and the filum terminale, which now occupy the lower end of the vertebral canal, collectively form the **cauda equina**.

We now know how the cauda equina is enclosed within the subarachnoid space down as far as the level of the second sacral vertebra. In this region, below the level of the lower end of the spinal cord, a **lumbar puncture** can be performed (see p. 19).

As the result of the development of the limb buds during the fourth month and the additional sensory and motor neurons, the spinal cord becomes swollen in the cervical and lumbar regions to form the **cervical** and **lumbar enlargements**.

BRAIN

Once the neural tube has closed, the **three primary vesicles**—the **forebrain vesicle**, the **midbrain vesicle**, and the **hindbrain vesicle**—complete their development (Fig. 18-2). The forebrain vesicle will become the forebrain (**prosencephalon**), the midbrain vesicle will become the midbrain (**mesencephalon**), and the hindbrain vesicle will become the hindbrain (**rhombencephalon**).

By the fifth week, the forebrain and hindbrain vesicles divide into two secondary vesicles. The forebrain vesicle forms (1) the **telencephalon**, with its primitive cerebral hemispheres, and (2) the **diencephalon**, which develops optic vesicles. The hindbrain vesicle forms (1) the **metencephalon**, the future pons and cerebellum, and (2) the **myelencephalon**, or medulla oblongata (Table 18-1).

The basic pattern of the ventricular system is now established. The cavity in each cerebral hemisphere is known as the **lateral ventricle**. The cavity of the diencephalon is known as the **third ventricle**. With continued growth, the cavity of the midbrain vesicle becomes small and forms the **cerebral aqueduct** or **aqueduct of Sylvius**. The cavity of the hindbrain vesicle forms the **fourth ventricle**, which is continuous with the central canal of the spinal cord. The lateral ventricles communicate with the third ventricle through the **interventricular foramina**. The ventricular system and the central canal of the spinal cord are lined with ependyma and are filled with CSF. In the earliest stages, the CSF within the ventricular system is not continuous with that of the subarachnoid space.

Early in development, the embryo is a flat disc, and the neural tube is straight. Later, with the development of the head fold and tail fold, the neural tube becomes curved.

Medulla Oblongata (Myelencephalon)

The walls of the hindbrain vesicle initially show the typical organization seen in the neural tube, with the anterior thickenings, known as the **basal plates**, and the posterior thickenings, known as the **alar plates**, being separated by the **sulcus limitans** (Fig. 18-3). As development proceeds, the lateral walls are moved laterally (like an opening clamshell) at higher levels by the expanding fourth ventricle. As a result, the alar plates come to lie lateral to the basal plates. The neurons of the basal plate form the motor nuclei of cranial nerves (CNs) IX, X, XI, and XII and are situated in the floor of the fourth ventricle medial to the sulcus limitans. The neurons of the alar plate form the sensory nuclei of CNs V, VIII, IX, and X and the **gracile** and **cuneate nuclei**. Other cells of the alar plate migrate ventrolaterally and form the **olivary nuclei**.

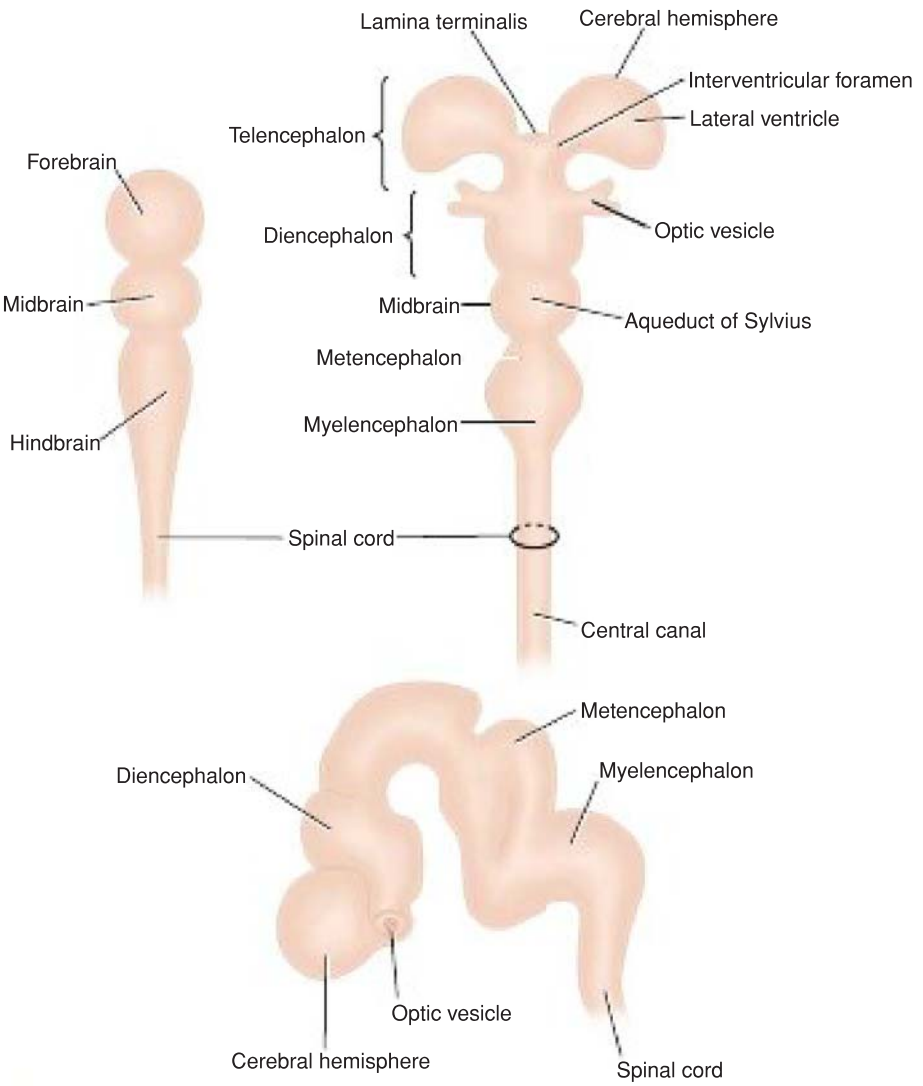

Figure 18-2 Division of the forebrain vesicle into the telencephalon and the diencephalon, and the hindbrain vesicle into the metencephalon and myelencephalon. Also shown is the way in which the cerebral hemisphere on each side develops as a diverticulum from the telencephalon.

Table 18-1 Primary Divisions of the Developing Brain

Primary Vesicle	Primary Division	Subdivision	Adult Structures
Forebrain vesicle	Prosencephalon (forebrain)	Telencephalon	Cerebral hemisphere, basal ganglia, hippocampus
		Diencephalon	Thalamus, hypothalamus, pineal body, infundibulum
Midbrain vesicle	Mesencephalon (midbrain)	Mesencephalon (midbrain)	Tectum, tegmentum, crus cerebri
Hindbrain vesicle	Rhombencephalon (hindbrain)	Metencephalon	Pons, cerebellum
		Myelencephalon	Medulla oblongata

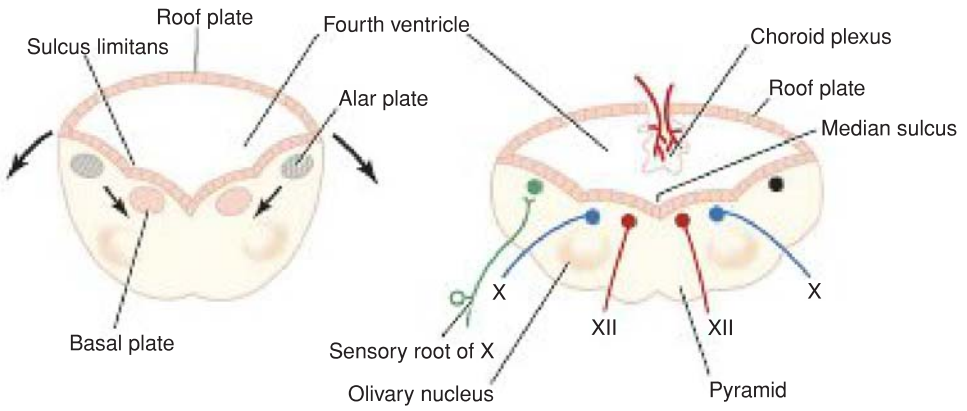

Figure 18-3 Development of the medulla oblongata (myelencephalon).

The roof plate becomes stretched into a thin layer of ependymal tissue. The vascular mesenchyme lying in contact with the outer surface of the roof plate forms the pia mater, and the two layers together form the **tela choroidea**. Vascular tufts of tela choroidea project into the cavity of the fourth ventricle to form the **choroid plexus**. Between the fourth and fifth months, local resorptions of the roof plate occur; forming paired lateral foramina, the **foramina of Luschka**, and a median foramen, the **foramen of Magendie**. These important foramina allow the escape of the CSF, which is produced in the ventricles, into the subarachnoid space (see p. 443).

The floor plate remains narrow and forms the region of the median sulcus. In the marginal layer on the anterior aspect of the medulla, descending axons from the neurons in the motor areas of the cerebral cortex (precentral gyrus) produce prominent swellings called the **pyramids**.

Pons (Ventral Part of Metencephalon)

The pons arises from the anterior part of the metencephalon (Fig. 18-4), but it also receives a cellular contribution from the alar part of the myelencephalon.

The neurons of the basal plates form the motor nuclei of CNs V, VI, and VII. The neurons of the ventromedial part of each alar plate form the main sensory nucleus of CN V, a sensory nucleus of CN VII, and the vestibular and cochlear nuclei of CN VIII; they also form the **pontine nuclei**. The axons of the pontine nuclei grow transversely to enter the developing cerebellum of the opposite side, thus forming the **transverse pontine fibers** and the **middle cerebellar peduncle**.

Cerebellum (Posterior Part of Metencephalon)

The cerebellum is formed from the posterior part of the alar plates of the metencephalon. On each side, the alar plates bend medially to form the **rhombic lips** (Fig. 18-5). As alar plates enlarge, the lips project caudally over the roof plate of the fourth ventricle and unite with each other in the midline to form the cerebellum (Fig. 18-6; also see Fig. 18-5). At the 12th week, a small midline portion, the **vermis**, and two lateral portions, the **cerebellar hemispheres**, may be recognized. At about the end of the fourth month, fissures develop on the surface of the cerebellum, and the characteristic folia of the adult cerebellum gradually develop.

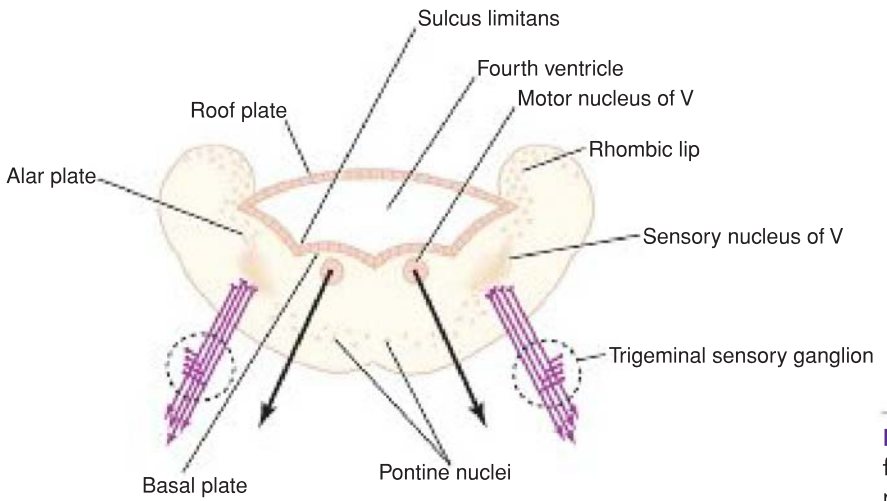

Figure 18-4 Development of the pons from the anterior part of the metencephalon.

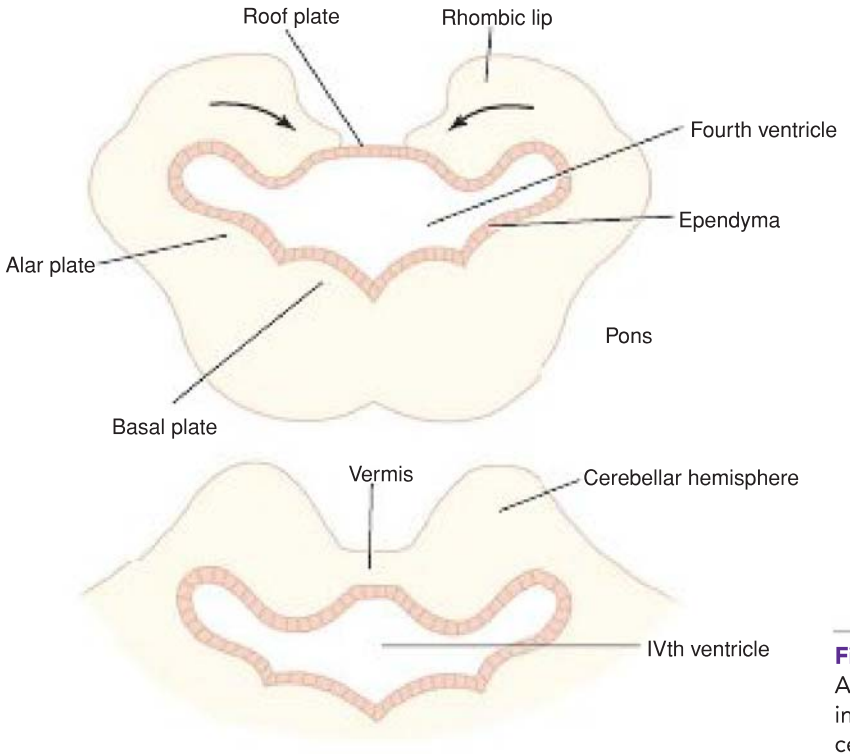

Figure 18-5 Development of the cerebellum. Also shown is the fusion of the rhombic lips in the midline to form the dumbbell-shaped cerebellum.

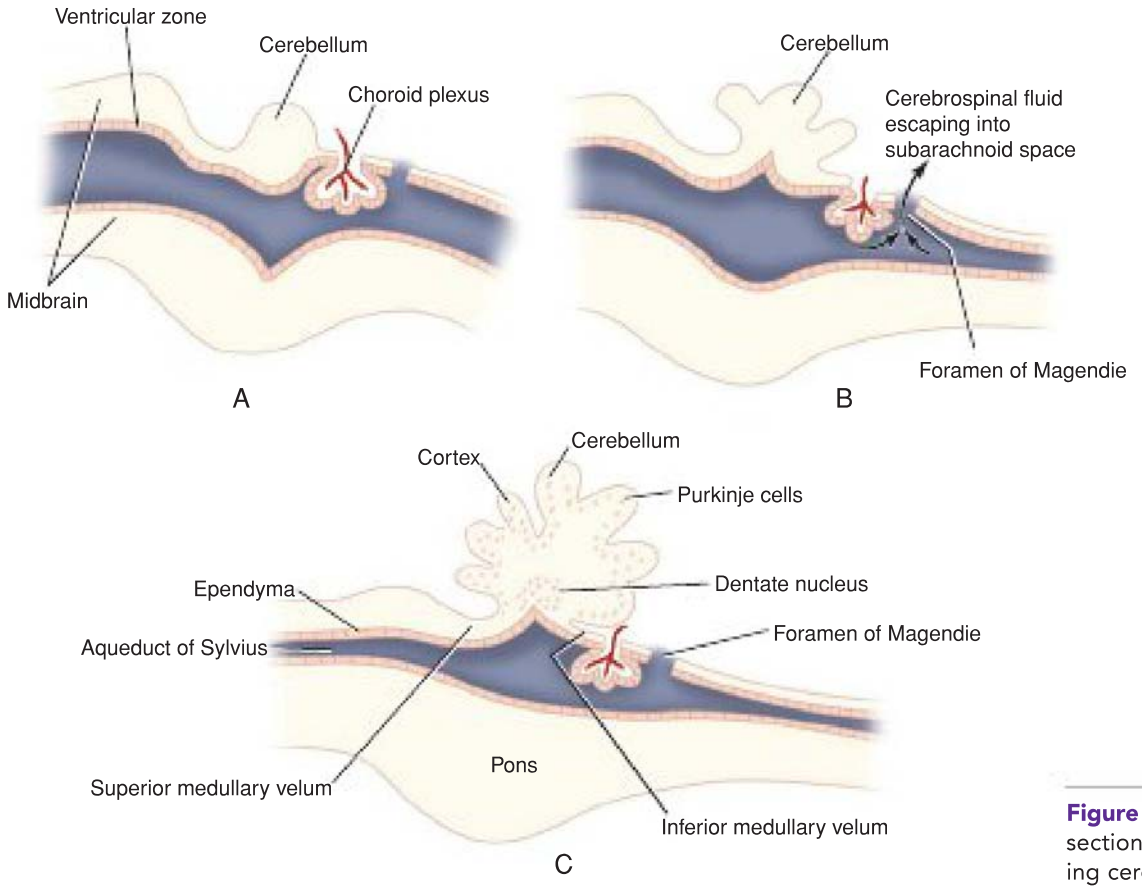

Figure 18-6 Sagittal sections of the developing cerebellum.

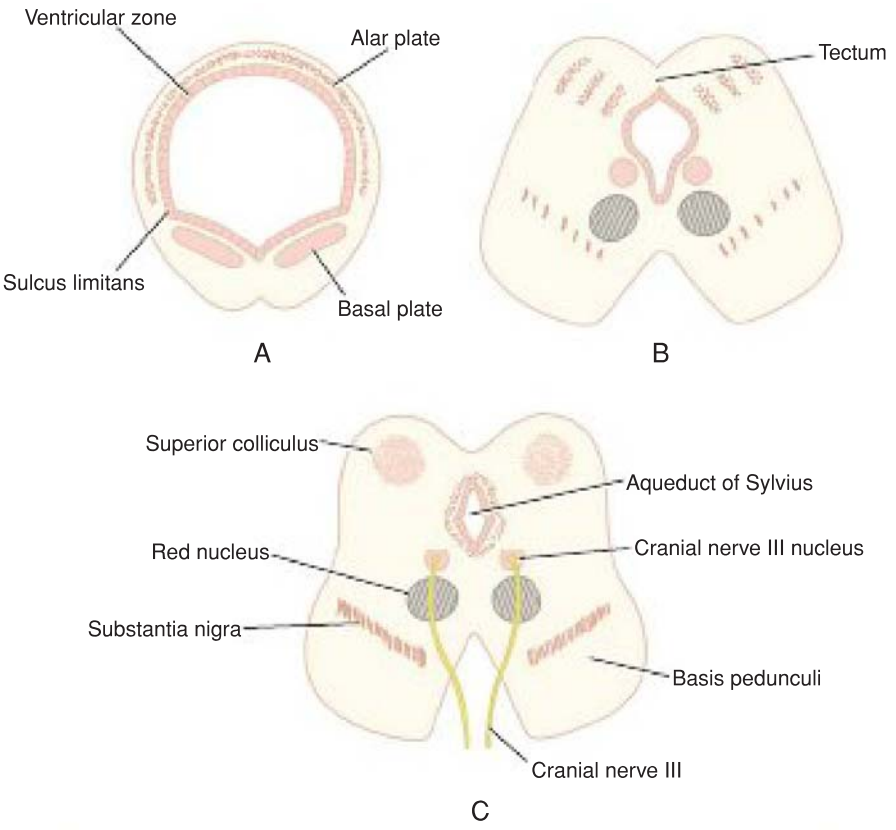

Figure 18-7 Successive stages in the development of the midbrain.

The neuroblasts derived from the matrix cells in the ventricular zone migrate toward the surface of the cerebellum and eventually give rise to the neurons forming the **cerebellar cortex**. Other neuroblasts remain close to the ventricular surface and differentiate into the **dentate** and other deep cerebellar nuclei. With further development, the axons of neurons forming these nuclei grow out into the mesencephalon (midbrain) to reach the forebrain, and these fibers will form the greater part of the superior cerebellar peduncle. Later, the growth of the axons of the pontocerebellar fibers and the corticopontine fibers will connect the cerebral cortex with the cerebellum, and so the middle cerebellar peduncle will be formed. The inferior cerebellar peduncle will be formed largely by the growth of sensory axons from the spinal cord, the vestibular nuclei, and olivary nuclei.

Midbrain (Mesencephalon)

The midbrain develops from the midbrain vesicle, the cavity of which becomes much reduced to form the **cerebral aqueduct** or **aqueduct of Sylvius** (Fig. 18-7). The sulcus limitans separates the alar plate from the basal plate on each side, as seen in the developing spinal cord. The neuroblasts in the basal plates will differentiate into the neurons forming the nuclei of **CNs III and IV** and possibly the **red nuclei**, the **substantia nigra**, and the **reticular formation**. The marginal zone of each basal plate enlarges considerably, thus forming the **basis pedunculi** by the descent of nerve fibers from the cerebral cortex to the lower motor centers in the pons and spinal cord—that is, the **corticopontine**, **corticobulbar**, and **corticospinal tracts**.

The two alar plates and the original roof plate form the **tectum.** The neuroblasts in the alar plates differentiate into the sensory neurons of the **superior** and **inferior colliculi**. Four swellings representing the four colliculi appear on the posterior surface of the midbrain. The superior colliculi are associated with visual reflexes, and the inferior colliculi are associated with auditory reflexes.

With further development, the fibers of CN IV emerge on the posterior surface of the midbrain and decussate completely in the superior medullary velum. The fibers of CN III emerge on the anterior surface between the cerebral peduncles.

Forebrain (Prosencephalon)

The forebrain develops from the forebrain vesicle. The roof and floor plates remain thin, whereas the lateral walls become thick, as in the developing spinal cord. At an early stage, a lateral diverticulum called the **optic vesicle** appears on each side of the forebrain. That part of the forebrain that lies rostral to the optic vesicle is the telencephalon, and the remainder is the diencephalon (Fig. 18-8). The optic vesicle and stalk ultimately will form the retina and optic nerve.

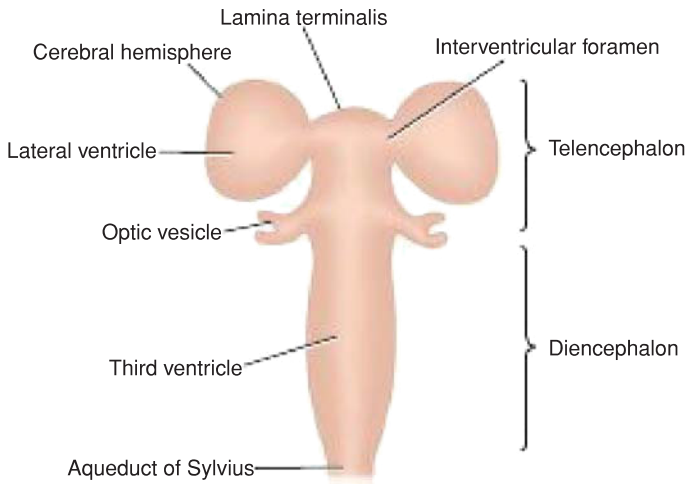

Figure 18-8 Division of the forebrain vesicle into the telencephalon and the diencephalon.

The telencephalon now develops a lateral diverticulum on each side of the cerebral hemisphere, and its cavity is known as the **lateral ventricle**. The anterior part of the third ventricle, therefore, is formed by the medial part of the telencephalon and ends at the **lamina terminalis**, which represents the rostral end of the neural tube. The opening into each lateral ventricle is the future **interventricular foramen**.

Diencephalon Fate

The cavity of the diencephalon forms the greater part of the third ventricle (see Fig. 18-8). Its roof shows a small diverticulum immediately anterior to the midbrain, which will form the **pineal body**. The remainder of the roof forms the **choroid plexus of the third ventricle** (Fig. 18-9). In the lateral wall of the third ventricle, the

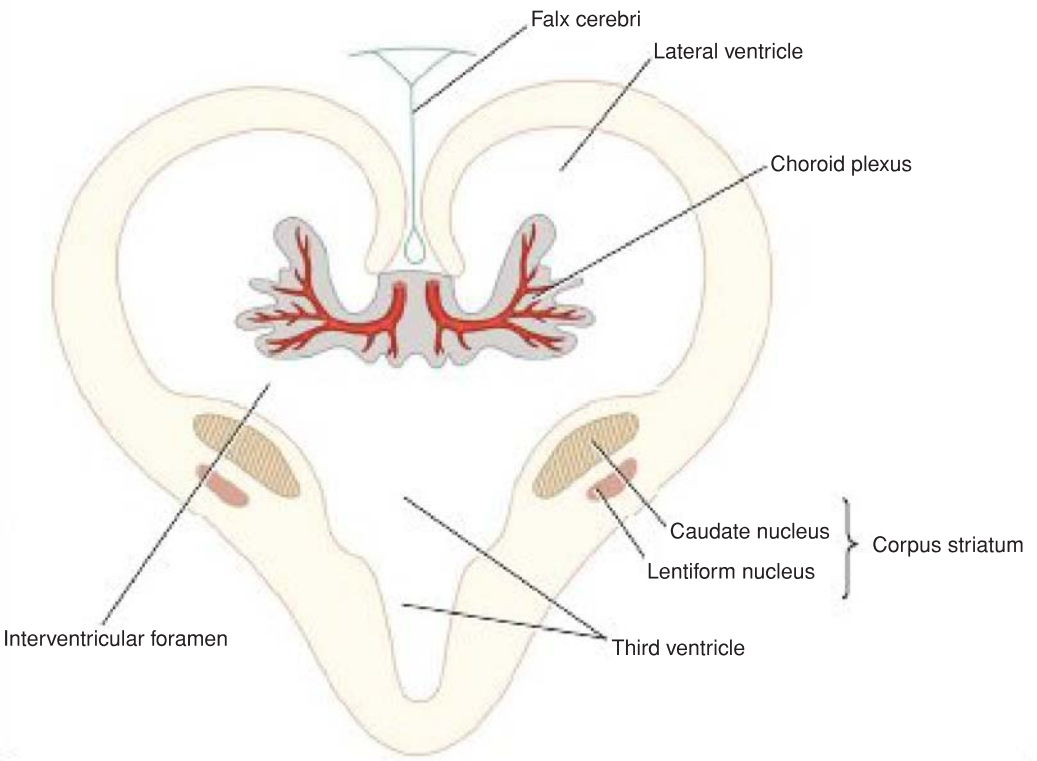

Figure 18-9 Diagrammatic representation of a coronal section of the cerebral hemispheres showing the developing choroid plexuses in the third and lateral ventricles.

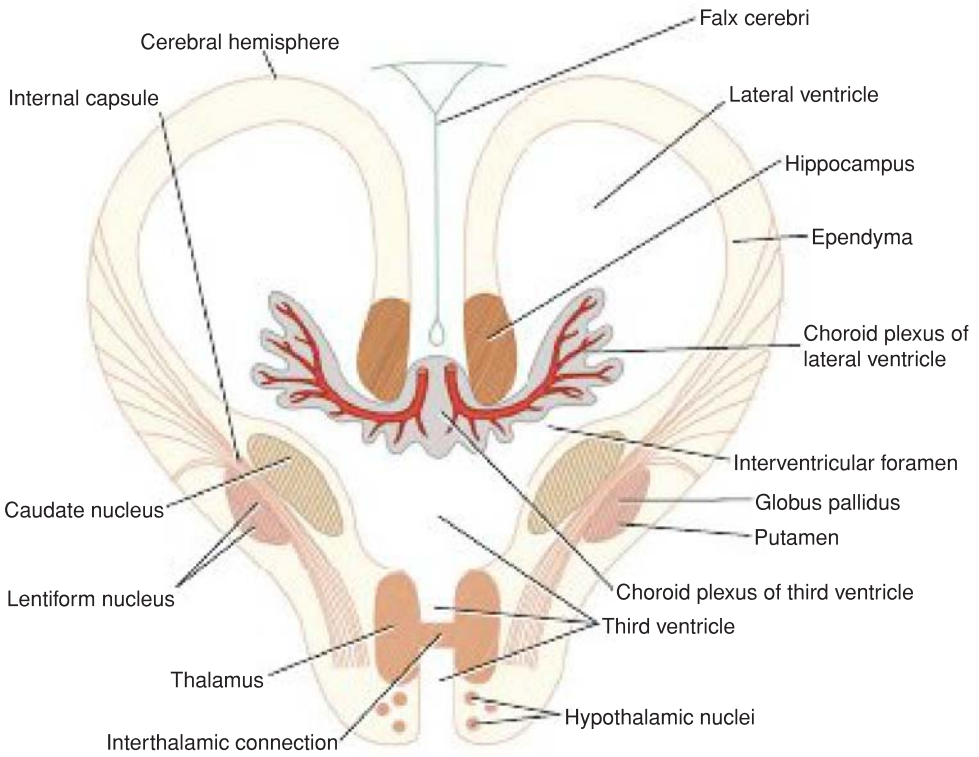

Figure 18-10 Diagrammatic representation of a coronal section of the cerebral hemispheres showing the choroid plexuses in the third and lateral ventricles. Also shown are the caudate and lentiform nuclei and the thalami. The ascending and descending nerve tracts can be seen passing between the masses of gray matter to form the internal capsule.

thalamus arises as a thickening of the alar plate on each side. Posterior to the thalamus, the **medial** and **lateral geniculate bodies** develop as solid buds. With the continued growth of the two thalami, the ventricular cavity becomes narrowed, and in some individuals, the two thalami may meet and fuse in the midline to form the **interthalamic connection** of gray matter that crosses the third ventricle (Fig. 18-10).

The lower part of the alar plate on each side will differentiate into a large number of **hypothalamic nuclei**. One of these becomes conspicuous on the inferior surface of the hypothalamus and forms a rounded swelling on each side of the midline called the **mammillary body**.

The **infundibulum** develops as a diverticulum from the floor of the diencephalon and from it will originate the **stalk** and **pars nervosa of the hypophysis**.

Telencephalon Fate

The telencephalon forms the anterior end of the third ventricle, which is closed by the lamina terminalis, while the diverticulum on either side forms the cerebral hemisphere.

Cerebral Hemispheres

Each cerebral hemisphere arises at the beginning of the fifth week of development. As it expands superiorly, its walls thicken, and the interventricular foramen becomes reduced in size (see Figs. 18-8 to 18-10). The mesenchyme between each cerebral hemisphere condenses to form the **falx cerebri**. As development proceeds, the cerebral hemispheres grow and expand rapidly, first anteriorly to form the **frontal lobes**, then laterally and superiorly to form the **parietal lobes**, and finally posteriorly and inferiorly to produce the **occipital** and **temporal lobes**. As the result of this great expansion, the hemispheres cover the midbrain and hindbrain (Fig. 18-11).

The medial wall of the cerebral hemisphere remains thin and is formed by the ependymal cells. This area becomes invaginated by vascular mesoderm, which forms the **choroid plexus of the lateral ventricle** (see Fig. 18-10). The occipital lobe of the cerebral hemisphere is separated from the cerebellum by mesenchyme, which condenses to form the **tentorium cerebelli**.

Meanwhile, the matrix cells lining the floor of the forebrain vesicle proliferate, producing large numbers of neuroblasts. These collectively form a projection that encroaches on the cavity of the lateral ventricle and is known as the **corpus striatum** (see Fig. 18-9). Later, this differentiates into two parts: (1) the dorsomedial portion, the **caudate nucleus**, and (2) a ventrolateral part, the **lentiform nucleus**. The latter becomes subdivided

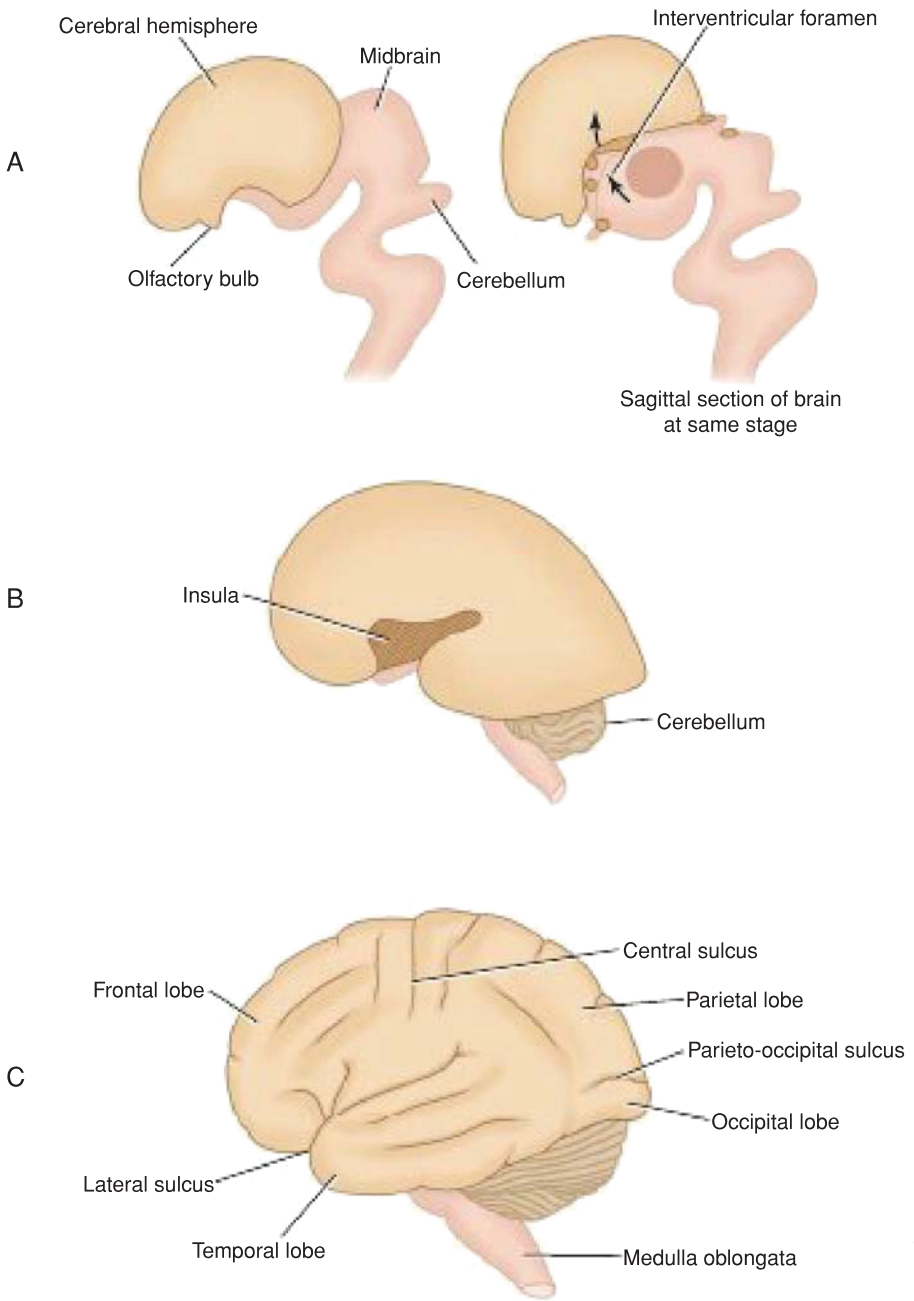

Figure 18-11 Successive stages in the development of the cerebral cortex.

into a lateral part, the **putamen**, and a medial part, the **globus pallidus** (see Fig. 18-10). As each hemisphere expands, its medial surface approaches the lateral surface of the diencephalon; thus, the caudate nucleus and thalamus come in close contact.

A further longitudinal thickening occurs in the wall of the forebrain vesicle, and the thickening protrudes into the lateral ventricle and forms the **hippocampus**.

While these various masses of gray matter are developing within each cerebral hemisphere, maturing neurons in different parts of the nervous system are sending axons either to or from the differentiating cortex. These axons form the large **ascending** and **descending tracts**, which, as they develop, are forced to pass between the thalamus and caudate nucleus medially and the lentiform nucleus laterally. The compact bundle of ascending and descending tracts is known as the **internal capsule**. The **external capsule** consists of a few cortical projection fibers that pass lateral to the lentiform nucleus.

Cerebral Cortex

As each cerebral hemisphere rapidly expands, the **convolutions** or **gyri** separated by **fissures** or **sulci** become evident on its surface. The cortex covering the lentiform nucleus remains as a fixed area called the **insula** (see Fig. 18-11B). Later, this region becomes buried in

the **lateral sulcus** as the result of overgrowth of the adjacent temporal, parietal, and frontal lobes.

The matrix cells lining the cavity of the cerebral hemisphere produce large numbers of neuroblasts and **neuroglial cells** that migrate out into the marginal zone. The remaining matrix cells ultimately will form the **ependyma**, which lines the lateral ventricle. In the 12th week, the cortex becomes very cellular because of the migration of large numbers of neuroblasts. At term, the neuroblasts have become differentiated and have assumed a stratified appearance as the result of the presence of incoming and outgoing fibers. Different areas of the cortex soon show specific cell types; thus, the motor cortex contains a large number of **pyramidal cells**, whereas the sensory areas are characterized mainly by **granular cells**.

Commissures

The **lamina terminalis**, which is the cephalic end of the neural tube, forms a bridge between the two cerebral hemispheres and enables nerve fibers to pass from one cerebral hemisphere to the other (see Fig. 18-8).

The **anterior commissure** is the first commissure to develop. It runs in the lamina terminalis and connects the olfactory bulb and the temporal lobe of the cortex on one side with the same structures of the opposite hemisphere.

The **fornix** is the second commissure to develop and connects the cortex of the hippocampus in each hemisphere.

The **corpus callosum**, the largest and most important commissure, is the third commissure to develop. Its first fibers connect the frontal lobes of both sides and, later, the parietal lobes. As the corpus callosum increases in size because of increased numbers of fibers, it arches back over the roof of the developing third ventricle. The remains of the lamina terminalis, which lie between the corpus callosum and the fornix, become stretched out to form a thin septum, the **septum pellucidum**. The **optic chiasma** is formed in the inferior part of the lamina terminalis; it contains fibers from the medial halves of the retinae, which cross the midline to join the optic tract of the opposite side and so pass to the **lateral geniculate body** and the **superior colliculus**.

Myelination in the Central Nervous System

The myelin sheath in the central nervous system is formed and maintained by the oligodendrocytes of the neuroglia (see p. 54).

Myelination in the spinal cord begins first in the cervical region, and from here, the process extends caudally. The process of myelination begins within the cord at about the fourth month, and the sensory fibers are affected first. The last affected are the descending motor fibers.

Myelination in the brain begins at about the sixth month of fetal life but is restricted to the fibers of the basal ganglia. Later, the sensory fibers passing up from the spinal cord myelinate, but the progress is slow; therefore, at birth, the brain still is largely unmyelinated. Newborns have very little cerebral function; motor reactions such as respiration, sucking, and swallowing are essentially reflex. After birth, the corticobulbar, corticospinal, tectospinal, and corticopontocerebellar fibers begin to myelinate. This process of myelination is not haphazard but systematic, occurring in different nerve fibers at specific times. The corticospinal fibers, for example, start to myelinate at about 6 months after birth, and the process is largely complete by the end of the second year. It is believed that some nerve fibers in the brain and spinal cord do not complete myelination until puberty.

Clinical Notes

Congenital Anomalies

Practically any part of the nervous system can show defects of development, and these produce a wide variety of clinical signs and symptoms. Only the common defects of the central nervous system are considered here. Spina bifida, hydrocephalus, and anencephaly each occur about 6 times/1,000 births and are therefore the more common congenital anomalies.

Spina Bifida

In spina bifida, the spines and arches of one or more adjacent vertebrae fail to develop (Fig. 18-12). The condition occurs most frequently in the lower thoracic, lumbar, and sacral regions. Beneath this defect, the meninges and spinal cord may or may not be involved in varying degrees. The condition is a result of failure of the mesenchyme, which grows in between the neural tube and the surface ectoderm, to form the vertebral arches in the affected region. The types of spina bifida are as follows:

1. **Spina bifida occulta.** The spines and arches of one or more vertebrae, usually in the lumbar region, are absent, and the vertebral canal remains open posteriorly. The spinal cord and nerve roots usually are normal. The defect is covered by the postvertebral muscles and cannot be seen from the surface. A small tuft of hair or a fatty tumor may be present over the defect. Most cases are symptomless and are diagnosed by chance when the vertebral column is x-rayed.
2. **Meningocele.** The meninges project through the defect in the vertebral arches, forming a cystic swelling beneath the skin and containing CSF, which communicates with the subarachnoid space (Fig. 18-13; also see Fig. 18-12). The spinal cord and nerves usually are normal.

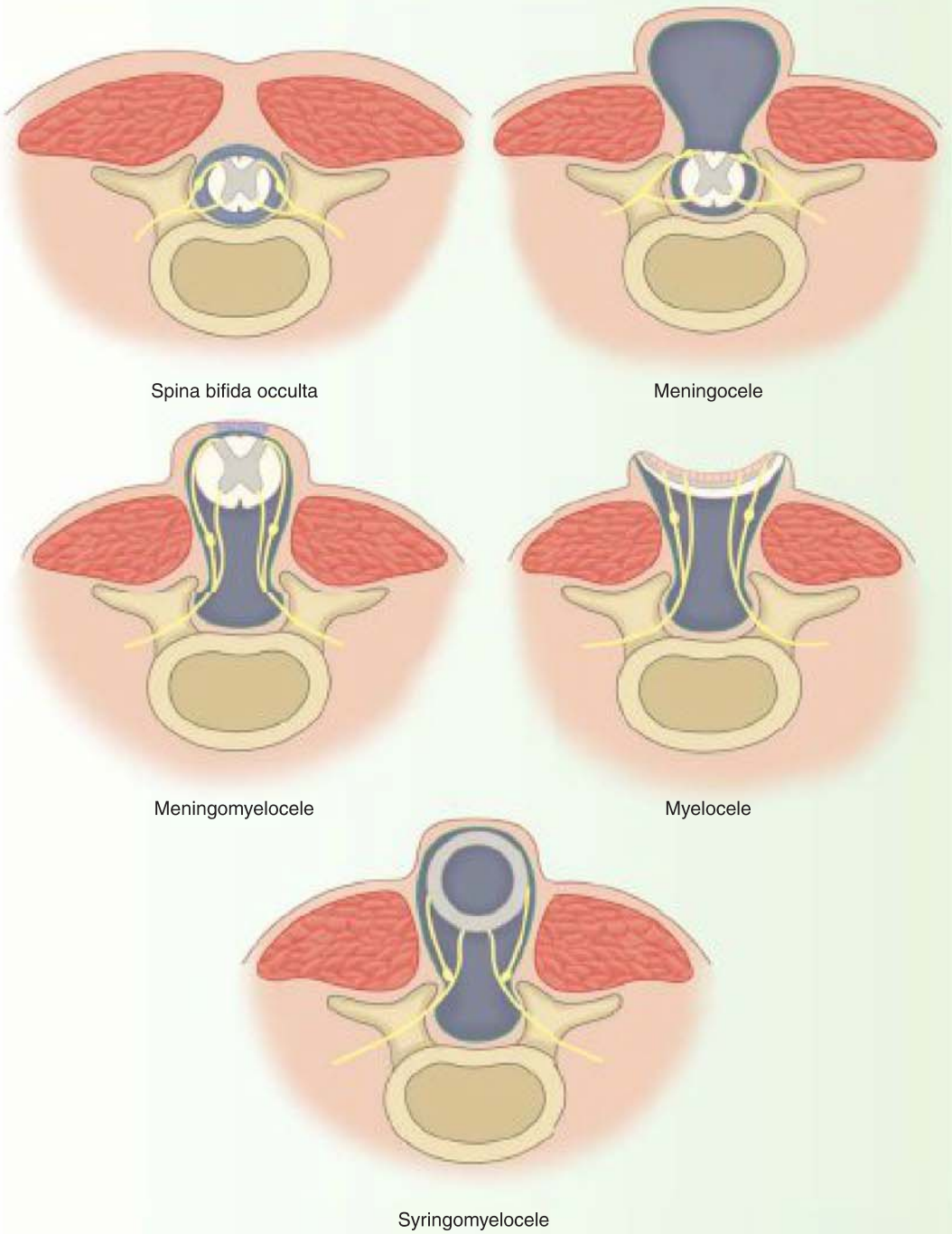

Figure 18-12 Different types of spina bifida.

3. **Meningomyelocele.** The normal spinal cord, or cauda equina, lies within the meningeal sac, which projects through the vertebral arch defect (see Fig. 18-12). The spinal cord or nerve roots are adherent to the inner wall of the sac.
4. **Myelocele.** The neural tube fails to close in the region of the defect. An oval raw area is found on the surface; this represents the neural groove whose lips are fused. The central canal discharges clear CSF onto the surface.
5. **Syringomyelocele.** This condition is rare. A meningomyelocele is present, and in addition, the central canal of the spinal cord at the level of the bony defect is grossly dilated.

Spina bifida occulta is the most common defect. The next most common defect is myelocele, and many afflicted infants are born dead. If the child is born alive, death from infection of the spinal cord may occur within a few days.

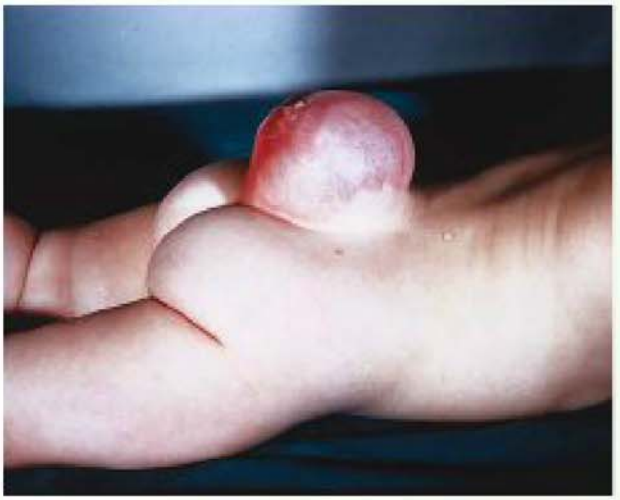

Figure 18-13 A meningocele in the lumbosacral region. (Courtesy Dr. L. Thompson.)

Most cases of spina bifida occulta require no treatment. A meningocele should be removed surgically within a few days of birth. Infants with meningomyelocele should also be treated surgically. The sac is opened, and the spinal cord or nerves are freed and carefully replaced in the vertebral canal. The meninges are sutured over the cord and the postvertebral muscles are approximated.

As the result of advances in medical and surgical care, many infants with the severe forms of spina bifida now survive. Unfortunately, these children are likely to have lifelong disabilities and psychosocial problems. The neurologic deficits alone may result in deformation of the limbs and spine and in bladder, bowel, and sexual dysfunction.

Hydrocephalus

Hydrocephalus is an abnormal increase in the volume of CSF within the skull. The condition may be associated with spina bifida and meningocele. Hydrocephalus alone may be caused by stenosis of the cerebral aqueduct or, more commonly, by the normal single channel being represented by many inadequate minute tubules. Another cause, which is progressive, is the overgrowth of neuroglia around the aqueduct. Inadequate development or failure of development of the interventricular foramen, or the foramina of Magendie and Luschka, may also be responsible.

In cases of hydrocephalus with spina bifida, the **Arnold–Chiari phenomenon** may occur. During development, the cephalic end of the spinal cord is fixed by virtue of the brain residing in the skull, and in the presence of spina bifida, the caudal end of the cord may also be fixed. The longitudinal growth of the vertebral column is more rapid and greater than that of the spinal cord, and this results in traction pulling the medulla and part of the cerebellum through the foramen magnum. This displacement of the hindbrain downward obstructs CSF flow through the foramina in the roof of the fourth ventricle.

Hydrocephalus may occur before birth and if it is advanced, it could obstruct labor. It usually is noticed during the first few months of life because of the enlarging head, which may attain a huge size, sometimes measuring more than 30 in in diameter (Fig. 18-14). The cranial sutures are widely separated, and the anterior fontanelle is much enlarged. The veins of the scalp are distended, and the eyes look downward. CN paralyses are common. The ventricles of the brain become markedly dilated. This ventricular expansion occurs largely at the expense of the white matter, and the neurons of the cerebral cortex are mostly spared. This results in the preservation of cerebral function, but the destruction of the tracts, especially the corticobulbar and corticospinal tracts, produces a progressive loss of motor function.

If the condition is diagnosed by sonography while the fetus is in utero, it is possible to perform prenatal surgery with the introduction of a catheter into the ventricles of the brain and CSF drainage into the amniotic cavity. Should the diagnosis be delayed until after birth, a drainage tube fitted with a nonreturn valve can connect the ventricles to the internal jugular vein in the neck.

Anencephaly

In anencephaly, the greater part of the brain and the vault of the skull are absent (Fig. 18-15). The anomaly is caused by the failure of the rostral end of the neural tube to develop and as a consequence, its cavity remains open. In place of the normal neural tissue are thin-walled vascular channels resembling the choroid plexus and masses of neural tissue. Although the eyes are present, the optic nerves are absent. The condition commonly involves the spinal cord, and the neural tube remains open in the cervical region. The condition is commonly diagnosed before birth with sonography or x-ray studies. Most anencephalic infants are stillborn or die shortly after birth.

Neural Defect Prevention

The development and closure of the neural tube are normally completed within 28 days. In practical terms, this means that neural tube defects have occurred before many women are aware that they are pregnant.

Extensive clinical research has demonstrated that environmental and genetic factors have a joint role in the

Figure 18-14 Hydrocephalus. Note the large size of the head. (Courtesy Dr. G. Avery.)

causation of neural tube defects. The increased risk of neural defects in the lower socioeconomic groups suggests that poor nutrition may also be an important factor. More recent clinical research has demonstrated that the risk of recurrent neural defects is significantly reduced among women who take 4,000 mg of **folic acid** daily compared with women who do not. Further studies have shown that a daily dose that is 10 times lower is effective in preventing the defect. These findings have stimulated much new research to identify the genetic and biochemical bases of neural tube defects.

Because as many as 50% of pregnancies in the United States are unplanned and since the neural tube closes before most women know that they are pregnant, physicians should strongly urge women capable of becoming pregnant to consume at least 400 mg of folic acid per day, preferably as a multivitamin supplement.

Embryonic Stem Cell Treatment of Neurologic Diseases

Freed et al. (2001) reported treating patients with severe Parkinson disease by transplanting precursors of dopamine nerve cells in fragments of mesencephalon isolated from human fetuses 7 to 8 weeks after conception. The results showed that the transplants survived and produced some clinical benefit in younger but not in older patients. It was demonstrated that the cells survived and differentiated, as demonstrated by positron emission tomography or by histologic examination (see Fig. 10-9). In view of the large numbers of patients with Parkinson disease worldwide, it is unlikely that transplantation of embryonic fragments would be a practical therapy.

Embryonic stem cells have the unique property of being able to produce all adult cell types, including those of the nervous system. The successful transplantation of embryonic stem cells has been achieved in animal models of Parkinson disease, motor neuron disease, and spinal cord injury. The great promise of these results has stimulated the imagination of scientists and patients. The use of cell lines derived from human embryonic stem cells, however, poses profound ethical questions.

Embryonic stem cells are derived from the inner cell mass of the blastocyst, the stage at which the developing embryo is implanted into the uterus. Human embryonic stem cells were first successfully harvested by Thomson et al. in 1998. The isolated inner cell mass cells were then cultured in the laboratory. Although substantial advances have been made in this field, enormous efforts must now be devoted to this subject so that we can improve the health of patients with chronic debilitating neurologic diseases.

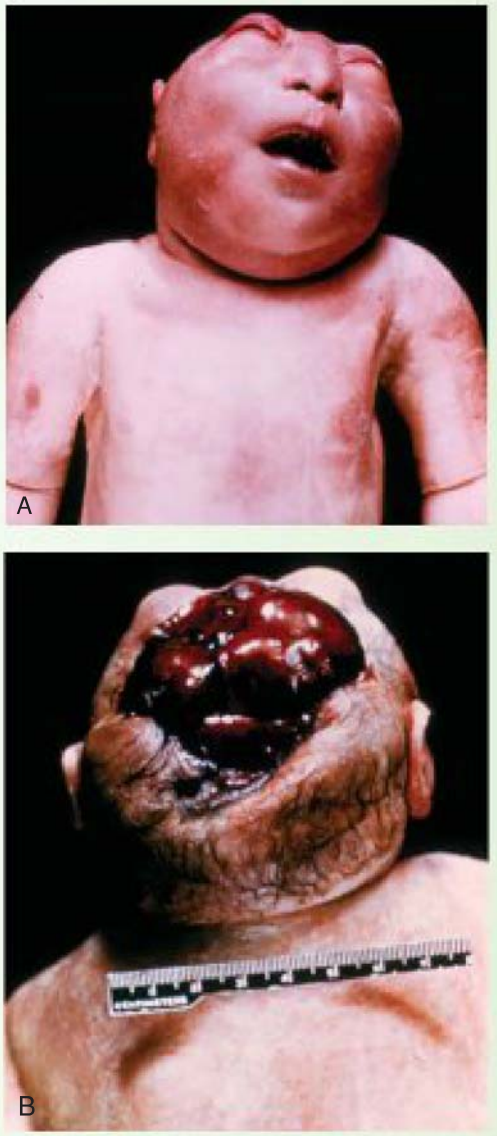

Figure 18-15 Example of anencephaly. Note that the greater part of the brain and the vault of the skull are absent. In the posterior view, the remainder of the brain is exposed. (Courtesy Dr. M. Platt.)

Key Concepts

Spinal Cord

- In early development, the neural tube dilates at the cephalic end to form the forebrain, midbrain, and hindbrain vesicles. The rest of the tube elongates to form the spinal cord.
- Matrix cells in the epithelial walls of the neural tube are referred to as the ventricular zone. Repeated divisions of the matrix cells result in increased length and diameter of the neural tube.
- Eventually, neuroblasts are formed and migrate to the intermediate zone to form the gray matter of the spinal cord.
- The cells of the intermediate zone grow fibers that extend and form a layer external to the intermediate zone, called the marginal zone. These fibers become myelinated and form the white matter of the spinal cord.
- Matrix cells will also give rise to astrocytes and oligodendrocytes. Microglial cells migrate in from the mesenchyme.
- The layers of the meninges are formed from the mesenchyme that surrounds the neural tube.

Brain

- Once the neural tube closes, the three primary vesicles complete their development.
- The forebrain vesicle forms the telencephalon, which matures into the cerebral hemisphere, basal ganglia, and hippocampus; and the diencephalon, which becomes the thalamus, hypothalamus, pineal body, and infundibulum.
- The midbrain vesicle forms the tectum, tegmentum, and crus cerebri components of the midbrain.
- The hindbrain vesicle forms the metencephalon, which includes the pons and cerebellum, and the myelencephalon, which includes the medulla oblongata.

Clinical Problem Solving

1. A 10-year-old boy fell off his bicycle and hurt his back. Following a complete physical examination in the emergency department, nothing abnormal is found. An x-ray examination, however, reveals the complete absence of the spine and laminae of the fifth lumbar vertebra. How do you explain the presence of the bony defect?
2. A male child is delivered normally to a 20-year-old woman. A pediatrician examines the infant and finds a large swelling in the lower part of his back over the fourth and fifth lumbar vertebrae. On closer examination, the summit of the swelling has an oval raw area from which a clear fluid is discharging. The legs show hyperextension of the knees, and the feet are held in the position of talipes calcaneus. What is the diagnosis? How do you explain the congenital defect on the back?
3. A 2-month-old girl is taken to a pediatrician because her mother is concerned about the size of her head. "She looks top-heavy," she says. Examination shows the head to be large and globular in shape. The anterior fontanelle is greatly enlarged and extends posteriorly to the enlarged posterior fontanelle. The enlarged head contrasts markedly with the small face. Neurologic examination reveals some evidence of optic atrophy on both sides, and tone is increased in the muscles of both lower limbs. What is the diagnosis? How do you explain this congenital anomaly? What is the prognosis if the patient is left untreated?

Answers and Explanations to Clinical Problem Solving

1. This patient has spina bifida occulta involving the fifth lumbar vertebra. The condition is a result of failure of the mesenchyme to grow between the neural tube and the surface ectoderm and form the vertebral arch; the vertebral canal remains open posteriorly. The defect, therefore, has existed since before birth and could not be seen or felt on physical examination because it was covered by the postvertebral muscles. The spinal cord and spinal nerve roots usually are normal. No treatment is required.
2. This child has a myelocele. In addition to the failure of the formation of the vertebral arches of the fourth and fifth lumbar vertebrae, the neural tube failed to close in this region. The oval raw area seen in this patient is the neural groove whose lips have not united. The central canal is discharging clear cerebrospinal fluid onto the skin surface. The deformities of the knee joints and feet are the result of the maldevelopment of the spinal cord in the lumbar region, with consequent interference with the innervation of certain muscle groups in the legs.
3. This child has hydrocephalus. A postmortem examination performed 1 year later showed that the cerebral aqueduct was not normally developed and consisted of a number of small tubules. This had resulted in the excessive accumulation of cerebrospinal fluid within the lateral and third ventricles of the brain. The distention of the ventricles, with the consequent enlargement of the brain and increased intracranial pressure, forced apart the bones of the cranial vault so that the head became greatly enlarged. The optic atrophy probably was caused by the stretching of the optic nerve on each side. The increased muscle tone of the lower limbs was almost certainly the result of destruction of the corticospinal and other descending tracts by the expanding lateral ventricles. Although in some cases the head ceases to enlarge spontaneously, in most patients the hydrocephalus is progressive, and death ultimately occurs. Surgical treatment of hydrocephalus may be attempted.

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 neural tube:
   (a) It is lined by stratified squamous cells.
   (b) The neuroblasts migrate medially to form the intermediate zone.
   (c) The repeated division of the matrix cells does not increase the length and diameter of the tube.
   (d) The ventricular zone will form the gray matter of the spinal cord.
   (e) The nerve fibers in the marginal zone become myelinated and form the white matter of the spinal cord.
2. The following statements concern the neural crest cells:
   (a) They are formed from the medial margin of the neural plate.
   (b) They give rise to the posterior root ganglia.
   (c) They do not form the neurons of the autonomic ganglia.
   (d) The Schwann cells of peripheral nerves are not formed from neural crest cells.
   (e) They form the cells of the suprarenal cortex.
3. The following statements concern the developing spinal cord:
   (a) The alar plates form the neurons in the anterior gray columns.
   (b) The nerve cells of the sympathetic outflow are not formed from the basal plates.
   (c) In the adult, the lower end of the spinal cord lies at the level of the lower border of the first lumbar vertebra.
   (d) At birth, the lower end of the spinal cord lies at the level of the third sacral vertebra.
   (e) The meninges surrounding the spinal cord are developed from the endoderm.
4. The following statements concern the development of the brainstem:
   (a) The cerebellum is formed from the dorsal part of the alar plates of the metencephalon.
   (b) The neurons of the deep cerebellar nuclei are derived from the matrix cells lining the cavity of the midbrain vesicle.
   (c) The neuroblasts in the dorsal plates will form the nuclei of the trochlear and oculomotor nerves.
   (d) The neuroblasts of the superior and inferior colliculi are also formed from the neurocytes in the basal plates.
   (e) The pons arises from the alar part of the metencephalon with cellular contributions from the alar part of the myelencephalon.

5. The following statements concern the fate of the forebrain vesicle:
   (a) The optic vesicle grows out of the midbrain vesicle.
   (b) The thalamus is formed from the alar plates in the medial walls of the diencephalon.
   (c) The lamina terminalis is formed from the rostral end of the diencephalon.
   (d) The pars nervosa of the hypophysis is formed from the floor of the diencephalon.
   (e) The hypothalamic nuclei are formed from the basal plates of the diencephalon.
6. The following statements concern the development of the cerebral hemispheres:
   (a) The corpus striatum is formed from the proliferation of the matrix cells lining the roof of the forebrain vesicle.
   (b) The interventricular foramen is formed by the cavity of the diencephalon.
   (c) The choroid plexus of the lateral ventricle is formed by vascular ectoderm covered by ependymal cells.
   (d) The internal capsule is formed by the developing ascending and descending tracts growing between the developing thalamus and caudate nucleus medially and the lentiform nucleus laterally.
   (e) The cortical neurons develop in situ and do not migrate out laterally from the matrix cells lining the cavity of the cerebral hemisphere.
7. The following statements concern the development of myelination in the brain:
   (a) Myelination begins at birth.
   (b) The sensory fibers are myelinated last.
   (c) The process of myelination is haphazard.
   (d) Myelination of the nerve tracts is largely complete by the fourth year of life.
   (e) Myelination is carried out by oligodendrocytes and not by neurons.
8. The following statements concern the condition of spina bifida:
   (a) It is one of the more common congenital anomalies of the central nervous system.
   (b) The most common form of spina bifida is syringomyelocele.
   (c) The condition occurs most often in the cervical and upper thoracic regions.
   (d) In a myelocele, the neural tube closes in the region of the defect.
   (e) Most cases of spina bifida occulta require explorative surgery.

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

A 6-month-old girl was seen by the plastic surgeon because of the presence of a swelling at the root of the nose. The mother said that she had noticed the swelling when the child was born and that since then, it had gradually increased in size.

9. The surgeon examined the child and found the following likely signs except:
   (a) The swelling was situated at the root of the nose in the midline.
   (b) The swelling was located between the frontal and nasal bones.
   (c) The swelling was fluctuant and, on gentle pressure, could be reduced in size.
   (d) The swelling was pulsatile, and the pulse coincided with the heart rate.
   (e) The pulse did not coincide with the pulse felt over the anterior fontanelle of the skull.
10. The neurosurgeon was consulted, and the following possible additional findings were ascertained except:
   (a) A lateral radiograph of the skull revealed a defect in the membranous bones involving the nasal process of the frontal bone.
   (b) The defect in the membranous bones is known as cranioschisis.
   (c) The condition was associated with a cephalic meningocele.
   (d) There was a herniation of the meninges through the defect in the skull.
   (e) Brain tissue is never found within the hernia.

Answers and Explanations to Review Questions

1. E is correct. The nerve fibers in the marginal zone of the developing neural tube become myelinated and form the white matter of the spinal cord. A. The wall of the neural tube is formed of a single layer of pseudostratified columnar epithelial cells (see Fig. 18-1). B. The neuroblasts migrate peripherally to form the intermediate zone (see Fig. 18-1). C. The repeated division of the matrix cells of the neural tube results in an increase in the length and diameter of the tube. D. The intermediate zone of the neural tube will form the gray matter of the spinal cord.
2. B is correct. The neural crest cells give rise to the posterior root ganglia (see Fig. 1-18). A. The neural crest cells are formed from the lateral margin of the neural plate (see Fig. 1-18). C. The neural crest cells form the neurons of the autonomic ganglia (see Fig. 1-18). D. The Schwann cells of peripheral nerves are formed from neural crest cells (see Fig. 1-18). E. The neural crest cells form the cells of the suprarenal medulla (see Fig. 1-18).
3. C is correct. In the adult, the lower end of the spinal cord lies at the level of the lower border of the first lumbar vertebra. A. The alar plates form the neurons in the posterior gray columns. B. The nerve cells of the sympathetic outflow are formed from the basal plates. D. At birth, the lower end of

the spinal cord lies at the level of the third lumbar vertebra. E. The meninges of the spinal cord are developed from the mesenchyme that surrounds the neural tube.

4. A is correct. The cerebellum is formed from the dorsal part of the alar plates of the metencephalon (see Fig. 18-6). B. The neurons of the deep cerebellar nuclei are derived from the matrix cells lining the cavity of the hindbrain vesicle. C. The neuroblasts in the basal plates will form the nuclei of the trochlear and oculomotor nerves. D. The neuroblasts of the superior and inferior colliculi are formed from the neurocytes in the alar plates (see Fig. 18-8). E. The pons arises from the anterior part of the metencephalon, with cellular contributions from the alar part of the myelencephalon.
5. D is correct. The pars nervosa of the hypophysis cerebri is formed from the floor of the diencephalon. A. The optic vesicle grows out of the forebrain vesicle (see Fig. 18-3). B. The thalamus is formed from the alar plates in the lateral walls of the diencephalon (see Fig. 18-10). C. The lamina terminalis is formed from the rostral end of the telencephalon. E. The hypothalamic nuclei are formed from the alar plates of the diencephalon.
6. D is correct. The internal capsule is formed by the developing ascending and descending tracts growing between the developing thalamus and caudate nucleus medially and the lentiform nucleus laterally (see Fig. 18-11). A. The corpus striatum is formed from the proliferation of the matrix cells lining the floor of the forebrain vesicle. B. The interventricular foramen is formed by the cavity of the telencephalon (see Fig. 18-11). C. The choroid plexus of the lateral ventricle is formed by vascular mesenchyme covered by ependymal cells. E. The neurons of the cerebral cortex develop from matrix cells lining the cavity of the cerebral hemisphere. These cells produce large numbers of neuroblasts that migrate out into the marginal zone.
7. E is correct. In the developing brain, myelination is carried out by oligodendrocytes and not by neurons. A. In the developing brain, myelination begins at about the sixth month of fetal life. B. In the developing brain, the sensory fibers are myelinated first. C. Myelination of the nerve tracts is not haphazard but systematic, occurring in different nerve fibers at specific times. D. Myelination of the nerve tracts is largely complete by the end of the second year.
8. A is correct. Spina bifida is one of the more common congenital anomalies of the central nervous system. B. The most common form of spina bifida is spina bifida occulta (see Fig. 18-13). C. Spina bifida occurs most often in the lower thoracic, lumbar, and sacral regions. D. In a myelocele, the neural tube fails to close in the region of the defect (see Fig. 18-13). E. Most cases of spina bifida occulta require no treatment.
9. E is the exception. In a cephalic meningocele, the cerebrospinal fluid (CSF) within the swelling is in direct communication with that in the subarachnoid space. The pulsation of the swelling is produced by the pulse wave of the cerebral arteries through the CSF. This pulse wave will coincide with the pulse felt over the anterior fontanelle of the skull.
10. E is the exception. Cranioschisis is characterized by a defect in the membranous bones of the skull through which meninges, or meninges and neural tissue may protrude. The defect usually occurs in the midline in the occipital region or between the frontal and nasal bones. The condition is probably the result of anomalous formation and separation of the neural tube from the surface ectoderm of the embryo.

Appendix

NEUROANATOMICAL DATA OF CLINICAL SIGNIFICANCE AND CLINICAL NEUROANATOMY TECHNIQUES

Baseline of the Skull

The baseline of the skull extends from the lower margin of the orbit backward through the upper margin of the external auditory meatus. The **cerebrum** lies entirely above the line, and the **cerebellum** lies in the posterior cranial fossa below the posterior third of the line (Fig. A-1).

Falx Cerebri, Superior Sagittal Sinus, and the Longitudinal Cerebral Fissure Between the Cerebral Hemispheres

The position of the falx cerebri, superior sagittal sinus, and the longitudinal cerebral fissure between the cerebral hemispheres can be indicated by passing a line over the vertex of the skull in the sagittal plane that joins the root of the nose to the external occipital protuberance.

Parietal Eminence

The parietal eminence is a raised area on the lateral surface of the parietal bone that can be felt about 2 in (5 cm) above the auricle. It lies close to the lower end of the **central cerebral sulcus of the brain**.

Pterion

The pterion is the point where the greater wing of the sphenoid bone meets the anteroinferior angle of the parietal bone. Lying 1½ in (4 cm) above the midpoint of the zygomatic arch, it is not marked by an eminence or a depression, but it is important since the **anterior branches of the middle meningeal artery and vein lie beneath it**.

Intracranial Hematoma Treatment

Cranial decompression is performed in a patient with a history of progressive neurologic deterioration and signs of brain herniation, despite adequate medical treatment. The presence of a hematoma should be confirmed by a computed tomography scan, if possible.

Temporal Burr Hole

1. The patient is placed in a supine position with the head rotated so that the side for the burr hole is uppermost. For example, in a patient with a right-sided fixed and dilated pupil, indicating herniation of the right uncus with pressure on the right oculomotor nerve, a hematoma on the right side must be presumed, and a burr hole is placed on the right side.
2. The temporal skin is shaved and prepared for surgery in the usual way.
3. A 3-cm vertical skin incision is made two fingerbreadths anterior to the tragus of the ear and three fingerbreadths above this level (Fig. A-2A).
4. The following structures are then incised:
   a. Skin.
   b. Superficial fascia containing small branches of the superficial temporal artery.
   c. Deep fascia covering the outer surface of the temporalis muscle.
   d. The temporalis muscle is then incised vertically down to the periosteum of the squamous part of the temporal bone.
   e. The temporalis muscle is elevated from its attachment to the skull, and a retractor is positioned (some muscular bleeding will be encountered).
   f. A small hole is then drilled through the outer and inner tables of the skull at right angles to the skull surface, and the hole is enlarged with a burr (unless a blood clot is present between the inner table and the endosteal layer of dura).
   g. The white meningeal layer of dura is flexible and slightly compresses with gentle pressure.
   h. The hole may be enlarged with a curette, and bleeding from the diploe may be controlled with bone wax.

The surgical wound is closed in layers with interrupted sutures placed in the temporalis muscle, the deep fascia covering the temporalis muscle, and the scalp.

Epidural Hematoma Burr Hole

Once the inner table of the squamous part of the temporal bone (or the anterior inferior angle of the parietal bone) is pierced with a small bit and enlarged with a burr, the dark red clotted blood beneath the endosteal layer of dura is usually easily recognized. However, bright red liquid blood means that the middle meningeal artery or one of its branches is bleeding. The meningeal artery is located deep to the clot and between the endosteal layer of dura and the meningeal layer of dura or in the substance of the endosteal layer of dura; or it may lie in a tunnel of bone.

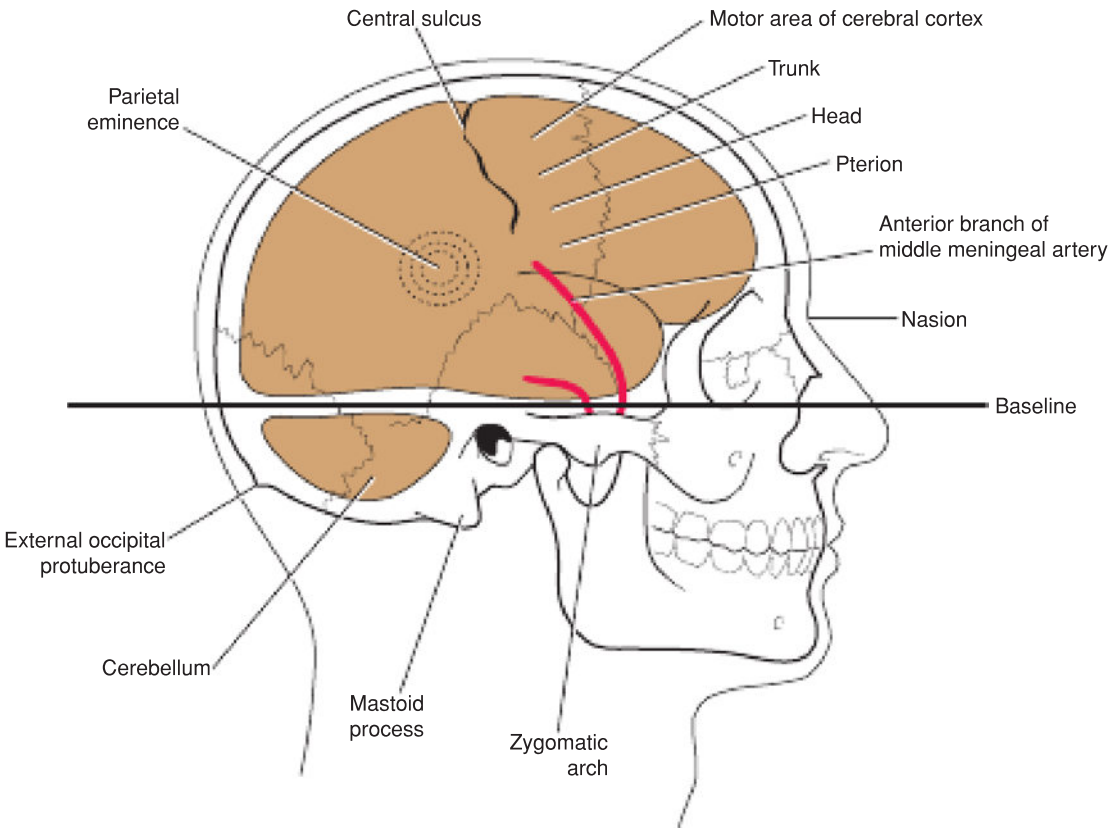

Figure A-1 Surface landmarks on the right side of the head. The relation of the middle meningeal artery and the brain to the surface of the skull is shown.

Subdural Hematoma Burr Hole

When the squamous part of the temporal bone is penetrated, as described earlier, the endosteal layer of dura will be exposed. In this case, there is no blood clot between the endosteal layer of dura and the meningeal layer of dura, but both fused layers of dura will be dark bluish. The dura (endosteal and meningeal layers) is gently incised to enter the space between the meningeal layer of dura and the arachnoid mater. The subdural blood usually gushes out, leaving the unprotected brain covered only by arachnoid and pia mater in the depths of the hole.

Ventriculostomy

Ventriculostomy is indicated in acute hydrocephalus, in which cerebrospinal fluid flow is suddenly obstructed.

Anatomy of the Technique

To perform a ventriculostomy, the needle is inserted into the lateral ventricle through either a frontal or parietal burr hole. The anatomy of these burr holes has been described previously. The needle is inserted through the burr hole using the following anatomical landmarks.

1. **Frontal Approach.** The needle is inserted through the frontal burr hole and is directed downward and forward in the direction of the inner canthus of the ipsilateral eye (Fig. A-3).
2. **Parietal Approach.** The needle is inserted through the parietal burr hole and is directed downward and forward in the direction of the pupil of the ipsilateral eye.

The needle is inserted to a depth of about 2 in (5.5 cm) from the skull opening; in cases of chronic hydrocephalus with gross dilatation of the ventricles, the depth of penetration to the ventricular cavity may be much less.

Vertebral Numbers and Spinal Cord Segments

Table A-1 relates which vertebral body is related to a particular spinal cord segment.

Segmental Innervation of Muscles

Test for the integrity of the segmental innervation of muscles by performing the following simple muscle reflexes.

Biceps brachii tendon reflex C5–C6 (flexion of the elbow joint by tapping the biceps tendon).
Triceps tendon reflex C6–C7 and C8 (extension of the elbow joint by tapping the triceps tendon).
Brachioradialis tendon reflex C5–C6 and C7 (supination of the radioulnar joints by tapping the insertion of the brachioradialis tendon).
Abdominal superficial reflexes (contraction of underlying abdominal muscles by stroking the skin). Upper

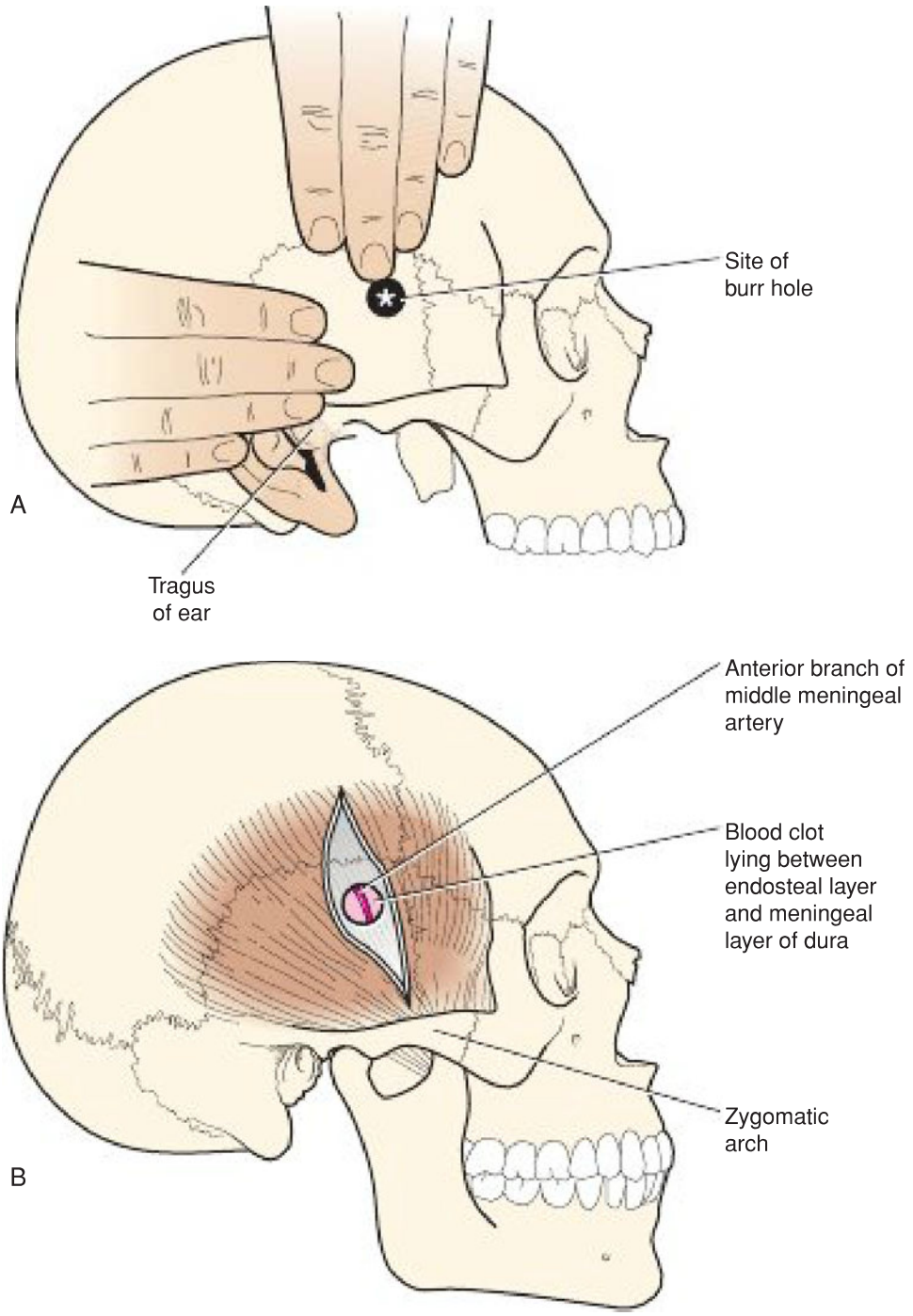

Figure A-2 **A:** Surface landmarks for a temporal burr hole. **B:** The vertical incision passes through the temporalis muscle down to bone. The middle meningeal artery lies between the endosteal and meningeal layers of dura and is embedded in the endosteal layer of dura or lies in a bony tunnel.

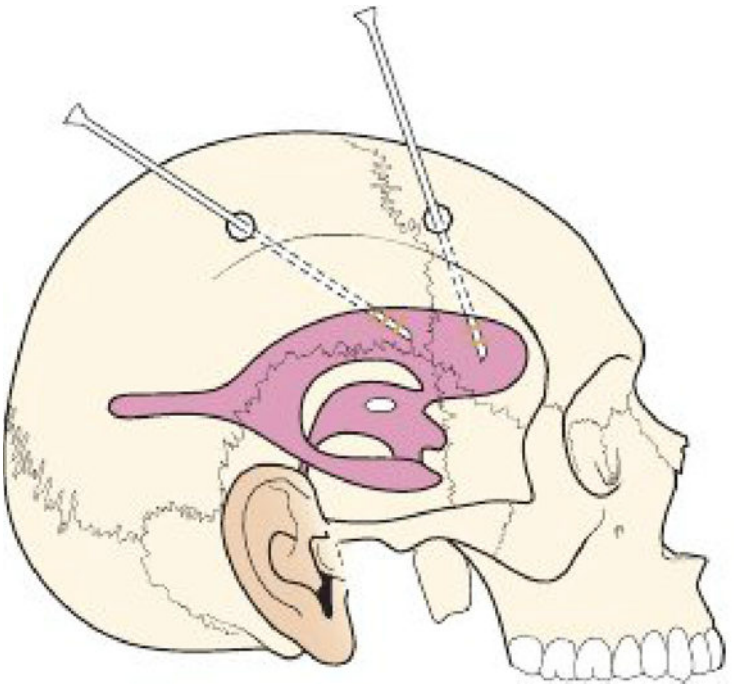

Figure A-3 Ventriculostomy. Needles passing through frontal or parietal burr holes to enter the lateral ventricle area are shown. The needle is inserted to a depth of about 2 in (5.5 cm) from the skull opening in order to enter the lateral ventricle.

abdominal skin T6–T7; middle abdominal skin T8–T9; lower abdominal skin T10–T12.

Patellar tendon reflex (knee jerk) L2, L3, and L4 (extension of knee joint on tapping the patellar tendon).

Achilles tendon reflex (ankle jerk) S1 and S2 (plantar flexion of ankle joint on tapping the Achilles tendon—tendo calcaneus).

Relationship Between Possible Intervertebral Disc Herniations and Spinal Nerve Roots

These are shown for the cervical and lumbar regions in Figure A-4.

A correlation between the nerve roots involved, the pain dermatome, the muscle weakness, and the missing or diminished reflex is shown in Table A-2.

Table A-1 Correlation of Vertebral Body With Spinal Cord Segment

Vertebra(e)	Spinal Segment(s)
Cervical vertebrae	Add 1
Upper thoracic vertebrae	Add 2
Lower thoracic vertebrae (7–9)	Add 3
Tenth thoracic vertebra	L1–L2 cord segments
Eleventh thoracic vertebra	L3–L4 cord segments
Twelfth thoracic vertebra	L5 cord segment
First lumbar vertebra	Sacral and coccygeal cord segments

Surface Landmarks for Performing a Lumbar Puncture

To perform a lumbar puncture, the patient is placed in the lateral prone position or in the upright sitting position. The trunk is then bent well forward to open up to the maximum, the space between adjoining laminae in the lumbar region. A groove runs down the middle of the back over the tips of the spines of the thoracic and the upper four lumbar vertebrae. The spines are made more prominent when the vertebral column is flexed. An imaginary line joining the highest points on the iliac crests passes over the fourth lumbar spine. With a careful aseptic technique and under local anesthesia, the spinal tap needle—fitted with a stylet—is passed into the vertebral canal above or below the fourth lumbar spine.

The following structures are pierced by the needle before it enters the subarachnoid space (Fig. A-5):

1. Skin
2. Superficial fascia
3. Supraspinous ligament
4. Interspinous ligament
5. Ligamentum flavum
6. Areolar tissue containing the internal vertebral venous plexus in the epidural space
7. Dura mater
8. Arachnoid mater

The **depth** to which the needle will have to pass will vary from an inch or less in children to as much as 4 in (10 cm) in obese adults.

The **pressure** of the cerebrospinal fluid in the lateral recumbent position is normally about 60 to 150 mm of water.

See Table 16-1 for physical characteristics and composition of the cerebrospinal fluid.

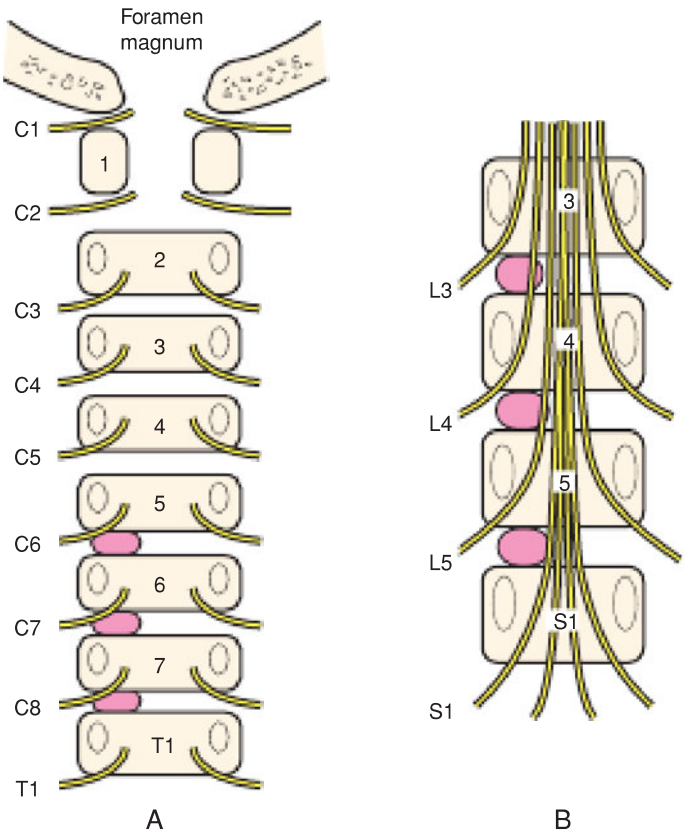

Figure A-4 **A,B:** Posterior views of vertebral bodies in the cervical and lumbar regions showing the relationship that might exist between herniated nucleus pulposus (pink) and spinal nerve roots. Note that there are eight cervical nerves and only seven cervical vertebrae. In the lumbar region, for example, the emerging L4 nerve roots pass out laterally close to the pedicles of the fourth lumbar vertebra and are not related to the intervertebral disc between the fourth and the fifth lumbar vertebrae. Pressure on the L5 motor nerve root produces weakness of plantar flexion of the ankle joint.

Table A-2 Correlation Between Nerve Roots, Pain Dermatome, Muscle Weakness, and Missing or Diminished Reflex

Root Injury	Dermatome Pain	Muscles Supplied	Movement Weakness	Reflex Involved
C5	Lower lateral aspect of upper arm	Deltoid and biceps	Shoulder abduction, elbow flexion	Biceps
C6	Lateral aspect of forearm	Extensor carpi radialis longus and brevis	Wrist extensors	Brachioradialis
C7	Middle finger	Triceps and flexor carpi radialis	Extension of elbow and flexion of wrist	Triceps
C8	Medial aspect of forearm	Flexor digitorum superficialis and profundus	Finger flexion	None
L1	Groin	Iliopsoas	Hip flexion	Cremaster
L2	Anterior aspect of thigh	Iliopsoas, sartorius, hip adductors	Hip flexion, hip adduction	Cremaster
L3	Medial aspect of knee	Iliopsoas, sartorius, quadriceps, hip adductors	Hip flexion, knee extension, hip adduction	Patellar
L4	Medial aspect of calf	Tibialis anterior, quadriceps	Foot inversion, knee extension	Patellar
L5	Lateral part of lower leg and dorsum of foot	Extensor hallucis longus, extensor digitorum longus	Toe extension, ankle dorsiflexion	None
S1	Lateral edge of foot	Gastrocnemius, soleus	Ankle plantar flexion	Ankle jerk
S2	Posterior part of thigh	Flexor digitorum longus, flexor hallucis longus	Ankle plantar flexion, toe flexion	None

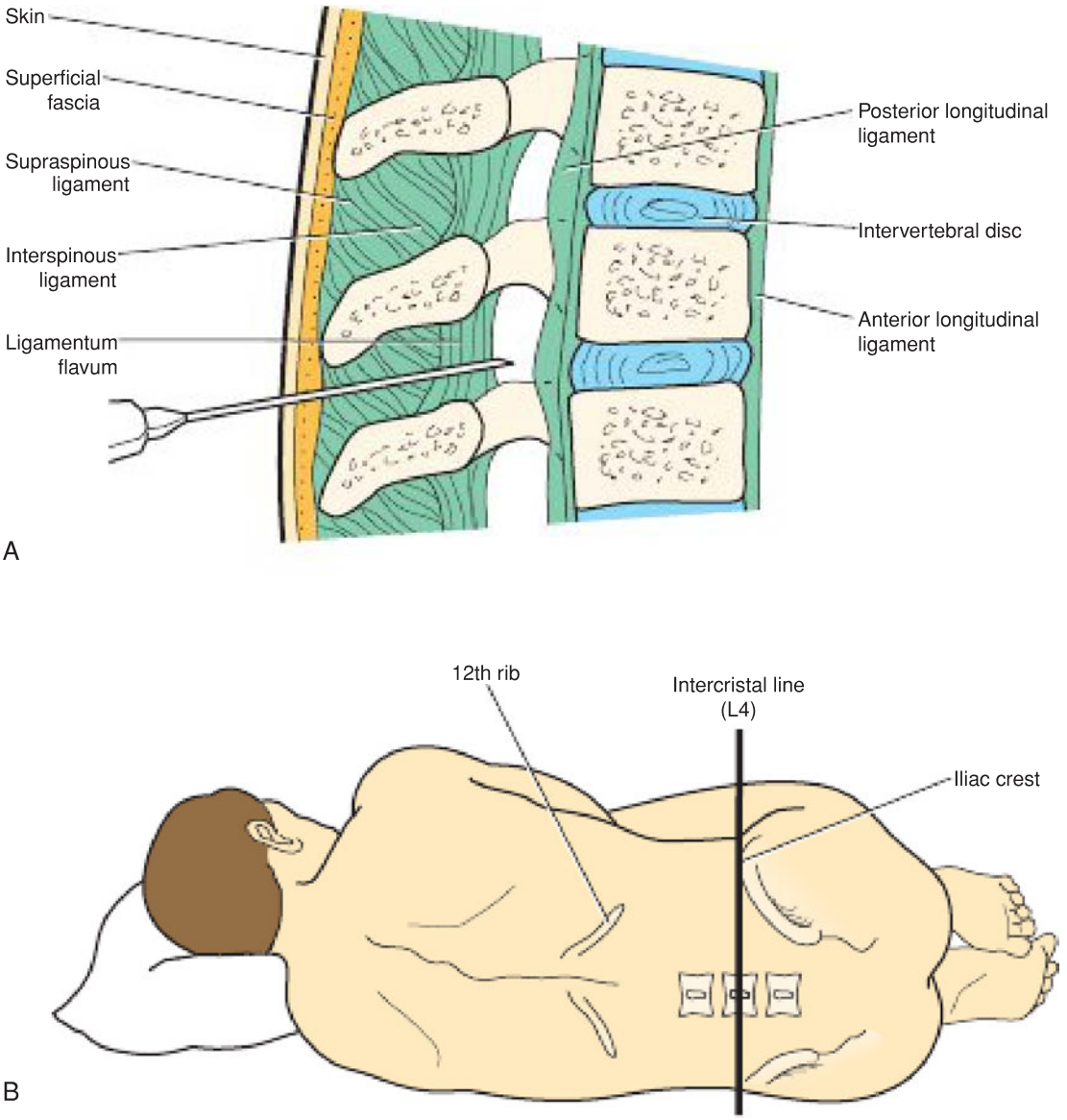

Figure A-5 **A:** Structures penetrated by the spinal tap needle before it reaches the dura mater. **B:** Important anatomic landmarks when performing a spinal tap. Although this is usually performed with the patient in a lateral recumbent position with the vertebral column well flexed, the patient may be placed in the sitting position and bent well forward.

Index

Page numbers followed by "*f*" indicate figures. Page numbers followed by "*t*" indicate tables.

C

M

T