17 Blood Supply of the Brain and Spinal Cord

CHAPTER OBJECTIVES

- To review the main arteries and veins supplying the brain and spinal cord
- To learn the areas of the cerebral cortex and spinal cord supplied by a particular artery and to understand the dysfunction that would result if the artery were blocked
- To review the circle of Willis as well as the blood supply to the internal capsule

A 61-year-old woman collapsed in the supermarket and was in a coma when admitted to the emergency department of the local hospital. Twenty-four hours later, she recovered consciousness and was found to have paralysis on the left side of her body, mainly involving the lower limb. There was also some sensory loss of the left leg and foot. She was able to swallow normally and did not appear to have difficulty with her speech. The left-sided hemiplegia and hemianesthesia strongly suggested a cerebrovascular accident involving the right cerebral hemisphere. The limitation of the paralysis and anesthesia to the leg and foot indicated that the right anterior cerebral artery or one of its branches was blocked by a thrombus or embolus. The diagnosis was confirmed by positron emission tomography (PET), which showed an absence of blood flow through the leg area on the medial surface of the right cerebral hemisphere.

Cerebrovascular accidents (stroke) remain the third leading cause of morbidity and death in the United States. Consequently, clinicians must know the areas of the cerebral cortex and spinal cord supplied by a particular artery and to understand the dysfunction that would result if the artery were blocked. The internal capsule that contains the major ascending and descending pathways to the cerebral cortex is commonly disrupted by arterial hemorrhage or thrombosis.

ARTERIES OF THE BRAIN

The brain is supplied by the two internal carotid and the two vertebral arteries. The four arteries lie within the subarachnoid space, and their branches anastomose on the inferior surface of the brain to form the circle of Willis.

Internal Carotid Artery

The internal carotid artery begins at the bifurcation of the common carotid artery (Fig. 17-1), where it usually possesses a localized dilatation, called the **carotid sinus**. It ascends the neck and perforates the base of the skull by passing through the carotid canal of the temporal bone. The artery then runs horizontally forward through the cavernous sinus and emerges on the medial side of the anterior clinoid process by perforating the dura mater. It now enters the subarachnoid space by piercing the arachnoid mater and turns posteriorly to the region of the medial end of the lateral cerebral sulcus. Here, it divides into the **anterior** and **middle cerebral arteries** (Fig. 17-2; also see Fig. 17-1).

Cerebral Portion Branches

1. The **ophthalmic artery** arises as the internal carotid artery emerges from the cavernous sinus. It enters the orbit through the optic canal below and lateral to the optic nerve. It supplies the eye and other orbital structures, and its terminal branches supply the frontal area of the scalp, the ethmoid and frontal sinuses, and the dorsum of the nose.
2. The **posterior communicating artery** is a small vessel that originates from the internal carotid artery close to its terminal bifurcation. The posterior communicating artery runs posteriorly above the oculomotor nerve to join the posterior cerebral artery, thus forming part of the **circle of Willis**.
3. The **choroidal artery**, a small branch, also originates from the internal carotid artery close to its terminal

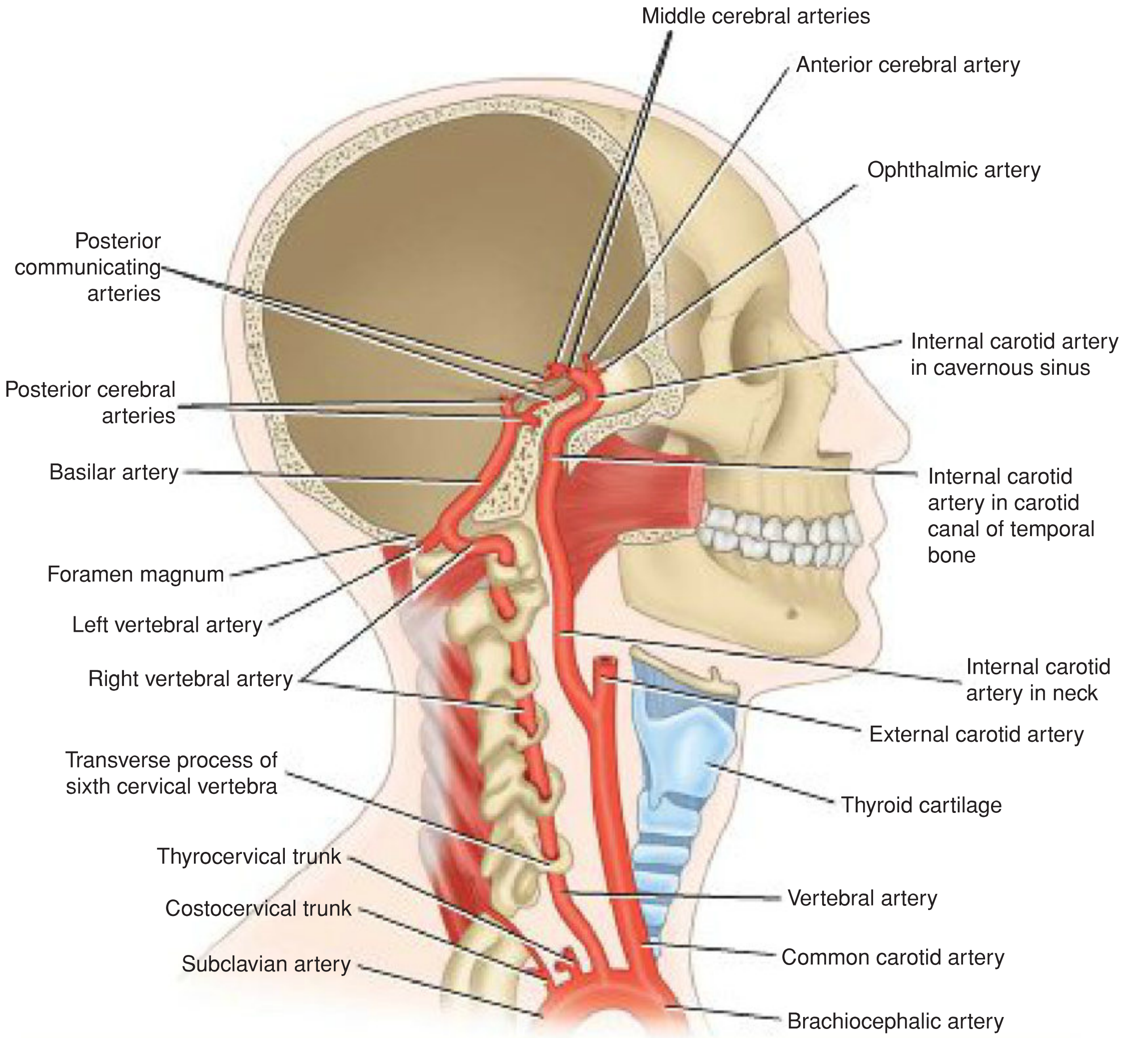

Figure 17-1 Origin and courses of the internal carotid and vertebral arteries as they ascend the neck to enter the skull.

bifurcation. The choroidal artery passes posteriorly close to the optic tract, enters the inferior horn of the lateral ventricle, and ends in the choroid plexus. It gives off numerous small branches to surrounding structures, including the crus cerebri, the lateral geniculate body, the optic tract, and the internal capsule.

4. The **anterior cerebral artery** is the smaller terminal branch of the internal carotid artery. It runs forward and medially superior to the optic nerve and enters the longitudinal fissure of the cerebrum. Here, it is joined to the anterior cerebral artery of the opposite side by the **anterior communicating artery**. It curves backward over the corpus callosum and, finally, anastomoses with the posterior cerebral artery (Fig. 17-3; also see Fig. 17-8). The **cortical branches** supply the entire medial surface of the cerebral cortex as far back as the parieto-occipital sulcus. They also supply a strip of cortex about 1 in (2.5 cm) wide on the adjoining lateral surface. The anterior cerebral artery thus supplies the "leg area" of the precentral gyrus. A group of **central branches** pierces the anterior perforated substance and helps to supply parts of the lentiform and caudate nuclei and the internal capsule.
5. The **middle cerebral artery,** the largest branch of the internal carotid, runs laterally in the lateral cerebral sulcus (see Fig. 17-2). **Cortical branches** supply the entire lateral surface of the hemisphere except for the narrow strip supplied by the anterior cerebral artery, the occipital pole, and the inferolateral surface of the hemisphere, which are supplied by the posterior cerebral artery (see Fig. 17-3). This artery thus supplies the entire motor area except the "leg area." **Central branches** enter the anterior perforated substance and supply the lentiform and caudate nuclei and the internal capsule (Fig. 17-4).

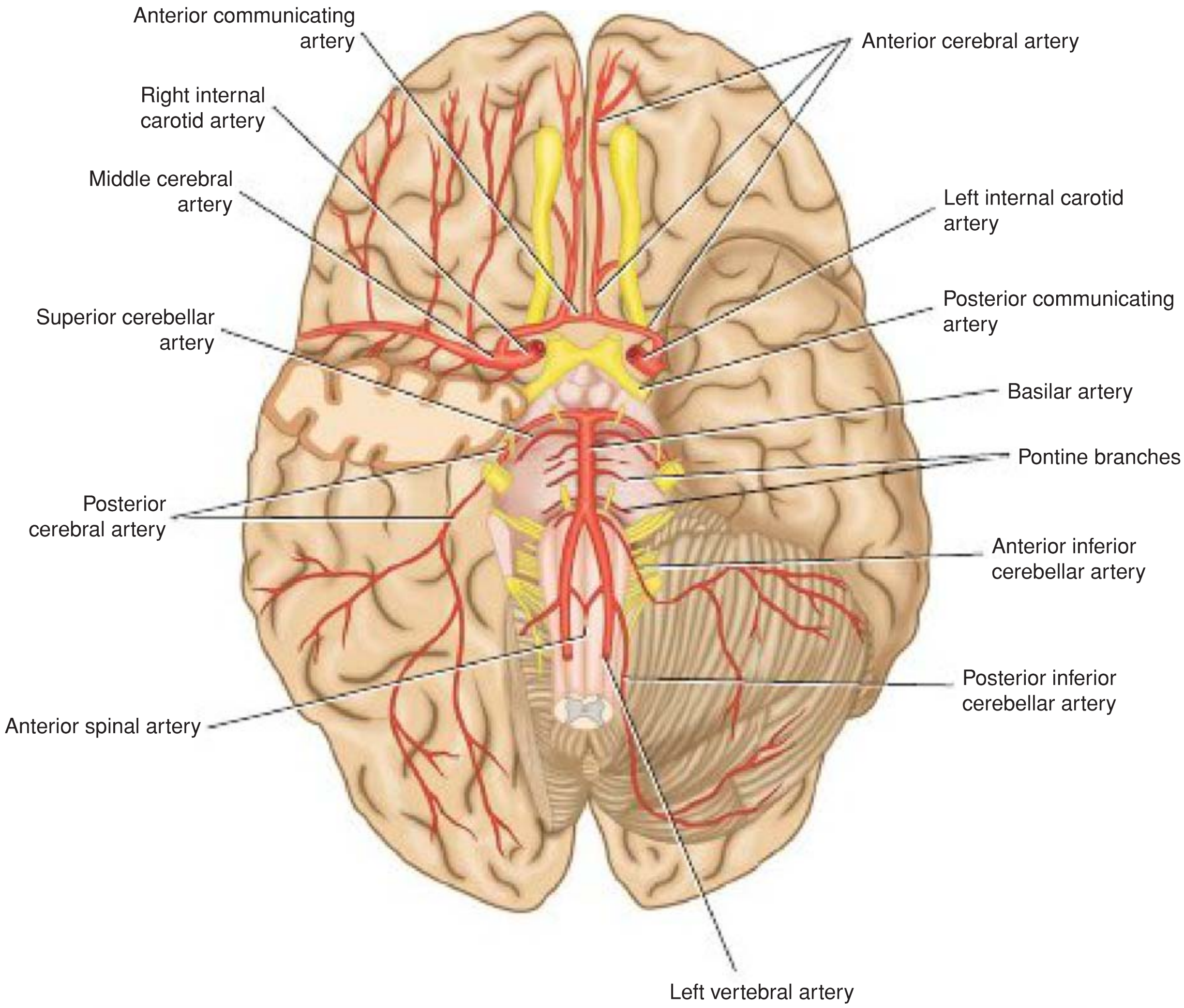

Figure 17-2 Arteries of the inferior surface of the brain. Note the formation of the circle of Willis. Part of the right temporal lobe has been removed to show the course of the middle cerebral artery.

Vertebral Artery

The vertebral artery, a branch of the first part of the subclavian artery, ascends the neck by passing through the foramina in the transverse processes of the upper C6 six cervical vertebrae (see Fig. 17-1). It enters the skull through the foramen magnum and pierces the dura mater and arachnoid to enter the subarachnoid space. It then passes upward, forward, and medially on the medulla oblongata (see Fig. 17-2). At the lower border of the pons, it joins the vessel of the opposite side to form the **basilar artery**.

Branches of the Cranial Portion

1. The **meningeal branches** are small and supply the bone and dura in the posterior cranial fossa.
2. The **posterior spinal artery** may arise from the vertebral artery or the posterior inferior cerebellar artery. It descends on the posterior surface of the spinal cord close to the posterior roots of the spinal nerves. The branches are reinforced by radicular arteries that enter the vertebral canal through the intervertebral foramina. For the detailed distribution of this artery, see page 471.
3. The **anterior spinal artery** is formed from a contributory branch from each vertebral artery near its termination (see Fig. 17-2). The single artery descends on the anterior surface of the medulla oblongata and spinal cord and is embedded in the pia mater along the anterior median fissure. The artery is reinforced by radicular arteries that enter the vertebral canal through the intervertebral foramina. For the detailed distribution of this artery, see page 472.
4. The **posterior inferior cerebellar artery**, the largest branch of the vertebral artery, passes on an irregular course between the medulla and the cerebellum (see Fig. 17-2; also see Figs. 17-12 and 17-14). It supplies the inferior surface of the vermis, the central nuclei of the cerebellum, and the undersurface of the cerebellar hemisphere; it also supplies the medulla oblongata and the choroid plexus of the fourth ventricle.

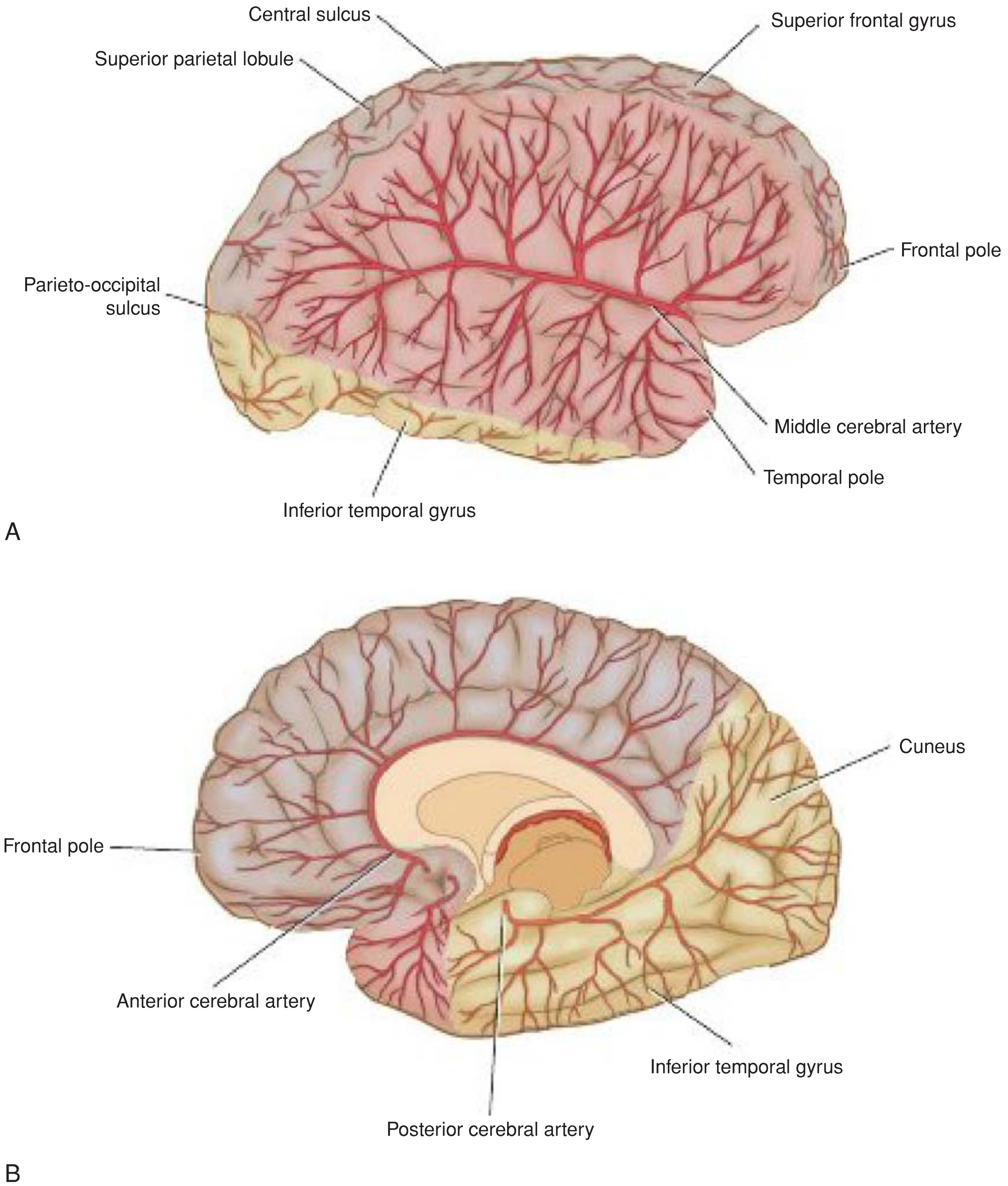

Figure 17-3 Areas supplied by the cerebral arteries. **A:** The lateral surface of the right cerebral hemisphere. **B:** The medial surface of the right cerebral hemisphere. The area supplied by the anterior cerebral artery is colored blue, the area supplied by the middle cerebral artery is pink, and the area supplied by the posterior cerebral artery is brown.

5. The **medullary arteries** are very small branches that are distributed to the medulla oblongata.

Basilar Artery

The basilar artery, formed by the union of the two vertebral arteries (see Fig. 17-1), ascends in a groove on the anterior surface of the pons (see Fig. 17-2; also see Figs. 17-13 and 17-14). At the upper border of the pons, it divides into the two posterior cerebral arteries.

Branches

1. The **pontine arteries** are numerous small vessels that enter the substance of the pons.
2. The **labyrinthine artery** is a long, narrow artery that accompanies the facial and the vestibulocochlear nerves into the internal acoustic meatus and supplies the internal ear. It often arises as a branch of the anterior inferior cerebellar artery.

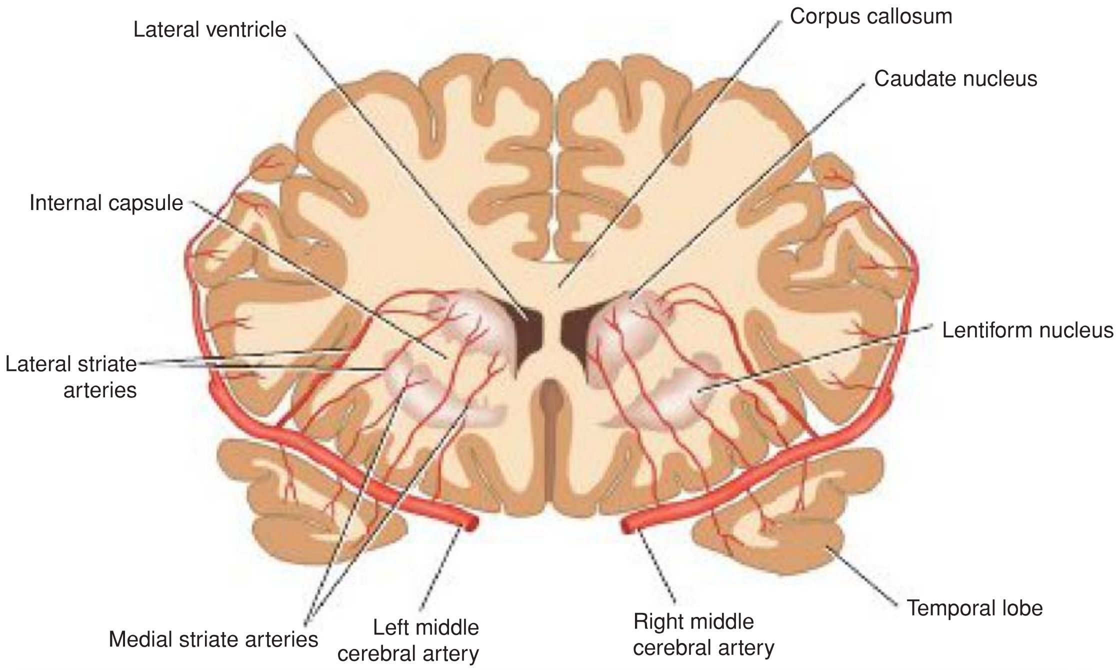

Figure 17-4 Coronal section of the cerebral hemispheres showing the arterial supply to the deep cerebral structures from the middle cerebral artery.

3. The **anterior inferior cerebellar artery** passes posteriorly and laterally and supplies the anterior and inferior parts of the cerebellum. A few branches pass to the pons and the upper part of the medulla oblongata.
4. The **superior cerebellar artery** arises close to the termination of the basilar artery (see Fig. 17-2; also see Figs. 17-11 to 17-14). It winds around the cerebral peduncle and supplies the superior surface of the cerebellum. It also supplies the pons, the pineal gland, and the superior medullary velum.
5. The **posterior cerebral artery** curves laterally and backward around the midbrain and is joined by the posterior communicating branch of the internal carotid artery (see Figs. 17-1 and 17-2; also see Figs. 17-11 to 17-14). **Cortical branches** supply the inferolateral and medial surfaces of the temporal lobe and the lateral and medial surfaces of the occipital lobe (see Fig. 17-3). Thus, the posterior cerebral artery supplies the visual cortex. **Central branches** pierce the brain substance and supply parts of the thalamus and the lentiform nucleus as well as the midbrain, the pineal, and the medial geniculate bodies. A **choroidal branch** enters the inferior horn of the lateral ventricle and supplies the choroid plexus; it also supplies the choroid plexus of the third ventricle.

Circle of Willis

The circle of Willis lies in the interpeduncular fossa at the base of the brain. It is formed by the anastomosis between the two internal carotid arteries and the two vertebral arteries (see Fig. 17-2). The anterior communicating, anterior cerebral, internal carotid, posterior communicating, posterior cerebral, and basilar arteries all contribute to the circle. The circle of Willis allows blood that enters by either internal carotid or vertebral arteries to be distributed to any part of both cerebral hemispheres. Cortical and central branches arise from the circle and supply the brain substance.

Variations in the sizes of the arteries forming the circle are common, and the absence of one or both posterior communicating arteries has been reported.

Arteries to Specific Brain Areas

The **corpus striatum** and the **internal capsule** are supplied mainly by the medial and lateral striate central branches of the middle cerebral artery (see Fig. 17-4); the central branches of the anterior cerebral artery supply the remainder of these structures.

The **thalamus** is supplied mainly 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 and the 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.

Nerve Supply of Cerebral Arteries

The cerebral arteries receive a rich supply of sympathetic postganglionic nerve fibers. These fibers are derived from the superior cervical sympathetic ganglion. Stimulation of these nerves causes vasoconstriction of the cerebral arteries. However, under normal conditions, the local blood flow is mainly controlled by the concentrations of carbon dioxide, hydrogen ions, and oxygen present in the nervous tissue; a rise in the carbon dioxide and hydrogen ion concentrations and a lowering of the oxygen tension bring about a vasodilatation.

VEINS OF THE BRAIN

The veins of the brain have no muscular tissue in their very thin walls, and they possess no valves. They emerge from the brain and lie in the subarachnoid space. They pierce the arachnoid mater and the meningeal layer of the dura and drain into the cranial venous sinuses (Fig. 17-5).

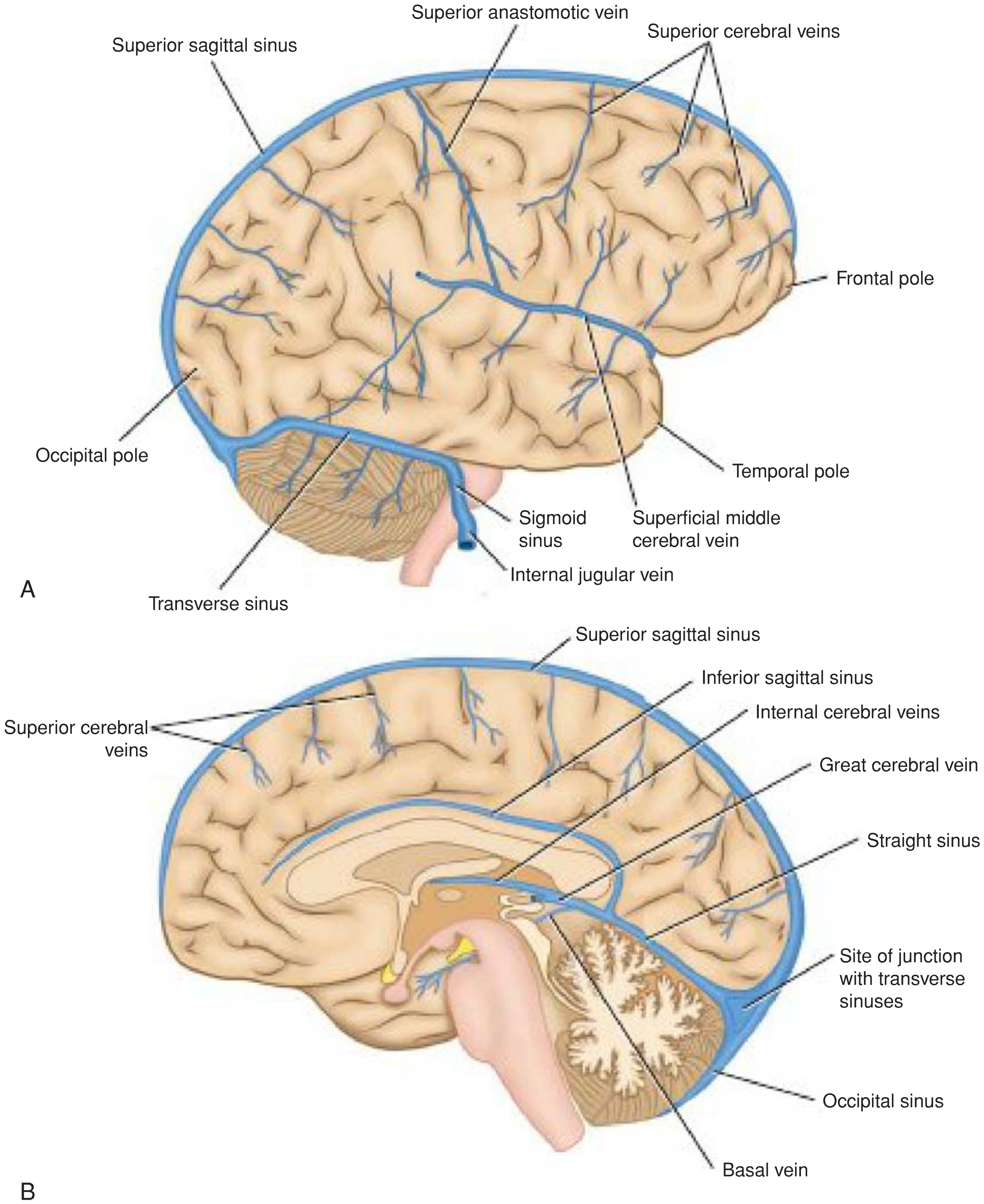

Figure 17-5 Venous drainage of the right cerebral hemisphere. **A:** Lateral surface. **B:** Medial surface.

External Cerebral Veins

The **superior cerebral veins** pass upward over the lateral surface of the cerebral hemisphere and empty into the superior sagittal sinus.

The **superficial middle cerebral vein** drains the lateral surface of the cerebral hemisphere. It runs inferiorly in the lateral sulcus and empties into the cavernous sinus.

The **deep middle cerebral vein** drains the insula and is joined by the **anterior cerebral** and **striate veins** to form the **basal vein**. The basal vein ultimately joins the great cerebral vein, which in turn drains into the straight sinus.

Internal Cerebral Veins

The two internal cerebral veins are formed by the union of the **thalamostriate vein** and the **choroid vein** at the interventricular foramen. The two veins run posteriorly in the tela choroidea of the third ventricle and unite beneath the splenium of the corpus callosum to form the great cerebral vein, which empties into the straight sinus.

Veins of Specific Brain Areas

The **midbrain** is drained by veins that open into the basal or great cerebral veins.

The **pons** is drained by veins that open into the basal vein, cerebellar veins, or neighboring venous sinuses.

The **medulla oblongata** is drained by veins that open into the spinal veins and neighboring venous sinuses.

The **cerebellum** is drained by veins that empty into the great cerebral vein or adjacent venous sinuses.

BRAIN CAPILLARIES

The capillary blood supply to the brain is greater in the gray matter than in the white matter. This is to be expected, since the metabolic activity in the neuronal cell bodies in the gray matter is much greater than in the nerve processes in the white matter. The blood–brain barrier isolates the brain tissue from the rest of the body and is formed by the tight junctions that exist between the endothelial cells in the capillary beds (see pp. 452-453).

CEREBRAL CIRCULATION

The blood flow to the brain must deliver oxygen, glucose, and other nutrients to the nervous tissue and remove carbon dioxide, lactic acid, and other metabolic by-products. The brain has been shown to be supplied with arterial blood from the two internal carotid arteries and the two vertebral arteries. The blood supply to half of the brain is provided by the internal carotid and vertebral arteries on that side, and their respective streams come together in the posterior communicating artery at a point where the pressure of the two is equal and they do not mix (Fig. 17-6). If, however, the internal carotid or vertebral artery is occluded, the blood passes forward or backward across that point to compensate for the reduction in blood flow. The arterial circle also permits the blood to flow across the midline, as shown when the internal carotid or vertebral artery on one side is occluded. It also has been shown that the two streams of blood from the vertebral arteries remain separate and on the same side of the lumen of the basilar artery and do not mix.

Although the cerebral arteries anastomose with one another at the circle of Willis and by means of branches on the surface of the cerebral hemispheres, once they enter the brain substance, no further anastomoses occur.

The most important factor in forcing the blood through the brain is the arterial blood pressure. This is opposed by such factors as a raised intracranial pressure, increased blood viscosity, and narrowing of the vascular diameter. Cerebral blood flow remains

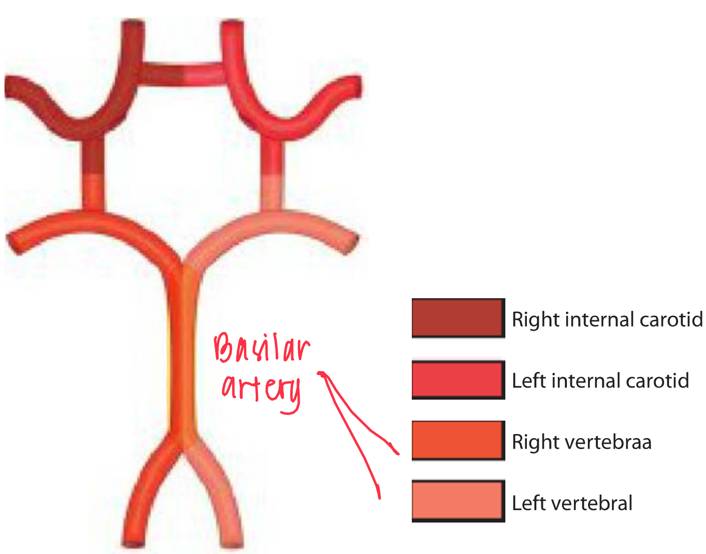

Figure 17-6 Circle of Willis showing the distribution of blood from the four main arteries.

remarkably constant despite changes in the general blood pressure. This autoregulation of the circulation is accomplished by a compensatory lowering of the cerebral vascular resistance when the arterial pressure is decreased and a rising of the vascular resistance when the arterial pressure is increased. Needless to say, this autoregulation does not maintain an adequate blood flow when the arterial blood pressure falls to a very low level.

The diameter of the cerebral blood vessels is the main factor contributing to the cerebrovascular resistance. While cerebral blood vessels are innervated by sympathetic postganglionic nerve fibers and respond to norepinephrine, they apparently play little or no part in the control of cerebrovascular resistance in normal human beings. The most powerful vasodilator influence on cerebral blood vessels is an increase in carbon dioxide or hydrogen ion concentration; a reduction in oxygen concentration also causes vasodilatation. It has been shown, using PET, that an increase in neuronal activity in different parts of the brain causes a local increase in blood flow. For example, viewing an object will increase the oxygen and glucose consumption in the visual cortex of the occipital lobes. This results in an increase in the local concentrations of carbon dioxide and hydrogen ions and brings about a local increase in blood flow.

The cerebral blood flow in patients can be measured by the intracarotid injection or inhalation of radioactive krypton or xenon. Normal cerebral blood flow, per minute, is around 50 to 60 mL/100g of brain tissue.

SPINAL CORD ARTERIES

The spinal cord receives its arterial supply from three small arteries: the two posterior spinal arteries and the anterior spinal artery. These longitudinally running arteries are reinforced by small segmentally arranged arteries that arise from arteries outside the vertebral column and enter the vertebral canal through the intervertebral foramina. These vessels anastomose on the surface of the cord and send branches into the substance of the white and gray matter. Considerable variation exists as to the size and segmental levels at which the reinforcing arteries occur.

posterior 1/3 ō spinal cord

Posterior Spinal Arteries

The posterior spinal arteries arise either directly from the vertebral arteries inside the skull or indirectly from the posterior inferior cerebellar arteries. Each artery descends on the posterior surface of the spinal cord close to the posterior nerve roots and gives off branches that enter the substance of the cord (Fig. 17-7). The posterior spinal arteries supply the posterior third of the spinal cord.

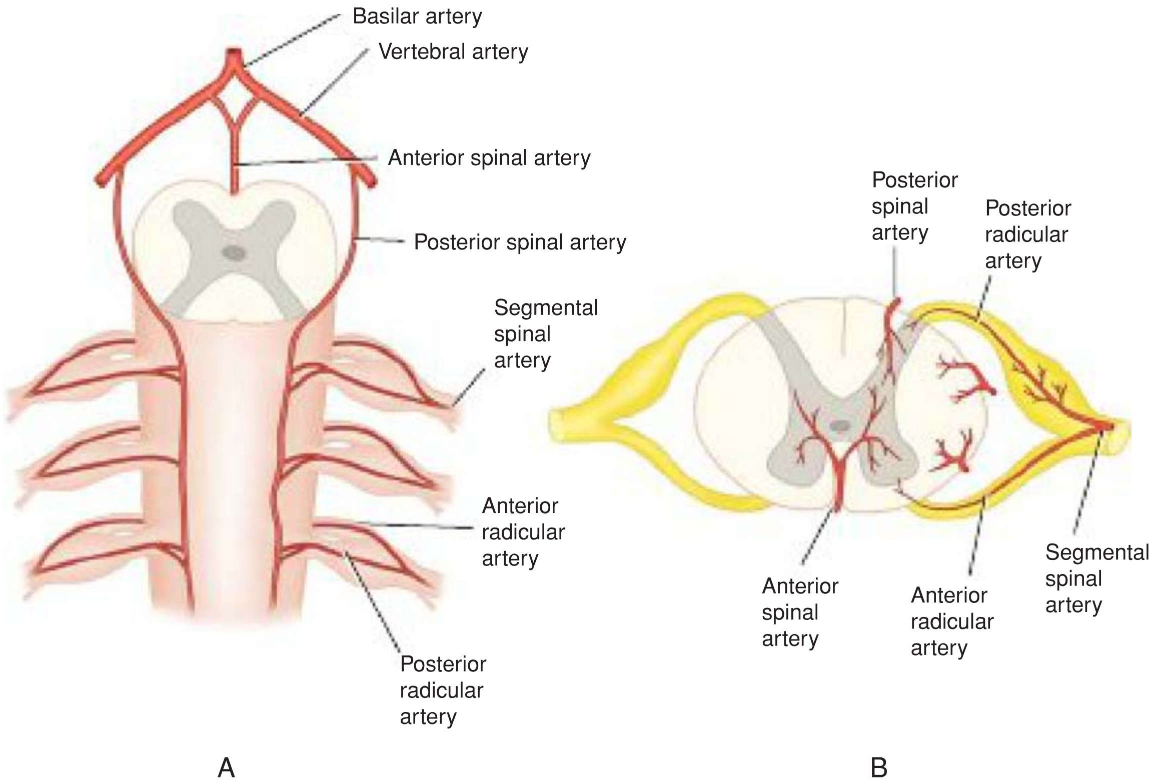

Figure 17-7 **A:** Arterial supply of the spinal cord showing the formation of two posterior spinal arteries and one anterior spinal artery. **B:** Transverse section of the spinal cord showing the segmental spinal arteries and the radicular arteries.

The posterior spinal arteries are small in the upper thoracic region, and the first three thoracic segments of the spinal cord are particularly vulnerable to ischemia should the segmental or radicular arteries in this region be occluded.

Anterior Spinal Artery

The anterior spinal artery is formed by the union of two arteries, each of which arises from the vertebral artery inside the skull. The anterior spinal artery then descends on the anterior surface of the spinal cord within the anterior median fissure. Branches from the anterior spinal artery enter the substance of the cord and supply the anterior two-thirds of the spinal cord.

In the upper and lower thoracic segments of the spinal cord, the anterior spinal artery may be extremely small. Should the segmental or radicular arteries be occluded in these regions, the fourth thoracic and the first lumbar segments of the spinal cord would be particularly liable to ischemic necrosis.

Segmental Spinal Arteries

At each intervertebral foramen, the longitudinally running posterior and anterior spinal arteries are reinforced by small segmental arteries on both sides. The arteries are branches of arteries outside the vertebral column (deep cervical, intercostal, and lumbar arteries). Having entered the vertebral canal, each segmental spinal artery gives rise to **anterior** and **posterior radicular arteries** that accompany the anterior and posterior nerve roots to the spinal cord.

Additional **feeder arteries** enter the vertebral canal and anastomose with the anterior and posterior spinal arteries; however, the number and size of these arteries vary considerably from one individual to another. One large and important feeder artery, the **great anterior medullary artery of Adamkiewicz**, arises from the aorta in the lower thoracic or upper lumbar vertebral levels; it is unilateral and, in the majority of persons, enters the spinal cord from the left side. The importance of this artery lies in the fact that it may be the major source of blood to the lower two-thirds of the spinal cord.

SPINAL CORD VEINS

The veins of the spinal cord drain into six tortuous longitudinal channels that communicate superiorly within the skull with the veins of the brain and the venous sinuses. They drain mainly into the internal vertebral venous plexus.

Clinical Notes

The brain receives about 15% of the resting cardiac output. The arterial blood reaches the brain through the two internal carotid and the two vertebral arteries; the internal carotid arteries are the major supply of arterial blood.

The distributing arteries—the anterior, middle, and posterior cerebral arteries—that arise from the circle of Willis pass over the outer surface of the brain and anastomose with one another. They give rise to branches that penetrate the brain at right angles. In the brain substance, further branching occurs, but no further anastomoses take place. Anastomoses on the brain surface provide the vital collateral circulation should one of the arteries be occluded by disease.

Despite the recent decrease in cerebrovascular disease, which has been brought about by the treatment of high blood cholesterol and the aggressive treatment of hypertension, cerebrovascular disease is still responsible for about 50% of all adult neurologic hospital admissions.

Cerebral Ischemia

Unconsciousness occurs in 5 to 10 seconds if the blood flow to the brain is completely cut off. Irreversible brain damage with death of nervous tissue rapidly follows complete arrest of cerebral blood flow. Neuronal function is estimated to cease after about 1 minute, and irreversible changes start to occur after about 4 minutes, although this time may be longer if the patient's body has been cooled. (However, brain damage might be reversed if the blood flow can be restored even after 5 minutes.) Cardiac arrest due to coronary thrombosis is the most common cause of this condition.

Cerebral Circulation Interruption

Vascular lesions of the brain are extremely common and the resulting neurologic defect will depend on the size of the artery occluded, the state of the collateral circulation, and the area of the brain involved.

CEREBRAL ARTERY SYNDROMES

Clinical studies and the examination of postmortem material have focused attention on the high frequency of lesions in the common carotid, internal carotid, and vertebral arteries in the neck.

ANTERIOR CEREBRAL ARTERY OCCLUSION

If the occlusion of the anterior cerebral artery is proximal to the anterior communicating artery, the collateral circulation is usually adequate to preserve the circulation. Occlusion distal to the communicating artery may produce the following signs and symptoms:

1. Contralateral hemiparesis and hemisensory loss involving mainly the leg and foot (paracentral lobule of cortex)
2. Inability to identify objects correctly, apathy, and personality changes (frontal and parietal lobes)

MIDDLE CEREBRAL ARTERY OCCLUSION

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

1. Contralateral hemiparesis and hemisensory loss involving mainly the face and arm (precentral and postcentral gyri)

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.

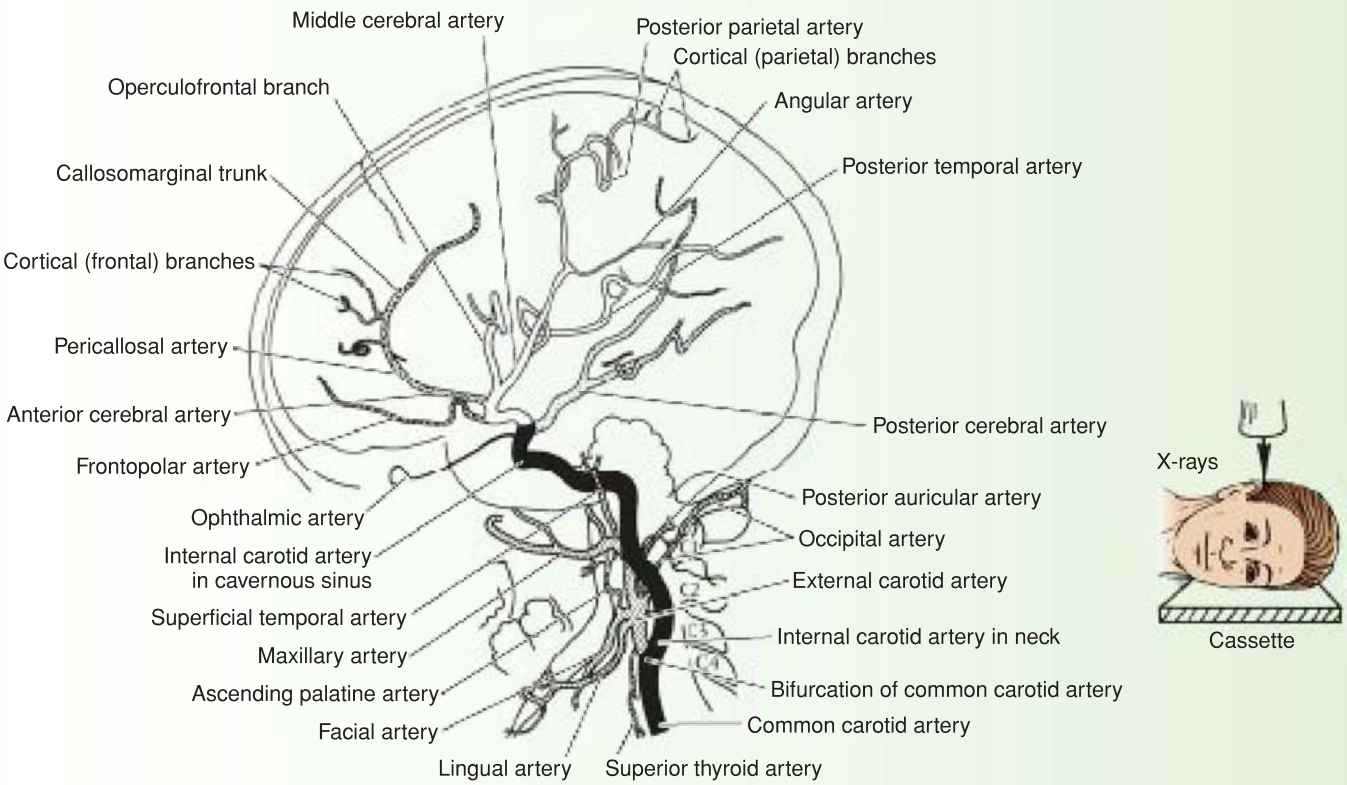

Figure 17-9 Main features seen in radiograph in Figure 17-8.

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

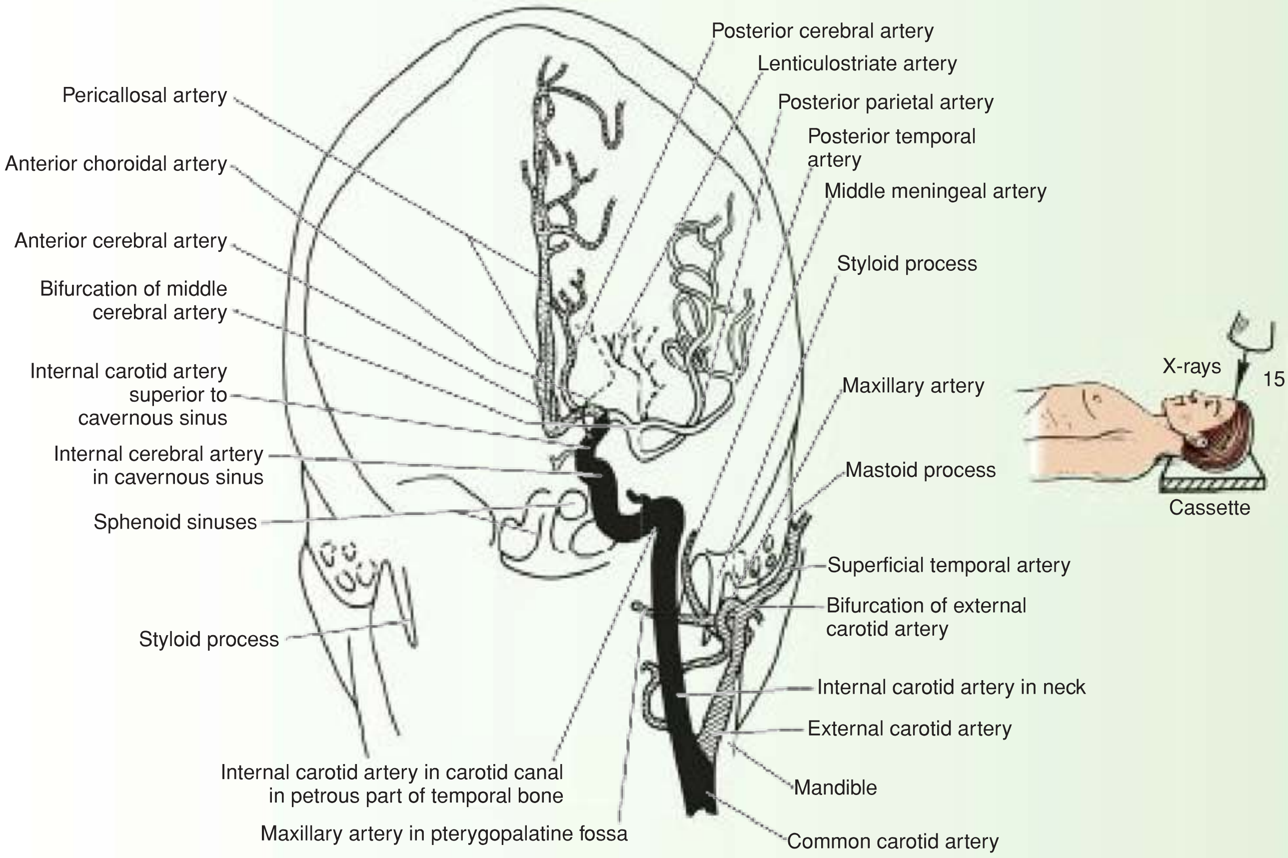

Figure 17-11 Main features seen in the radiograph in Figure 17-10.

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

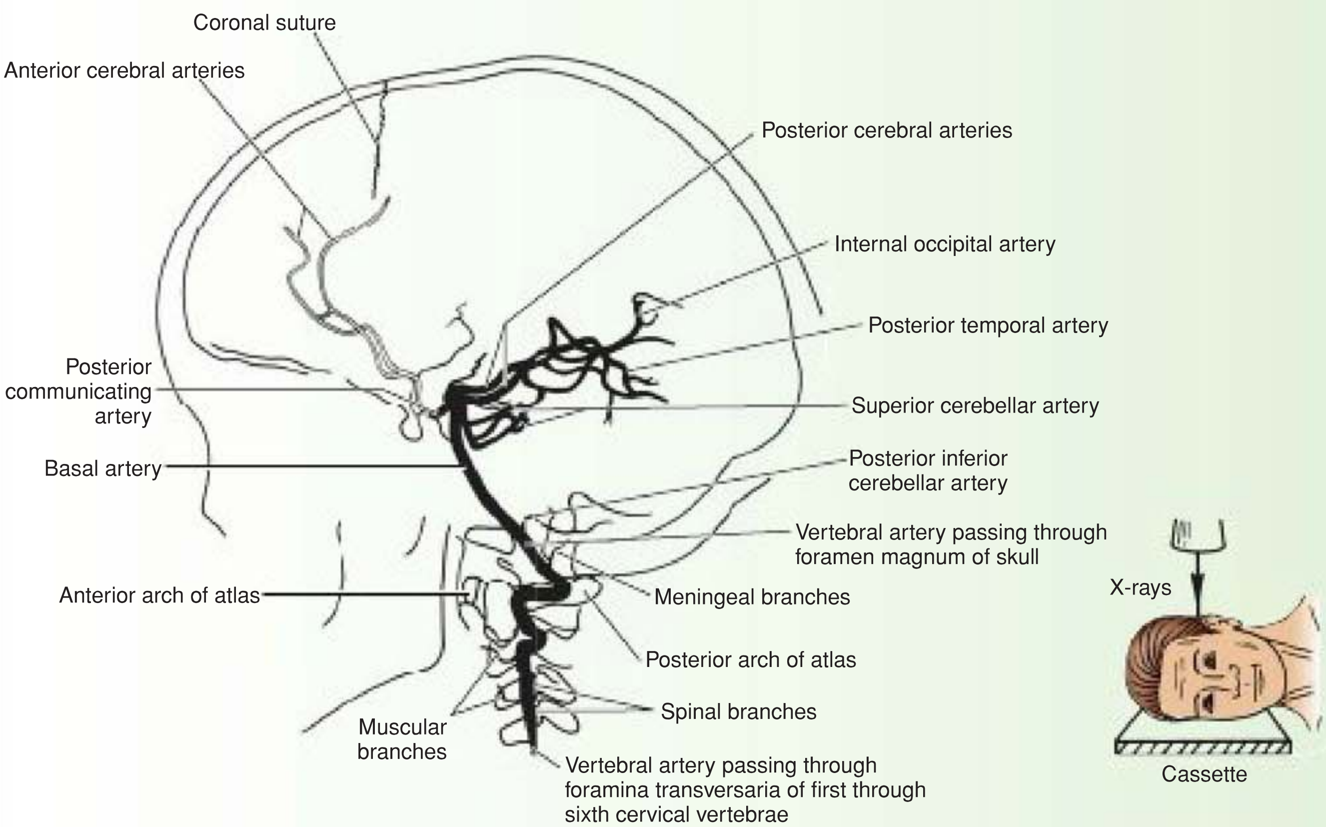

Figure 17-13 Main features shown in the radiograph in Figure 17-12.

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

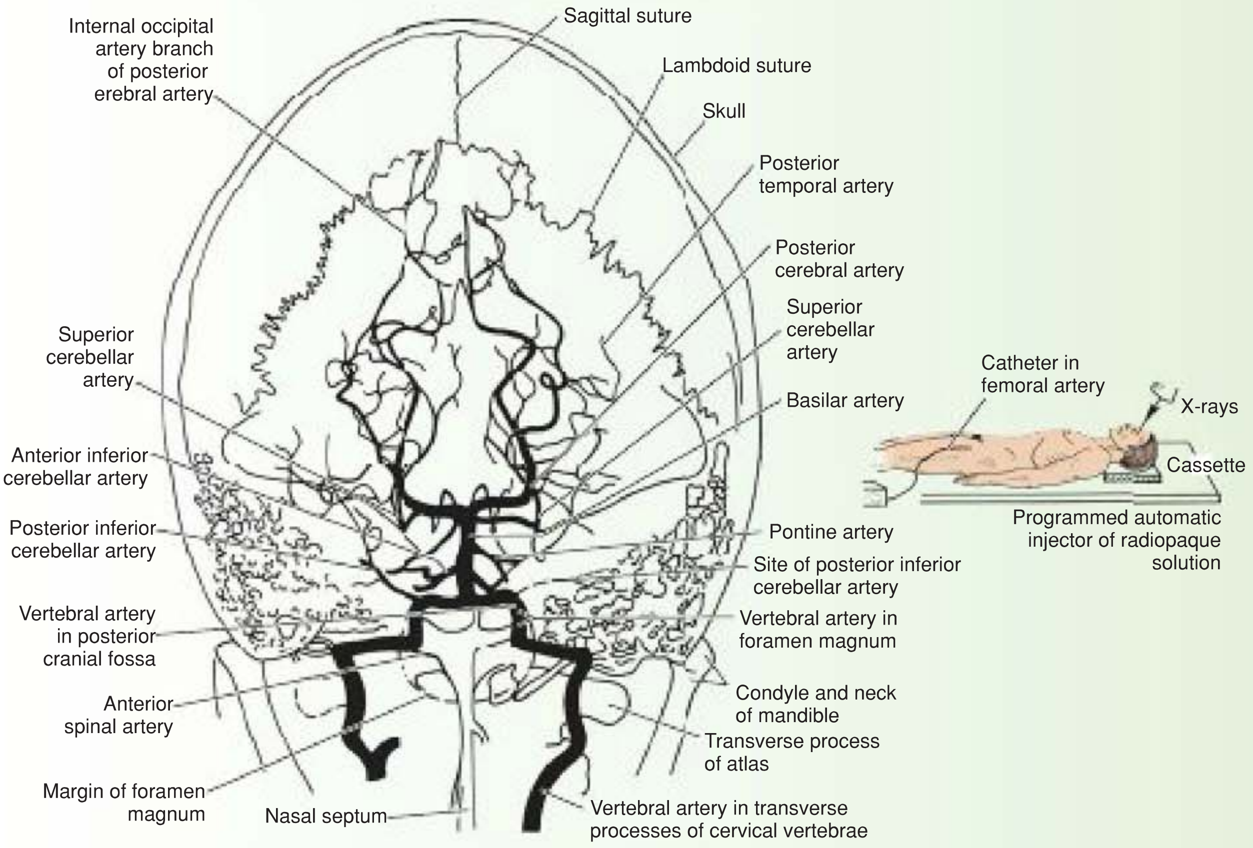

Figure 17-15 Main features shown in the radiograph in Figure 17-14.

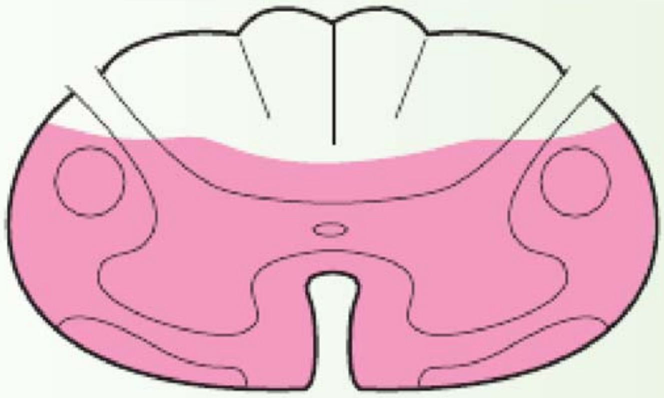

Figure 17-16 Anterior spinal artery occlusion. Pink area denotes region of spinal cord affected.

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.