



Module 3. The Blood Supply of the Brain Relating Vascular and Functional Anatomy

Objectives for Module 3

Knowledge

- Describe or sketch the course of the major arteries and their branches that comprise the carotid and vertebral-basilar systems.
- Name the major arteries or branches whose territories include the following structures:
 - Lateral parts of the hemisphere and large regions of internal capsule and basal ganglia (deep structures)
 - Medial parts of the hemisphere
 - Posterior and inferior parts of the hemisphere
 - Thalamus
 - Medial brainstem
 - Lateral brainstem and Cerebellum
- Name the major arteries (and branches) that supply: Primary motor cortex for face, arm, leg; and corticobulbar and corticospinal fibers in deep white matter of hemisphere, and throughout the rest of their course in the forebrain and brainstem.
- Name the major arteries that supply the different components of the visual system, regions involved in language processing/production, spatial attention and visual-spatial orientation.
- List 4 important regions where collateral circulation may provide alternate routes for blood flow to the brain.

Clinical Applications and Reasoning

- Explain why collateral circulation often does not protect against brain ischemia when a major vessel is abruptly occluded by an embolus.
- Explain how a slowly developing occlusion of the internal carotid artery in the neck might be totally asymptomatic.
- Explain two different ways that occlusion of a carotid branch might produce leg weakness.
- Name 3 structures where both hypertensive intracerebral hemorrhages and lacunar infarcts often occur, and relate this to at least one feature their blood supplies have in common.

We suggest that you look at the relevant StrokeSTOP reference drawings as you read...

The brain derives its arterial supply from the paired **carotid** and **vertebral** arteries. Every minute, about 600-700 ml of blood flows through the carotid arteries and their branches, while about 100-200 ml flows through the vertebral-basilar system.

The carotid and vertebral arteries begin extracranially, and course through the neck and base of the skull to reach the cranial cavity. The internal carotid arteries and their branches supply the anterior 2/3 of the cerebral hemispheres, including many deeper as well as superficial structures.

The vertebral arteries and basilar artery, with their branches, supply the remaining posterior and medial regions of the hemispheres, most of the diencephalon, the brainstem, cerebellum, and cervical spinal cord. The carotid and vertebral-basilar circulations are anatomically interconnected with each other, and with their counterparts in the opposite hemisphere, through the circle of Willis. However these connections may not be functionally significant if the connecting vessels are of small diameter or if pressure differences are too small to drive much blood flow.

The Carotid Circulation

Overview of Major Regions Supplied:

- **optic nerves and retina**
- **cortex and deep white matter of the frontal and parietal lobes, and lateral aspects of the temporal and occipital lobes**
- **all of the corpus callosum except its posterior regions**
- **most of the basal ganglia and internal capsule.**

Course of the Carotid Arteries and Formation of Major Branches

The right common carotid artery originates from the bifurcation of the brachiocephalic trunk, while the left common carotid artery originates directly from the aortic arch. Each common carotid then branches to form the internal and external carotid arteries. After the internal carotid artery ascends through the neck, traverses the temporal bone, and passes through the cavernous sinus it pierces the dura and finally reaches the subarachnoid space at the base of the brain.

Just after it enters the subarachnoid space the internal carotid artery usually gives rise to its first intracranial branch, the **ophthalmic artery**, which travels along the optic nerve into the orbit. There its branches supply the retina and other structures of the eyeball itself, as well as other structures in and around the orbit. The internal carotid artery continues in a superior direction and usually gives off two additional branches: the **posterior communicating** and **anterior choroidal** arteries.

The posterior communicating artery usually links the internal carotid to the posterior cerebral artery, and may be large or threadlike. However, in a number of individuals one or both of the posterior cerebral arteries retain their embryological state as direct branches of the internal carotid artery itself. The anterior choroidal artery also varies a great deal in size and importance in different individuals, and may branch from the middle cerebral artery rather than the internal carotid. For this reason, we will discuss it with the middle cerebral artery. Finally, the internal carotid artery divides to form the **anterior and middle cerebral arteries**.

Anterior Cerebral Artery

The **anterior cerebral artery (ACA)** arises from the internal carotid at nearly a right angle. It sends deep penetrating branches to supply the most anterior portions of the basal ganglia. It then sweeps forward into the interhemispheric fissure, and then runs up and over the genu of the corpus callosum before turning backwards along the corpus callosum. As it runs backwards it forms one branch that stays immediately adjacent to the corpus callosum while a second branch runs in the cingulate sulcus (just superior to the cingulate gyrus)

To summarize, **ACA** supplies the medial and superior parts of the frontal lobe, and of the anterior parietal lobe.

ACA Supplies these Key Functional Areas:

- septal area
- primary motor cortex for the leg and foot areas, and the urinary bladder
- additional motor planning areas in the medial frontal lobe, anterior to the precentral gyrus
- primary somatosensory cortex for the leg and foot
- most of the corpus callosum except its posterior part. Among other things, these callosal fibers enable the language-dominant hemisphere to find out what the other hemisphere is doing, and to direct its activities.

The short **anterior communicating artery** joins the two anterior cerebral arteries. It may allow collateral flow into the opposite hemisphere if the carotid artery is occluded on either side.

Middle Cerebral Artery

The **middle cerebral artery (MCA)** has a large diameter and branches at an acute angle from the internal carotid. The MCA passes laterally just underneath the frontal lobe, ultimately taking up a position between the temporal and frontal lobes in the Sylvian (lateral) fissure. The initial part of the MCA is a single vessel --its stem or M1 segment. As it passes laterally, the stem gives off a series of 6-12 long, small diameter, penetrating vessels, which travel directly upward to supply much of the basal ganglia and internal capsule. These are the **lenticulostriate arteries**.

Clinical Note: The lenticulostriate vessels are small diameter arteries that originate as right angle branches from the MCA stem (a large diameter vessel with a brisk, high pressure blood flow). These small arteries are particularly susceptible to damage from hypertension. They may either rupture, producing an intracerebral hemorrhage that is initially centered in the region they supply, or they may collapse, blocking the lumen and producing a small (lacunar) infarct in the tissue they normally supply. The lenticulostriate arteries are 'end arteries' and regions that they supply do not have significant collateral blood supply. Therefore their occlusion leads to stereotyped stroke syndromes.

Clinical Note: In the case of the lenticulostriate arteries, hemorrhage may remain localized to the putamen (and caudate), may involve neighboring structures like the internal capsule and other more distant white matter of the hemisphere, or may even rupture into the ventricular system. Lacunar infarcts may have serious functional consequences if they involve motor or sensory fibers in the internal capsule but may be 'silent' (produce no functional deficit) if they involve other small regions of white matter or the basal ganglia.

Once in the Sylvian fissure itself, the MCA stem divides into two or, in a smaller number of cases, three main cortical branches that supply almost the entire lateral surface of the brain as well as the insula.

Clinical Note: Large emboli carried up the carotid tend to be swept into MCA, and are prone to getting stuck at the branch point within the Sylvian fissure.

The **superior (upper or suprasylvian) cortical MCA branch** gives rise to several arteries that supply much of the lateral and inferior frontal lobe and often the anterior lateral parts of the parietal lobe. The **inferior (lower or infrasyllian) cortical MCA branch** gives rise to arteries that supply the lateral temporal lobe including its anterior tip and the amygdala, variable amounts of the lateral parietal lobe, and much of the lateral occipital lobe. Note that details of the territories supplied by the superior and inferior cortical branches vary in different individuals.

Clinical Note: Emboli can lodge in one of these two major cortical branches, as well as in the smaller arteries that each of them will subsequently form.

Superior cortical branches of MCA Supply these Key Functional Areas:

- Primary motor cortex for face and arm, and *axons* originating in the leg as well as face and arm areas that are traveling in the deep white matter toward the internal capsule as part of the corticobulbar or corticospinal tracts
- Broca's area and other related gray and white matter important for language expression -- in the language-dominant (usually L) hemisphere
- Frontal eye fields (important for 'looking at' eye movements to the opposite side)
- Primary somatosensory cortex for face and arm (But be aware that this cortex and even the primary motor cortex can be supplied by inferior branches in some people)
- Parts of lateral frontal and parietal lobes important for 3-D visuospatial perceptions of one's own body and of the outside world, and for the ability to interpret and express emotions -- in the nondominant (usually R) hemisphere

Inferior cortical branches of MCA Supply these Key Functional Areas:

- Wernicke's and other related areas important for language comprehension in the language-dominant (usually L) hemisphere
- Parts of the lateral parietal and temporal lobe important for spatial attention and visuospatial perceptions of one's own body and of the outside world, and for the ability to interpret emotions -- in the nondominant (usually R) hemisphere
- Variable amounts of the lateral primary somatosensory cortex, and even primary motor cortex
- Optic radiations, particularly fibers that represent information from the contralateral superior quadrants and loop forward into the temporal lobe (they are located anterior and lateral to the temporal horn of the lateral ventricle) as they travel from the lateral geniculate body to the striate cortex, which is located in the medial occipital lobe

Clinical Note: There is a tendency for atheromatous plaques to form at branchings and curves of the cerebral arteries. Thus in the carotid circulation the most frequent sites are in the internal carotid artery at its origin from the common carotid, in the stem MCA or its bifurcation into superior and inferior divisions, or in the ACA as it curves backwards over the corpus callosum.

Vertebral-Basilar Circulation

Overview of Major Regions Supplied

- upper cervical spinal cord
- brainstem and cerebellum
- most but not all of the thalamus and hypothalamus
- cortex and deep white matter of the posterior medial parietal lobes, and medial and inferior temporal and occipital lobes (including the posterior hippocampus)
- posterior part of the corpus callosum (splenium)

The **vertebral arteries** usually arise from the subclavian arteries. They ascend through the upper cervical transverse foramina, turn medially along the upper surface of the atlas, pierce the dura to enter the subarachnoid space and ascend into the foramen magnum into the cranial cavity. The vertebral arteries run alongside the medulla, giving rise to branches that participate in supplying the rostral spinal cord as well as the brainstem. They end by fusing to form the basilar artery.

Clinical Note: Cardiac emboli tend to enter the vertebral circulation far less frequently than the carotid circulation. Several facts of vascular anatomy may account for this. Each vertebral artery takes off from the subclavian at a sharp angle, and has a much smaller diameter. By contrast, the internal carotid artery is about the same diameter as the common carotid, and makes only a slight bend at its origin. Also, the vertebral-basilar system handles just 20% of the total cerebral blood flow, while the carotid system handles much more.

The vertebral arteries help to supply the cervical spinal cord. The posterior spinal arteries and the two anterior spinal arteries, which fuse to form a single midline vessel, supply the upper cervical cord. Blood that supplies more caudal regions of the spinal cord flows to it via radicular arteries that are branches of the thoracic and abdominal aorta. There is a great deal of variability in this pattern. The artery of Adamkiewicz is one of the most important radicular arteries, and in some individuals it may provide the entire arterial supply for the lower two-thirds of the cord.

The vertebral and basilar arteries supply the brainstem and cerebellum. Perhaps the most important thing to recognize about the brainstem's blood supply is just how variable the arteries can be in size and position, but still provide adequate perfusion. This means that clinical syndromes produced by occlusion of a particular artery are also variable. Patients whom you will encounter may present with fragments or combinations of syndromes.

Brainstem arteries in the medulla, pons and midbrain have similar patterns of distribution:

- **medial parts of the brainstem** as far dorsal as the ventricle are supplied by long, slender penetrating branches (paramedian branches).

Clinical Note: Like the lenticulostriate branches of MCA, these paramedian vessels, are at risk for hypertensive damage, particularly in the pons. Large pontine hemorrhages classically involve the corticospinal tracts and reticular formation bilaterally; pontine lacunar infarcts may also damage the corticospinal tracts.

- **dorsolateral parts of the brainstem** are supplied by direct circumferential branches of the vertebral or basilar arteries, by branches of one of the major 'cerebellar' arteries as they curve around the brainstem to reach the cerebellum, or by the posterior cerebral arteries..

The blood supply of the medulla is derived from the two vertebral arteries. The **midline anterior spinal artery**, formed from the fusion of medial branches from each vertebral, supplies part of the central medulla (as well as much of the upper cervical cord). From its lateral side each vertebral gives off a variable branch the **posterior inferior cerebellar artery (PICA)**. PICA has a complicated looping course as it swings out around the inferior olives, and runs along the dorsal lateral surface of the medulla before turning laterally and supplying the inferior surface of the cerebellum. The vertebral arteries fuse at the junction between the medulla and the pons to form the single midline **basilar artery**, which then proceeds rostrally along the surface of the anterior pons. The basilar artery also gives rise to additional large lateral arteries, most importantly, the **anterior inferior cerebellar arteries** and the **superior cerebellar arteries**.

The three pairs of named cerebellar arteries supply the posterior inferior, anterior inferior, and superior surfaces of the cerebellum respectively. The superior cerebellar artery also sends small branches penetrating deeply into the internal (deep) nuclei of the cerebellum.

Clinical Note: Although it is less common, these penetrating superior cerebellar artery branches are also at risk for hypertensive hemorrhage, with bleeding often occurring near the dentate nucleus. Such a cerebellar hemorrhage can produce deficits related to the cerebellum such as postural instability or limb ataxia, or may affect brainstem function by compression or by rupture into the fourth ventricle.

Vertebral-basilar branches supply the following key functional areas:

<u>Brainstem Region</u>	<u>Medial Structures</u>	<u>Dorsolateral Structures</u>
Rostral Midbrain	*CST and CBT in cerebral peduncle Superior cerebellar peduncle Oculomotor nucleus / nerve Medial longitudinal fasciculus Reticular formation	
Mid-Pons	Medial longitudinal fasciculus Reticular formation CST and CBT	Middle cerebellar peduncle Trigeminal sensory and motor nuclei / nerve
Caudal Pons	Abducens nucleus / 6 th nerve Motor fibers of 7 th nerve PPRF – lateral gaze center CST and CBT Medial lemniscus	Facial motor nucleus / 7 th nerve Middle cerebellar peduncle Descending tract/nucleus of 5 Spinothalamic tract Vestibular and Cochlear nuclei 8 th nerve
Rostral medulla	Hypoglossal nucleus / 12 th nerve CST Medial lemniscus	Nucleus ambiguus Exiting 9 th and 10 th nerves Descending tract/nucleus of 5 Spinothalamic tract Vestibular nuclei

*CST = corticospinal tract; CBT = corticobulbar tract

Posterior Cerebral Artery

At the level of the midbrain the basilar artery bifurcates to form the two **posterior cerebral arteries (PCA)**.

Clinical Note: If an embolus travels in a vertebral branch its passage may be blocked where the vertebral arteries join to form the basilar artery. More often, however, it keeps going, traversing the basilar (which has a large diameter) and is arrested at the upper bifurcation of the basilar into the posterior cerebral arteries or in a PCA branch.

As each PCA passes around the cerebral peduncles, it forms short penetrating branches to the **midbrain**, and gives rise to a series of long, slender penetrating arteries that supply much of the **hypothalamus and thalamus**. The circle of Willis partially surrounds the hypothalamus, and additional small perforators from its other vessels also help to supply the hypothalamus.

Clinical Note: After the basal ganglia and internal capsule, the thalamus is the next most frequent site of hypertensive intracerebral hemorrhage and lacunar infarcts. Thalamic hemorrhages may be confined to the thalamus, or the bleeding may involve the neighboring internal capsule, subthalamic nucleus and midbrain, and even rupture into the third ventricle.

The **cortical branches of PCA** supply the posterior medial parietal lobe and the splenium of the corpus callosum, inferior and medial part of the temporal lobe including the hippocampal formation, and the medial and inferior surfaces of the occipital lobe.

Penetrating branches of PCA Supply these Key Functional Areas:

DIENCEPHALON including thalamus, subthalamic nucleus, and hypothalamus

MIDBRAIN including cerebral peduncle, third nerve and nucleus, red nucleus and its connections, superior cerebellar peduncle, reticular formation

Cortical branches of PCA Supply these Key Functional Areas

PARIETAL AND OCCIPITAL LOBE (Posterior branches)

- Optic radiations and striate cortex (the primary visual cortex may be entirely supplied by PCA, or the tip of the occipital lobe where the fovea is mapped may be located in the border zone shared by PCA and MCA)
- Splenium of the corpus callosum (these crossing fibers participate in the transfer of visual information to the language-dominant hemisphere)

MEDIAL TEMPORAL LOBE (Anterior branches)

- Posterior hippocampal formation and the fornix (these structures are critical for laying down new declarative memories)

Clinical Note: Recall that atherosclerotic plaque forms at branchings or curves in vessels. In the vertebral-basilar circulation, it is most frequent in the cervical part of the vertebral arteries and where the vertebral arteries join to form the basilar artery. Plaques are also common in the PCA as it swings around the midbrain on its way to medial parts of the parietal, occipital, and temporal lobes.

Overall cerebral blood flow is constant, but can vary locally

Although we've discussed anatomic variations of the cerebral arteries, our description up to now suggests that they are a system of rigid branching pipes. In reality, however, the cerebral vessels continuously adjust their own caliber by contraction and relaxation of smooth muscle in their walls so that:

- constant cerebral blood flow is normally maintained over mean arterial pressures ranging between approximately 60-150 mm Hg. Thus as intra-arterial pressure goes up, cerebral vessels normally constrict and conversely when pressure drops, cerebral vessels dilate. At extremely low or high arterial pressure levels this response fails, and in those situations cerebral blood flow follows blood pressure more directly. The concept that cerebral vessels themselves have a role in controlling cerebral blood flow is often referred to as **autoregulation**.
- local blood flow can change in response to local neuronal metabolism. For example, increases in arterial (and hence extracellular) carbon dioxide tension in a specific brain region will lead to dilation of its arterioles and an immediate increase in local blood flow.

These responses protect the brain from ischemia by increasing cerebral blood flow (delivery of oxygen and glucose, and removal of carbon dioxide and other metabolites) in the face of decreased arterial pressures. They also support regional variations in brain activity by providing rapid local adjustments of blood flow.

Collateral vessels may modify the effects of cerebral ischemia

There is usually not enough redundancy in the blood vessels of the brain to support function if one vessel is suddenly occluded. If there were, ischemic strokes would be far less frequent.

Many smaller penetrating brain arteries such as the lenticulostriate branches of MCA that supply the basal ganglia and internal capsule, as well as the penetrating branches from arteries on the brain surface that supply deep white matter, are **terminal arteries**. This means that they form few if any connections with other arteries. When they are occluded, the brain regions they supply will therefore become ischemic.

Other vessels form anastomoses that potentially could protect the brain from infarction, or limit the amount of damage, by providing alternative routes for blood flow.

Common and Important Anastomoses can occur between:

- External carotid and internal carotid via branches of the ophthalmic artery
- The major intracranial arteries via the circle of Willis (for example one carotid might supply parts of the contralateral hemisphere by connections through the anterior cerebral and anterior communicating vessels)
- Muscular branches of cervical arteries and the extracranial vertebral or external carotid arteries
- Small cortical branches of ACA, MCA, and PCA, or branches of the major cerebellar arteries

How effective the collateral circulation can be in supporting blood flow and hence neurologic function depends on the size of the vessels. The smaller the diameter of the collaterals, the less likely it is that they will be able to carry enough blood to prevent infarction.

The speed at which the occlusion of a vessel occurs therefore can play a role in determining whether collateral circulation can save the region it supplies from infarction. If a major artery is gradually occluded by atherosclerosis, there may be time for preexisting collateral channels to enlarge to the point where they can support major blood flow. This may happen, for instance, when there is gradual occlusion of the internal carotid artery in the neck by the build up of atherosclerotic plaque. In this situation retrograde flow may develop *from* the external carotid through the ophthalmic artery into the intracranial internal carotid, bypassing the blockage. Some people with one or both internal carotid arteries largely or entirely occluded show no neurologic deficits thanks to collateral circulation around the orbit.

The ‘circle’ of Willis can be a source of effective collateral circulation. At first glance, the anatomy of the circle of Willis suggests that blood can be easily shunted from one side of the brain to the other, or from the carotid to the vertebral-basilar system or vice versa. This may indeed occur, especially in younger individuals. However if one or more of the arteries that forms the circle is narrowed, then the circular connections might not allow enough blood flow to compensate for most abrupt arterial blockages. In this case, it would provide little ‘protection’ against sudden blockage of a vessel by, for example, a cardiac embolus. In the same patient, the circle may be able to compensate for slowly developing arterial occlusions produced by build-up of atherosclerotic plaque, since even tiny arteries can expand their diameters over time in response to steadily increasing hemodynamic demands.

Before we leave the circle of Willis, we should point out that places where large arteries branch or bifurcate are favorite locations for the formation of **saccular (‘berry’) aneurysms**. In these locations the muscular part of the arterial wall is relatively weak, and balloon-like swellings that are prone to rupture may occur. The greatest number of aneurysms involve the anterior portion of the circle of Willis: the junction of the anterior communicating artery with ACA, the junction of the internal carotid and posterior communicating artery, the division of MCA into superior and inferior branches within the Sylvian fissure. If an aneurysm ruptures, blood under high pressure is forced into the subarachnoid space, which contains the circle of Willis, and possibly into the interior of neighboring brain substance as well. Such subarachnoid hemorrhages account for about 3% of all strokes.

Concept of Border zone versus core territory of the cerebral vessels

We have seen that the cerebral cortex is supplied by the cortical branches of MCA, ACA, and PCA. These arteries reach the cortex, divide, and give off branches that penetrate the cortex perpendicularly. Long arteries and arterioles pass through the gray matter and penetrate the white matter to a depth of 3-4 cm, where they supply the core of the hemisphere’s white matter. These arteries intercommunicate very little, and thus constitute many independent small systems. The deeply penetrating vessels that branch directly from major arterial stems (like the lenticulostriate branches of MCA) also do not interconnect. Therefore if one of these arteries is occluded, the tissue it normally supplies will be infarcted since it has no other source of blood flow.

By contrast, the surface arteries supplying the cortical gray matter do anastomose. The anastomoses form a continuous network of tiny arteries covering the perimeters or **border zones** between the core (central) territories of the 3 major cerebral arteries. Since these anastomoses are usually tiny, they carry little blood. Therefore, if one of the major arteries is occluded, the anastomoses cannot carry enough blood to rescue the core territory of that artery from infarction. However, they may be able to supply the border zone, so that the size of the infarction is reduced a little. Conversely, if there is a dramatic impairment of systemic blood pressure (secondary to cardiac arrest or massive bleeding), or decreased pressure specifically in the carotid system (due to an occlusive event), the regions of each vascular territory farthest from the core will become ischemic first. Thus there is risk of infarction specifically in the border zones.

ACA – MCA Border Zone may include these Key Functional Areas:

- Hip, shoulder or less usually arm region of primary motor or somatosensory cortex
- Areas related to language production – in the dominant hemisphere
- Frontal eye fields
- Frontal lobe motor planning areas

ACA/MCA – PCA Border Zone may include these Key Functional Areas:

- Visual radiations
- Foveal region of the striate cortex in some people (in others it may be in PCA territory)
- Inferior temporal lobe cortex important for visual recognition
- Areas related to language comprehension, word finding, and possibly reading –in the dominant hemisphere
- Areas of parietal lobe important for attention and visuospatial perceptions –in the nondominant hemisphere

Why we have not discussed the cerebral veins

Infarction or hemorrhage caused by problems in the venous rather than the arterial system is fairly rare. Venous thrombosis is associated with medical conditions that lead to a prothrombotic state, and also with blood volume depletion, medications, or head trauma. Its frequency increases in women during pregnancy particularly in the third trimester, and in the first 6 weeks postpartum. Usually large sinuses (e.g. the superior sagittal sinus) and large veins are most affected. Said simply, what often happens is that blockage of a large vein can ‘back up’ the circulation in a region, causing decreased arterial flow that in turn produces ischemia and infarction (and sometimes hemorrhage into the infarcted tissue).

Clinical findings in these patients typically do not reflect the typical arterial territory syndromes that you have been learning about. One of the reasons for this may be that there are far more functional anastomoses in the venous than in the arterial system. While problems secondary to occlusion of cerebral veins may not be particularly helpful in learning about the territories supplied by the cerebral arteries, they are very important to consider from a clinical perspective.