Section C

NEUROLOGICAL NEUROANATOMY

INTRODUCTION

A thorough understanding of the structure and function of the nervous system is the foundation for clinical neurology. The neurologist's task is to analyze the history of the illness and the symptoms and signs of the patient, decide whether the problem is in fact neurological, configure the patient's complaints and the physical findings to establish where in the nervous system the problem is located (localization), and then to ascertain a cause for the disease (etiology). At some stage, laboratory investigations and imaging studies are used to confirm the localization of the disease and to assist in establishing the diagnosis. An appropriate therapeutic plan would then be proposed, and the patient can be advised of the long-term outlook of his or her disease (the prognosis), and its impact on life, family, and employment (psychosocial issues).

A simple mnemonic using the letter "w" helps to recall the basic steps necessary to establish a neurological diagnosis:

- **Whether** the signs and symptoms are consistent with involvement of the nervous system, based upon a detailed history and a complete neurological examination
- **Where** the nervous system problem is located (i.e., **localization**)
- **What** is the etiology of the disease, its pathophysiological mechanism(s)

Diseases can be recognized by skilled and knowledgeable expert clinicians based upon their presentation (for example, vascular lesions have a sudden onset vs. a slow onset for tumors), the age of the patient, the part(s) of the nervous system involved, and the evolution of the disease process. The task is more complex in children, depending on the age, because the nervous system continues to develop through infancy and childhood; diseases interfere with and interrupt this developmental pattern. Knowledge of normal growth and development is necessary to practice pediatric neurology.

LEARNING PLAN

The learning objective of this section is to synthesize the structural and functional aspects of the nervous system. This should enable the student to localize the disease process within the nervous system.

The vascular supply of the brain will be studied at this point, allowing the learner to integrate the vascular information with the functioning of the nervous system. The thalamus will be presented once again, permitting a synthesis of the connections of the thalamic nuclei, both on the input side and with the cerebral cortex.

There is an emphasis in this section on the brainstem microanatomy; often the brainstem presents an overwhelming challenge to students struggling to learn the nervous system (see below). Finally, the spinal cord will be presented with all the ascending (sensory) and descending (motor) tracts.

VASCULAR SUPPLY

The CNS is dependent upon a continuous supply of blood; viability of the neurons depends upon the immediate and constant availability of both oxygen and glucose. Interruption of this lifeline causes sudden loss of function. Study of the nervous system must include a complete knowledge of the blood supply and which structures (nuclei and tracts) are situated in the vascular territory of the various arteries. Failure of the blood supply to a region, either because of occlusion or hemorrhage, will lead to death of the neurons and axons, leading to functional deficits.

Areas of gray matter, where the neurons are located, have a greater blood supply than white matter. Loss of oxygen and glucose supply to these neurons will lead to loss of electrical activity after a few minutes (in adults), and if continued for several minutes, to neuronal death. Although white matter requires less blood supply, loss of adequate supply leads to destruction of the axons in the area of the infarct and an interruption of pathways. After loss of the cell body or interruption of the axon, the distal portion of the axon (the part on the other side of the lesion separated from the cell body) and the synaptic connections will degenerate, leading to a permanent loss of function.

Every part of the nervous system lies within the vascular territory of an artery, sometimes with an overlap from adjacent arteries. Visualization of the arterial (and venous) branches can be accomplished using:

- **Arteriogram**: By injecting a radiopaque substance into the arteries (this is a procedure that is done by a neuroradiologist) and following its course through a rapid series of x-rays (called an **arteriogram**), a detailed view of the vasculature of the brain is obtained; either the carotid or vertebral artery is usually injected, according to which arterial tree is under investigation. This is an invasive procedure carrying a certain degree of risk.
- **MR Angiogram**: Using neuroradiology imaging with MRI (discussed with Figure 59), the major blood vessels (such as the circle of Willis) can be visualized; this is called a magnetic resonance angiogram (**MRA**).

CLINICAL ASPECT

It is extremely important to know which parts of the brain are located in the territory supplied by each of the major cerebral and brainstem blood vessels, and to understand the functional contribution of these parts. This is fundamental for clinical neurology.

A clinical syndrome involving the arteries of the brain is often called a cerebrovascular accident (**CVA**) or "**a stroke**." The nature of the process, blood vessel occlusion through infarction or embolus, or hemorrhage, is not specified by the use of this term; nor does the term indicate which blood vessel is involved. The clinical event is a sudden loss of function; the clinical deficit will depend upon where the occlusion or hemorrhage occurred.

Occlusion is more common than hemorrhage, often caused by an embolus (e.g., from the heart). Hemorrhage may occur into the brain substance (parenchymal), causing destruction of the brain tissue and at the same time depriving areas distally of blood.

HISTOLOGICAL NEUROANATOMY

This section presents the detailed neuroanatomy that is needed for localization of lesions in the brainstem. A series of illustrations is presented through the brainstem to enable the learner to integrate the nuclei, both cranial nerve and other important nuclei, and the tracts passing through that region. Accompanying these schematics are photographs of the brainstem from the human brain — at the same levels. The same approach is used for the spinal cord, a common site for clinical disease and traumatic injuries.

INTRACRANIAL PRESSURE (ICP)

In addition to knowledge of the brain and the function of the various parts and the blood supply, many disease processes exert their effect because of a rise in intracranial pressure (ICP). This may lead to a displacement of brain tissue within the skull. The adult skull is a rigid container filled with the brain, the cerebrospinal fluid (CSF), and blood. The interior of the skull is divided into compartments by folds of dura: the **falx cerebri** in the midline between the hemispheres (see Figure 16) and the **tentorium cerebelli**, which partially separates the hemispheres from the contents of the posterior cranial fossa, the brainstem and cerebellum (see Figure 17 and Figure 30). The opening in the tentorium for the brainstem, called the tentorial notch or incisura, is at the level of the upper midbrain (see Figure 30). (**Note to the Learner**: Anatomy texts should be consulted for a visual understanding of these structures.)

CLINICAL ASPECT

Any increase in volume inside the skull — due to brain swelling, tumor, abscess, hemorrhage, abnormal amount of CSF — causes a rise in pressure inside the skull (i.e., ICP). Although brain tissue itself has no pain fibers, the blood vessels and meninges do, hence any pulling on the meninges may give rise to a headache. This process may be acute, subacute, or chronic. A prolonged increase in ICP can be detected clinically by examining the optic disc; its margins will become blurred and the disc itself engorged, called **papilledema**.

Any space-occupying lesion (e.g., sudden hemorrhage, slow-growing tumor), depending upon the lesion and its progression, will sooner or later cause a displacement of brain tissue from one compartment to another. This pathological displacement causes damage to the brain. This is called a **brain herniation** syndrome and typically occurs:

- Through the foramen magnum, **tonsillar herniation** (discussed with Figure 9B)
- Through the tentorial notch, **uncal herniation** (discussed with Figure 15B)
- Under the falx cerebri

These shifts are life-threatening and require emergency management. (**Note to the Learner:** This would be an opportune time to review the signs and symptoms associated with these clinical emergencies, such as testing of the pupillary light reflex and the pathway involved.)

FIGURE 58
BLOOD SUPPLY 1

THE ARTERIAL CIRCLE OF WILLIS (PHOTOGRAPHIC VIEW WITH OVERLAY)

The arterial circle (of Willis) is a set of arteries interconnecting the two sources of blood supply to the brain, the vertebral and internal carotid arteries. It is located at the base of the brain, surrounding the optic chiasm and the hypothalamus (the mammillary nuclei) (review Figure 15A and Figure 15B). Within the skull, it is situated above the pituitary fossa (and gland). The major arteries to the cerebral cortex of the hemispheres are branches of this arterial circle. This illustration is a photographic view of the inferior aspect of the brain, including brainstem and cerebral hemispheres, with the blood vessels (as in Figure 15A). Branches from the major arteries have been added to the photographic image.

The cut end of the **internal carotid** arteries is a starting point. Each artery divides into the **middle cerebral** artery (MCA) and the **anterior cerebral** artery (ACA). The MCA courses within the lateral fissure. The anterior portion of the temporal lobe has been removed on the left side of this illustration in order to follow the course of the MCA in the lateral fissure. Within the fissure, small arteries are given off to the basal ganglia, called the **striate** arteries (not labeled; see Figure 62). The artery emerges at the surface (see Figure 14A) and courses upward, dividing into branches that are distributed onto the dorsolateral surface of the hemispheres (see Figure 60).

By removing (or lifting) the optic chiasm, the ACA can be followed anteriorly. This artery heads into the interhemispheric fissure (see Figure 16) and will be followed when viewing the medial surface of the brain (see Figure 17 and Figure 61). A very short artery connects the ACAs of the two sides, the **anterior communicating** artery.

The vertebro-basilar system supplies the brainstem and cerebellum, and the posterior part of the hemispheres. The two **vertebral** arteries unite at the lower border of the pons to form the midline **basilar** artery, which courses in front of the pons. The basilar artery terminates at the midbrain level by dividing into two **posterior cerebral** arteries. These supply the inferior aspect of the brain and particularly the occipital lobe (see Figure 61).

The arterial circle is completed by the **posterior communicating** artery (normally one on each side), which connects the internal carotid (or middle cerebral) artery, often called the anterior circulation, with the posterior cerebral artery, the posterior circulation.

Small arteries directly from the circle (not shown) provide the blood supply to the diencephalon (thalamus and hypothalamus), some parts of the internal capsule, and part of the basal ganglia. The major blood supply to these regions is from the striate arteries (see Figure 62).
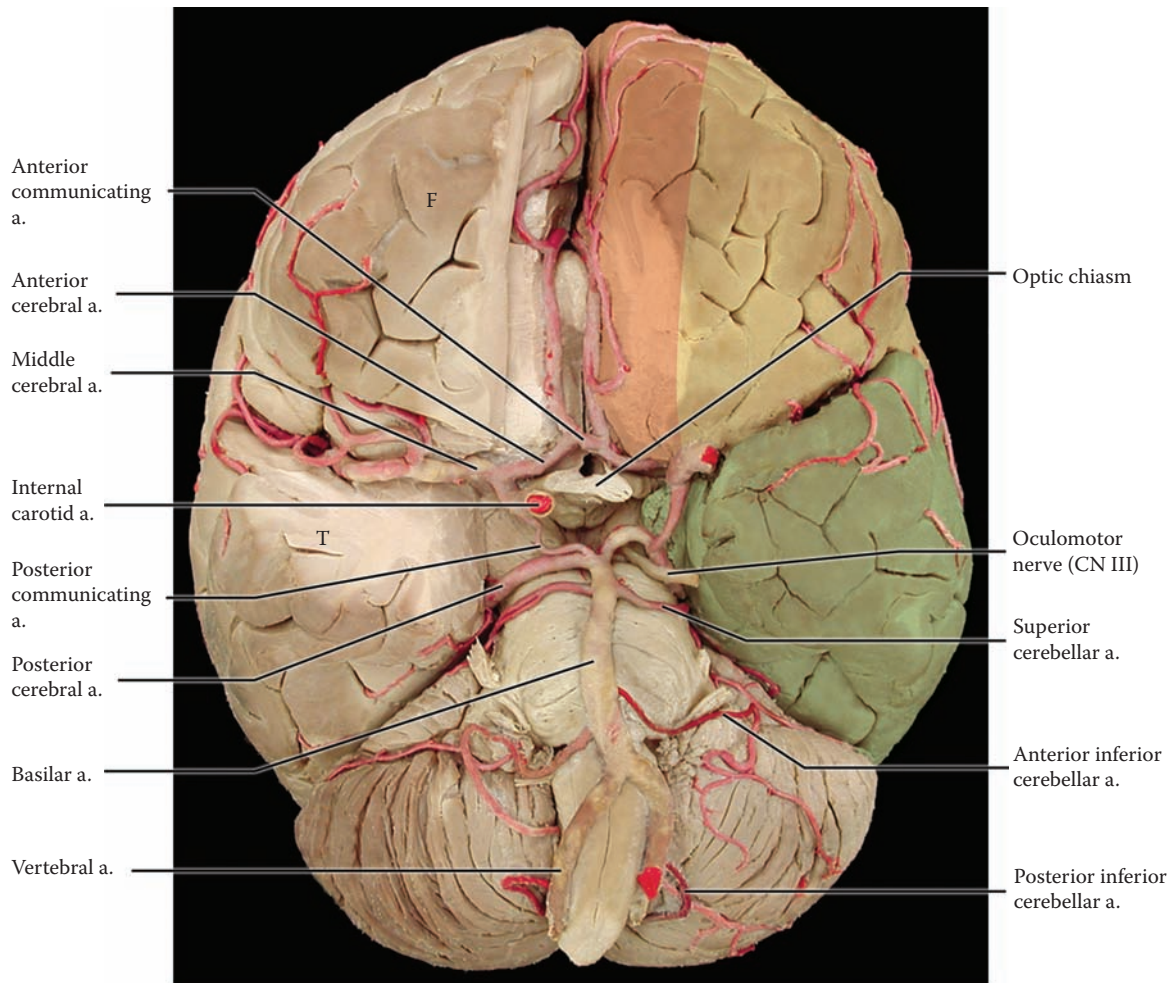
The branches from the vertebral and basilar artery supply the brainstem. Small branches directly from the vertebral and basilar arteries (not shown), known as **paramedian** arteries, supply the medial structures of the brainstem (further discussed with Figure 67B). There are three major branches from this arterial tree to the cerebellum — the **posterior inferior cerebellar** artery (**PICA**), **the anterior inferior cerebellar** artery (AICA), and the **superior cerebellar** artery. All supply the lateral aspects of the brainstem, including nuclei and tracts, en route to the cerebellum; these are often called the **circumferential** branches.

The blood supply to the spinal cord is shown in Figure 2B and is discussed with Figure 68.

CLINICAL ASPECT

The vascular territories of the various cerebral blood vessels are shown in color in this diagram. The most common clinical lesion involving the cerebral blood vessels is occlusion, often due to an embolus originating from the heart or the carotid bifurcation in the neck. These clinical deficits will be described with each of the major branches to the cerebral cortex (with Figure 60 and Figure 61).

In the eventuality of a slow occlusion of one of the major blood vessels of the circle, sometimes one of the communicating branches becomes large enough to provide sufficient blood to be shunted to the area deprived (see Figure 59B). One of the vascular syndromes of the brainstem, the lateral medullary syndrome (of Wallenberg) is discussed with Figure 67B.

Anterior
communicating
a.

Anterior
cerebral a.

Middle
cerebral a.

Internal
carotid a.

Posterior
communicating
a.

Posterior
cerebral a.

Basilar a.

Vertebral a.

F

T

Optic chiasm

Oculomotor
nerve (CN III)

Superior
cerebellar a.

Anterior inferior
cerebellar a.

Posterior inferior
cerebellar a.

F = Frontal lobe
T = Temporal lobe

Areas supplied by:
    Anterior cerebral a.
    Middle cerebral a.
    Posterior cerebral a.

FIGURE 58: Blood Supply 1 — Arterial Circle of Willis (photograph with overlay)

FIGURE 59A
BLOOD SUPPLY 2

MR ANGIOGRAM — MRA

Recent advances in technology have allowed for a visualization of the major blood vessels supplying the brain, notably the arterial circle of Willis. This investigation does not require an invasive procedure (described with the next illustration), although an injection intravenously of a contrast substance called gadolinium maybe used (discussed with Figure 28B). Although the quality of such images cannot match the detail seen after an angiogram of select blood vessels (shown in the next illustration), the noninvasive nature of this procedure, and the fact that the patient is not exposed to any risk, clearly establishes this investigation as desirable to provide some information about the state of the cerebral vasculature.

UPPER RADIOGRAPH

This arteriogram shows the **circle of Willis** as seen as if looking at the brain from below (as in the previous illustration). The internal carotid artery goes through the cavernous (venous) sinus of the skull, forming a loop that is called the carotid siphon. It then divides into the anterior cerebral artery, which goes anteriorly, and the middle cerebral artery, which goes laterally. The basilar artery is seen at its termination, as it divides into the posterior cerebral arteries. The anterior communicating artery is present, and there are two posterior communicating arteries completing the circle, joining the internal carotid with the posterior cerebral on each side.

LOWER RADIOGRAPH

This is the same angiogram, displayed at a different orientation, as though you are looking at the patient "face-on,' but, wtih his/her head tilted forward slightly. The two vertebral arteries can be seen, joining to form the basilar artery; it is not uncommon to see the asymmetry in these vessels. The posterior inferior cerebellar artery (PICA) can be seen, a branch of the vertebral (it is also labeled in the upper radiograph), but not the anterior inferior cerebellar artery, a branch of the basilar (see Figure 58). The basilar artery gives off the superior cerebellar arteries and then ends by dividing into the posterior cerebral arteries. The internal carotid artery can be followed through its curvature in the petrous temporal bone of the skull, before dividing into the anterior and middle cerebral arteries.

CLINICAL ASPECT

One of the characteristic vascular lesions in the arteries that make up the arterial circle of Willis is a type of aneurysm, called a **Berry aneurysm**. This is caused by a weakness of part of the wall of the artery, causing a local ballooning of the artery. Often these aneurysms rupture spontaneously, particularly if there is accompanying hypertension. This sudden rupture occurs into the subarachnoid space and may also involve nervous tissue of the base of the brain. The whole event is known as a **subarachnoid hemorrhage**, and this diagnosis must be considered when one is faced clinically with an acute major cerebrovascular event, without trauma, accompanied by intensely severe headache and often a loss of consciousness.

Sometimes these aneurysms leak a little blood, which causes an irritation of the meninges and accompanying symptoms of headache. An MRA can, at the minimum, visualize whether there is an aneurysm on one of the vessels of the circle, and whether the major blood vessels are patent.

Note to the Learner: One of the best ways of learning the arterial supply to the brain and the circle of Willis is to actually make a sketch drawing, accompanied by a list of the areas supplied and the major losses that would follow a sudden occlusion. The blood supply to the brainstem and the most common vascular lesions affecting this area will be discussed with the illustrations to follow.
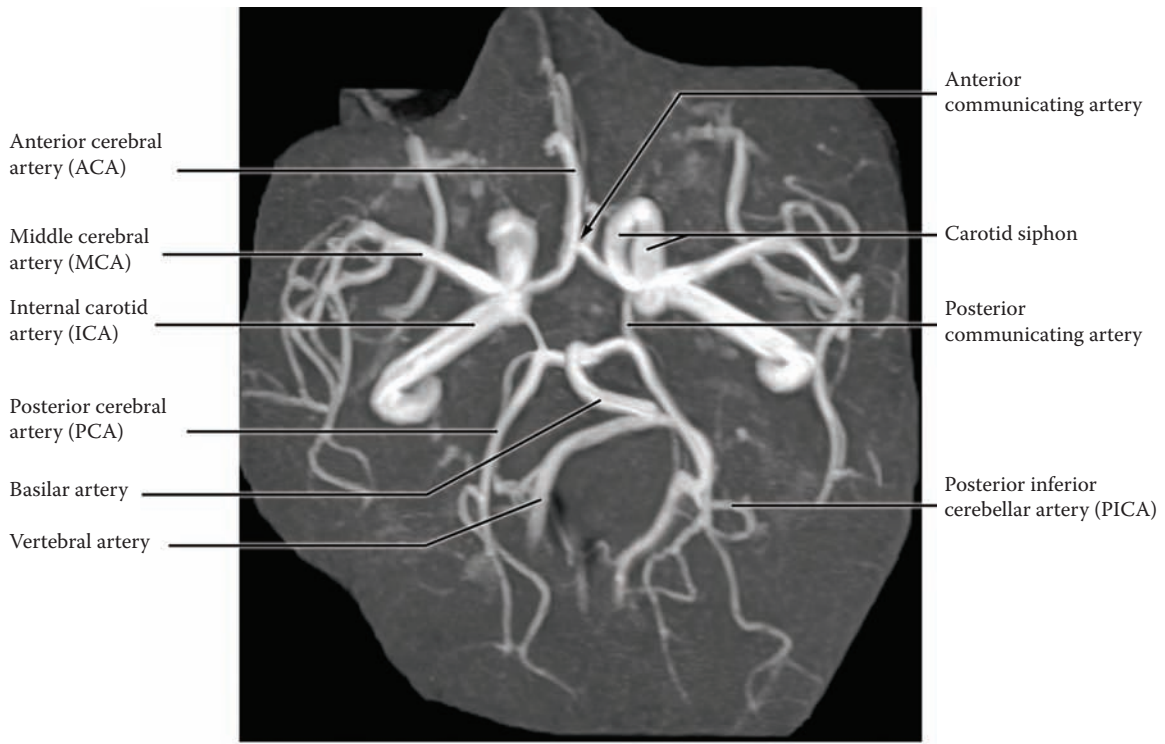
Inferior view
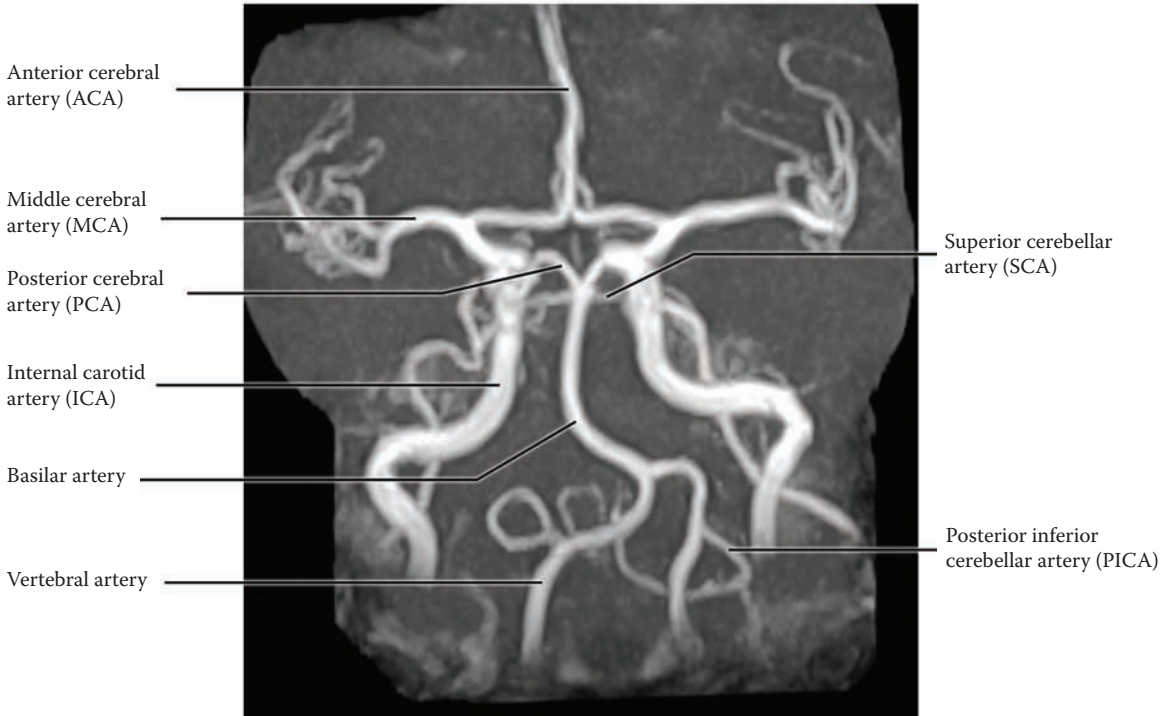
Tilted anterior view

FIGURE 59A: Blood Supply 2 — MR Angiogram: MRA (radiograph)

FIGURE 59B
BLOOD SUPPLY 3

CEREBRAL ANGIOGRAM

This radiograph was done by injecting a radiopaque dye into the left internal carotid artery. The usual procedure involves threading a catheter from the groin up the aorta and into the internal carotid artery, under fluoroscopic guidance, a procedure not without risk; then a radiopaque dye is injected within the artery.

In this particular case, there had been a slow occlusion of the right internal carotid, allowing time for the anterior communicating artery of the circle of Willis to become widely patent; therefore, blood was shunted into the anterior and middle cerebral arteries on the affected side. This is not usual, and in fact, this radiogram was chosen for this reason.

The middle cerebral artery goes through the lateral fissure and breaks up into various branches on the dorsolateral surface of the hemisphere (shown in the next illustration). The lenticulostriate (striate) arteries given off en route supply the interior structures of the hemisphere (to be discussed with Figure 62).

This radiograph shows the profuseness of the blood supply to the brain, the hemispheres, and is presented to give the student that visual image, as well as to show the appearance of an angiogram.

CLINICAL ASPECT

Visualization of the blood supply to the brain is required for the accurate diagnosis of aneurysms and occlusions affecting these blood vessels. Procedures are now done within the blood vessels (intravascular), using specialized catheters to destroy an identified blood clot, or to insert a metal "coil" into an aneurysm (thereby "curing" the problem). These procedures are done by interventional neuroradiologists.
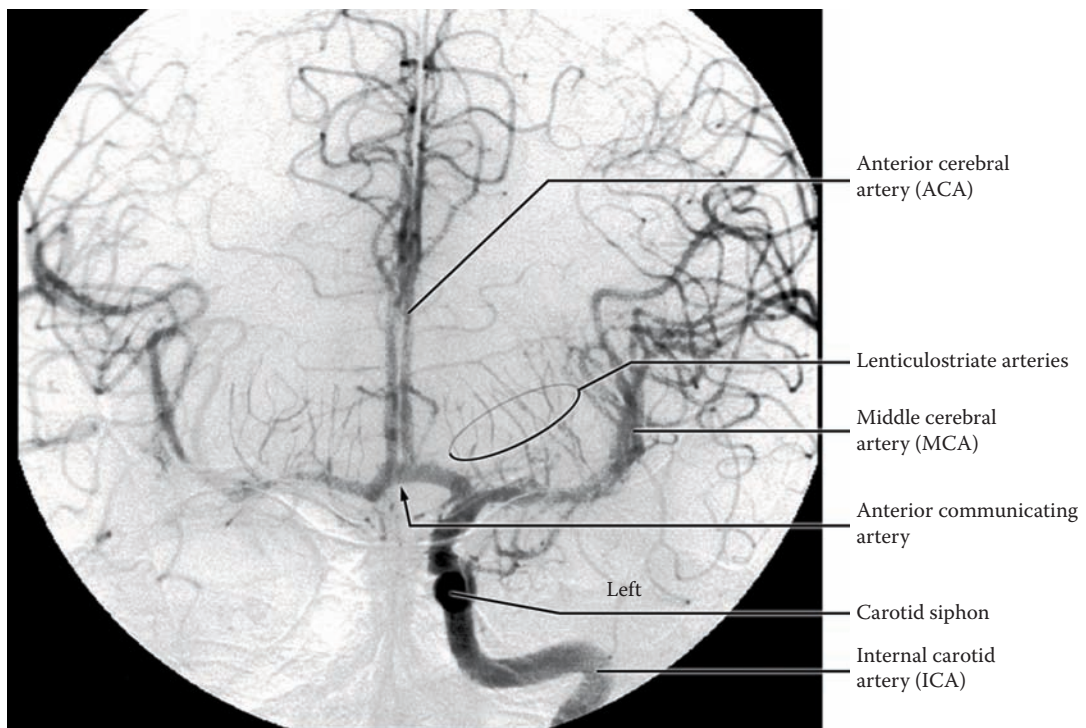
Anterior cerebral artery (ACA)

Lenticulostriate arteries

Middle cerebral artery (MCA)

Anterior communicating artery

Left

Carotid siphon

Internal carotid artery (ICA)

FIGURE 59B: Blood Supply 3 — Cerebral Angiogram (radiograph)

FIGURE 60
BLOOD SUPPLY 4

CORTICAL: DORSOLATERAL
(PHOTOGRAPHIC VIEW WITH
OVERLAY)

This illustration shows the blood supply to the cortical areas of the dorsolateral aspect of the hemispheres; it has been created by superimposing the blood vessels onto the photographic view of the brain (the same brain as in Figure 14A).

After coursing through the depths of the lateral fissure (see Figure 58 and Figure 59B), the **middle cerebral artery** emerges and breaks into a number of branches that supply different parts of the dorsolateral cortex — the frontal, parietal, and temporal areas of the cortex. Each branch supplies a different territory, as indicated; branches supply the precentral and post-central gyri, the major motor and sensory areas for the face and head and the upper limbs. On the dominant side, this includes the language areas (see Figure 14A).

The vascular territories of the various cerebral blood vessels are shown in color in this diagram. The branches of the middle cerebral artery extend toward the midline sagittal fissure, where branches from the other cerebral vessels (anterior and posterior cerebral) are found, coming from the medial aspect of the hemispheres (see next illustration). A zone remains between the various arterial territories — the arterial **borderzone** region (a watershed area). This area is poorly perfused and prone to infarction, particularly if there is a sudden loss of blood pressure (e.g., with cardiac arrest or after a major hemorrhage).

CLINICAL ASPECT

The most common clinical lesion involving these blood vessels is occlusion, often due to an embolus originating from the heart or the carotid bifurcation in the neck. This results in infarction of the nervous tissue supplied by that branch — the clinical deficit will depend upon which branch or branches are involved. For example, loss of sensory or motor function to the arm and face region will be seen after the blood vessel to the central region is occluded. The type of language loss that occurs will depend upon the branch affected, in the dominant hemisphere — a deficit in expressive language will be seen with a lesion affecting Broca's area, whereas a comprehension deficit is found with a lesion affecting Wernicke's area.

Acute strokes are now regarded as an emergency with a narrow therapeutic window. According to current evidence, if the site of the blockage can be identified and the clot (or embolus) removed within three hours, there is a good chance that the individual will have significant if not complete recovery of function. The therapeutic measures include a substance that will dissolve the clot, or interventional neuroradiology whereby a catheter is threaded through the vasculature and into the brain and the clot is removed. Major hospitals now have a "stroke protocol," including a CT scan, to investigate these people immediately when brought to emergency so that therapeutic measures can be instituted.

A clinical syndrome has been defined in which there is a temporary loss of blood supply affecting one of the major blood vessels. Some would limit this temporary loss to less than one hour, whereas others suggest that this period could extend to several hours. This syndrome is called **a transient ischemic attack (TIA)**. Its cause could be blockage of a blood vessel that resolves spontaneously, or perhaps an embolus that breaks up on its own. Regardless, people are being educated to look at this event as a *brain attack*, much like a heart attack, and to seek medical attention immediately. The statistics indicate that many of these people would go on to suffer a significant stroke.
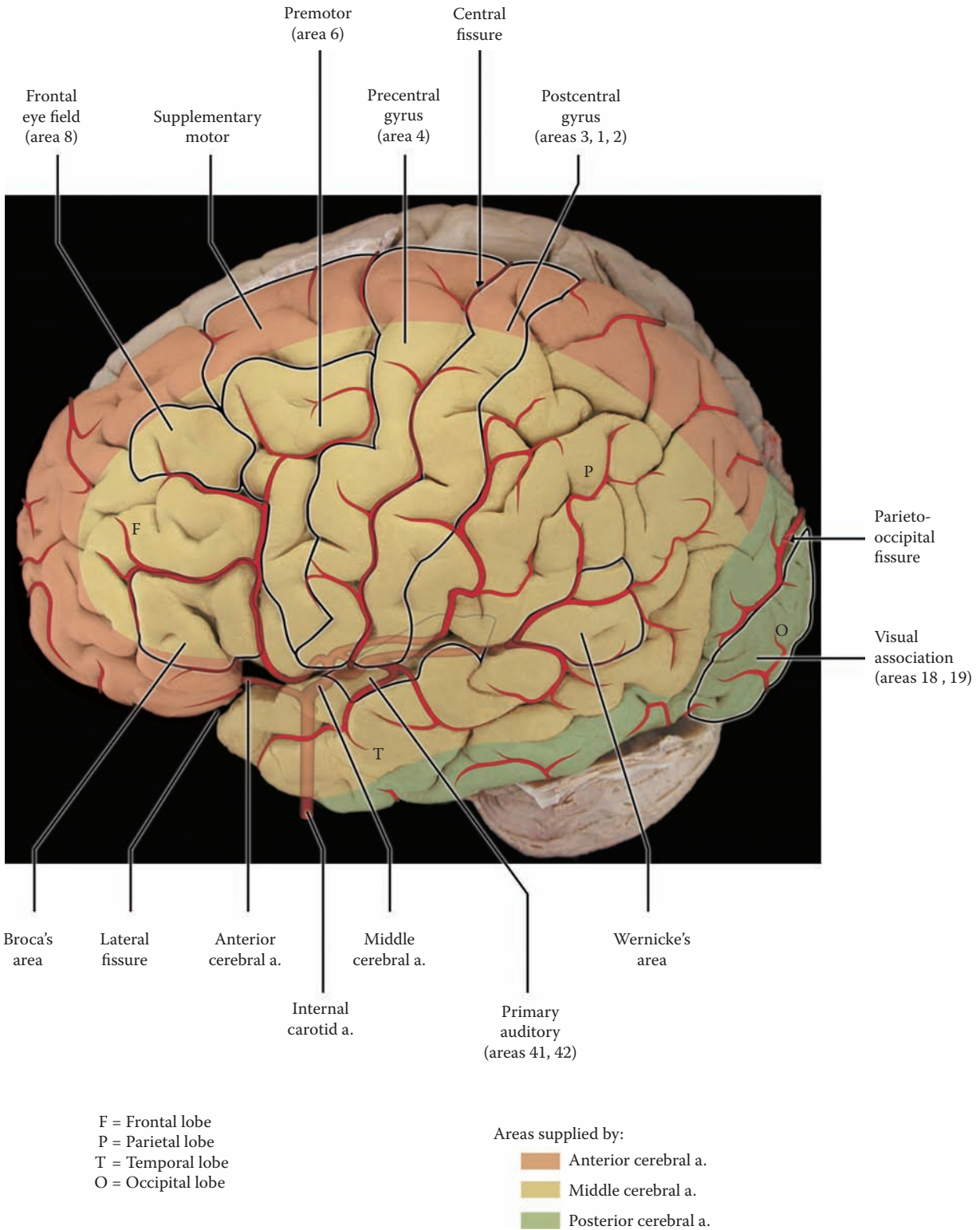
Premotor
(area 6)

Central
fissure

Frontal
eye field
(area 8)

Supplementary
motor

Precentral
gyrus
(area 4)

Postcentral
gyrus
(areas 3, 1, 2)

Parieto-
occipital
fissure

Visual
association
(areas 18 , 19)

Broca's
area

Lateral
fissure

Anterior
cerebral a.

Middle
cerebral a.

Wernicke's
area

Internal
carotid a.

Primary
auditory
(areas 41, 42)

F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Areas supplied by:

Anterior cerebral a.

Middle cerebral a.

Posterior cerebral a.

FIGURE 60: Blood Supply 4 — Cortical Dorsolateral Surface (photograph with overlay)

FIGURE 61
BLOOD SUPPLY 5

CORTICAL: MEDIAL (PHOTOGRAPHIC VIEW WITH OVERLAY)

In this illustration, the blood supply to the medial aspect of the hemispheres has been superimposed onto this view of the brain (see Figure 17). Two arteries supply this part — the anterior cerebral artery and the posterior cerebral artery. The vascular territories of the various cerebral blood vessels are shown in color in this diagram.

The **anterior cerebral artery** (ACA) is a branch of the internal carotid artery from the circle of Willis (see Figure 58, Figure 59A, and Figure 59B). It runs in the interhemispheric fissure, above the corpus callosum (see Figure 16) and supplies the medial aspects of both the frontal lobe and the parietal lobe; this includes the cortical areas responsible for sensory-motor function of the lower limb.

The **posterior cerebral artery** (PCA) supplies the occipital lobe and the visual areas of the cortex, areas 17, 18, and 19 (see Figure 41A and Figure 41B). The posterior cerebral arteries are the terminal branches of the basilar artery from the vertebral or posterior circulation (see Figure 58). The demarcation between these arterial territories is the parieto-occipital fissure.

Both sets of arteries have branches that spill over to the dorsolateral surface. As noted (in the previous illustration), there is a potential gap between these and the territory supplied by the middle cerebral artery, known as the arterial borderzone or watershed region.

BRAINSTEM

The blood supply to the brainstem and cerebellum is shown from this perspective, and should be reviewed with Figure 58. The three cerebellar arteries — posterior inferior, anterior inferior, and superior — are branches of the vertebro-basilar artery, supplying the lateral aspects of the brainstem en route to the cerebellum.

CLINICAL ASPECT

The deficit most characteristic of an occlusion of the ACA is selective loss of function of the lower limb. Clinically, the control of micturition seems to be located on this medial area of the brain, perhaps in the supplementary motor area (see Figure 53), and symptoms related to voluntary bladder control may also occur with lesions in this area.

The clinical deficit found after occlusion of the posterior cerebral artery on one side is a loss of one-half of the visual field of both eyes — a contralateral homonymous hemianopia. The blood supply to the calcarine cortex, the visual cortex, area 17, is discussed with Figure 41B. (**Note to the Learner**: This is an opportune time to review the optic pathway and to review the visual field deficits that are found after a lesion in different parts of the visual system.)

Recent studies indicate that the core of tissue that has lost its blood supply is surrounded by a region where the blood supply is marginal, but which is still viable and may be rescued — the "**penumbra**," as it is now called. In this area surrounding the infarcted tissue, the blood supply is reduced below the level of nervous tissue functionality and the area is therefore "silent," but the neurons are still viable.

These studies have led to a rethinking of the therapy of strokes:

- In the acute stage, if the patient can be seen quickly and investigated immediately, the site of the lesion might be identified. This is the basis for the immediate treatment of strokes with powerful drugs to dissolve the clot or the use of interventional neuroradiology (in large centers). If done soon enough after the "stroke," it may be possible to avert any clinical deficit.
- There may be an additional period beyond this timeframe when damaged neurons in the penumbra can be rescued through the use of neuroprotective agents — specific pharmacological agents that protect the neurons from the damaging consequences of loss of blood supply.

As loss of function and diminished quality of life are the end result of strokes, and with our aging population, it is clear that this is a most active area of neuroscience research.
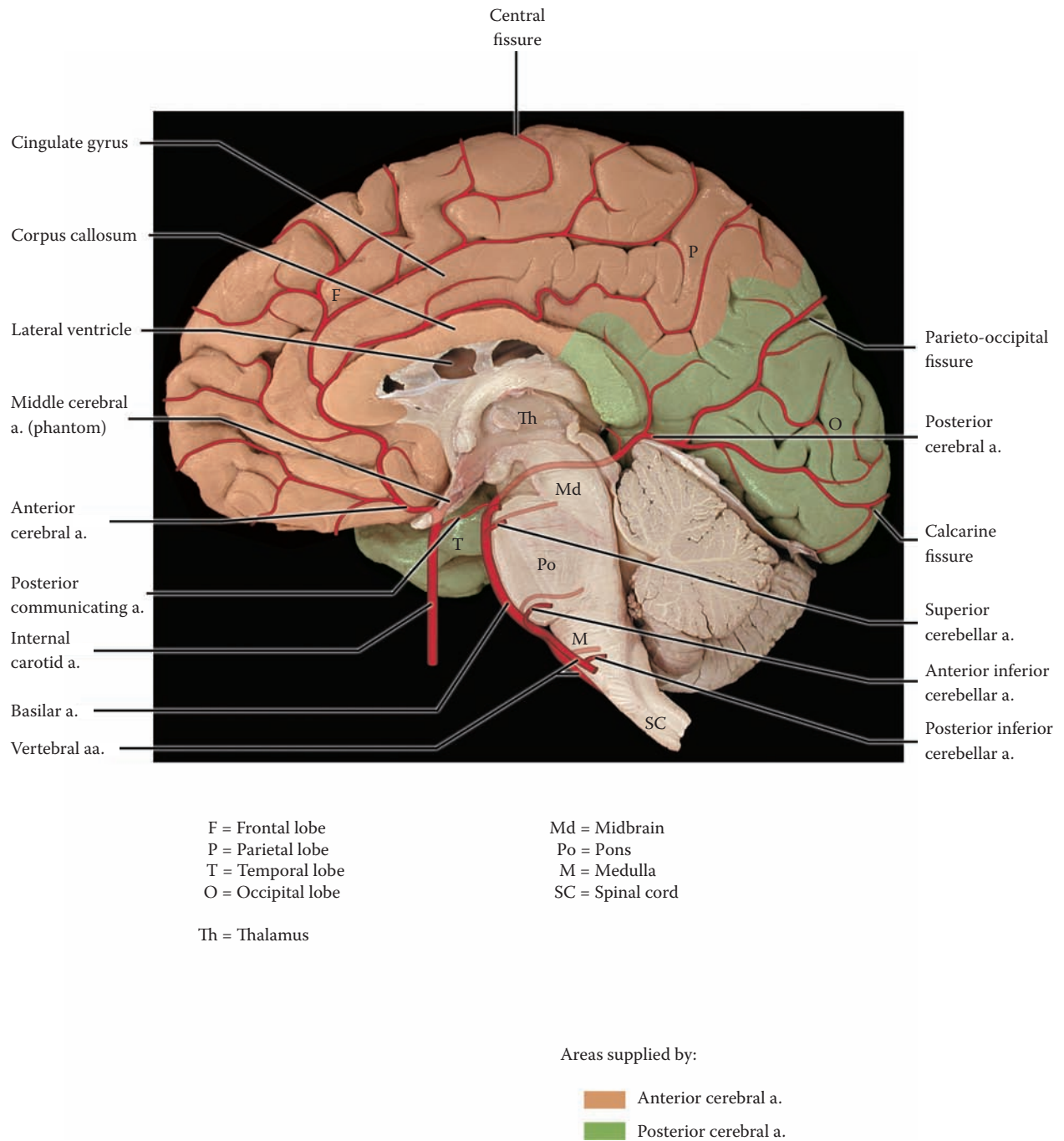
Central
fissure

Cingulate gyrus

Corpus callosum

Lateral ventricle

Middle cerebral
a. (phantom)

Anterior
cerebral a.

Posterior
communicating a.

Internal
carotid a.

Basilar a.

Vertebral aa.

P

F

Th

Md

T

Po

M

SC

O

Parieto-occipital
fissure

Posterior
cerebral a.

Calcarine
fissure

Superior
cerebellar a.

Anterior inferior
cerebellar a.

Posterior inferior
cerebellar a.

F = Frontal lobe
P = Parietal lobe
T = Temporal lobe
O = Occipital lobe

Md = Midbrain
Po = Pons
M = Medulla
SC = Spinal cord

Th = Thalamus

Areas supplied by:

Anterior cerebral a.

Posterior cerebral a.

FIGURE 61: Blood Supply 5 — Cortical Medial Surface (photograph with overlay)

FIGURE 62
BLOOD SUPPLY 6

INTERNAL CAPSULE (PHOTOGRAPHIC VIEW WITH OVERLAY)

One of the most important sets of branches of the middle cerebral artery is found within the lateral fissure (this artery has been dissected in Figure 58). These are known as the **striate** arteries, also called lenticulostriate arteries (see Figure 59B). These branches supply most of the internal structures of the hemispheres, including the internal capsule and the basal ganglia (discussed with Figure 26; see also Figure 27 and Figure 29).

In this illustration, a coronal section of the brain (see Figure 29), the middle cerebral artery is shown traversing the lateral fissure. The artery begins as a branch of the circle of Willis (see Figure 58; also Figure 59B). Several small branches are given off, which supply the area of the lenticular nucleus and the internal capsule, as well as the thalamus. The artery then emerges, after passing through the lateral fissure, to supply the dorsolateral cortex (see Figure 60).

These small blood vessels are the major source of blood supply to the internal capsule and the adjacent portions of the basal ganglia (head of caudate nucleus and putamen), as well as the thalamus (see Figure 26). Some of these striate arteries enter the brain through the anterior perforated space (area) which is located where the olfactory tract divides (see Figure 15B and Figure 79; also shown in Figure 80B). Additional blood supply to these structures comes directly from small branches of the circle of Willis (discussed with Figure 58).

CLINICAL ASPECT

These small-caliber arteries are functionally different from the cortical (cerebral) vessels. Firstly, they are end-arteries, and do not anastomose. Secondly, they react to a chronic increase of blood pressure (hypertension) by a necrosis of the muscular wall of the blood vessels, called fibrinoid necrosis. Following this there are two possibilities:

- These blood vessels may occlude, causing small infarcts in the region of the internal capsule. As these small infarcts resolve, they leave small "holes" called lacunes (lakes), which can be visualized radiographically. Hence, they are known as **lacunar infarcts**, otherwise called a "stroke."

The extent of the clinical deficit with this type of infarct depends upon its location and size in the internal capsule. A relatively small lesion may cause major motor and/or sensory deficits on the contralateral side. This may result in a devastating incapacity of the person, with contralateral paralysis. (**Note to the Leaner:** The learner should review the major ascending and descending tracts at this time and their course through the internal capsule.)

- The other possibility is that these weakened blood vessels can rupture, leading to hemorrhage deep in the hemispheres. (Brain hemorrhage can be visualized by CT, computed tomography; reviewed with Figure 28A).

Although the blood supply to the white matter of the brain is significantly less (because of the lower metabolic demand), this nervous tissue is also dependent upon a continuous supply of oxygen and glucose. A loss of blood supply to the white matter will result in the loss of the axons (and myelin) and, hence, interruption of the transmission of information. This type of stroke may result in a more extensive clinical deficit, due to the fact that the hemorrhage itself causes a loss of brain tissue, as well as a loss of the blood supply to areas distal to the site of the hemorrhage.

ADDITIONAL DETAIL

Choroidal arteries, branches from the circle, supply the choroid plexus of the lateral venrricles.
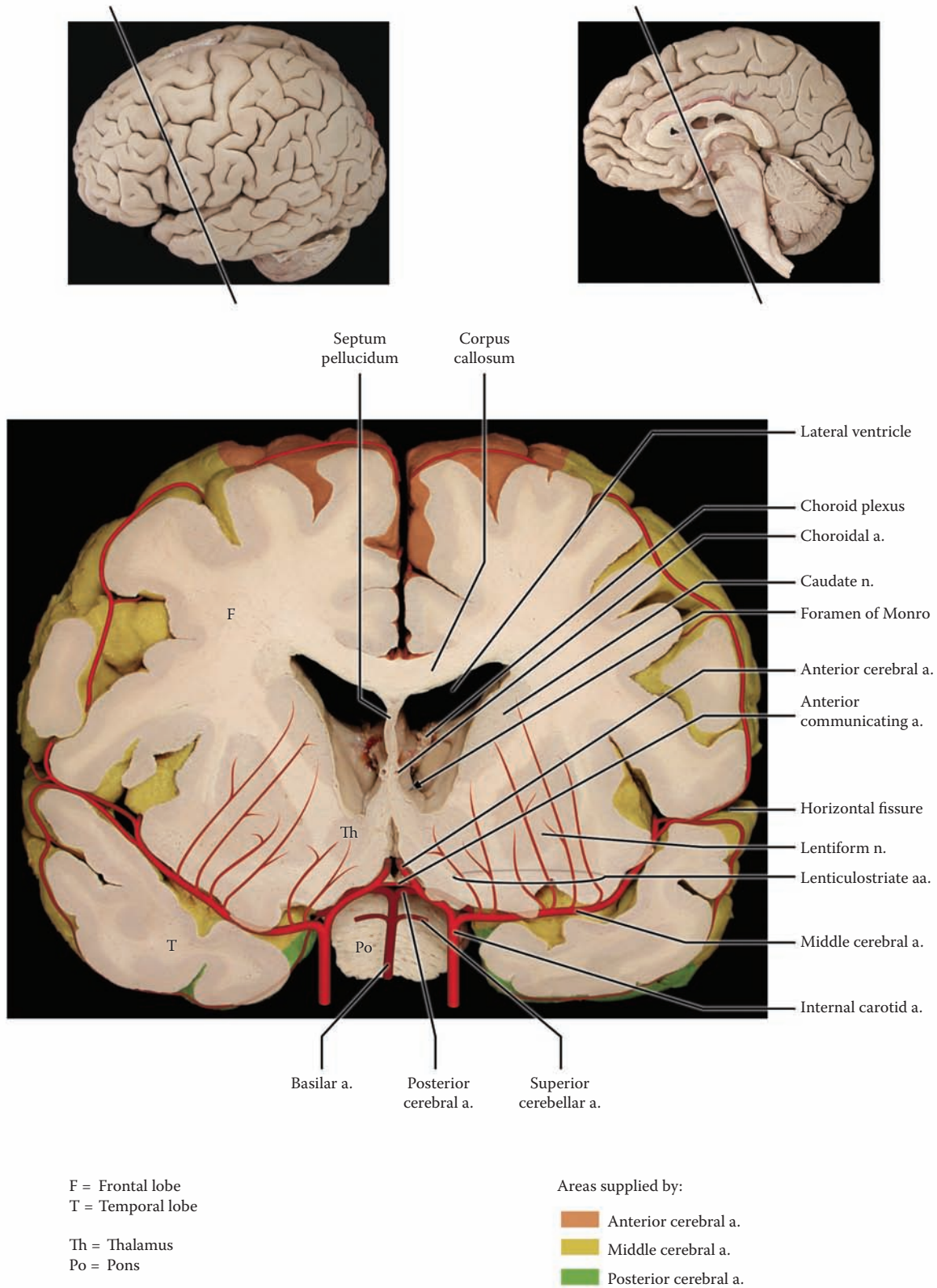
FIGURE 62: Blood Supply 6 — Internal Capsule (photograph with overlay)

FIGURE 63
THALAMUS

NUCLEI AND CONNECTIONS

The Thalamus was introduced previously in Section A (Orientation) with a schematic perspective, as well as an introduction to the nuclei and their functional aspects (see Figure 11 and Figure 12). At this stage, it is important to integrate knowledge of the thalamic nuclei with the inputs, both sensory and motor, and the connections (reciprocal) of these nuclei to the cerebral cortex. The limbic aspects will be discussed in the next section (Section D).

As was noted, there are two ways of dividing up the nuclei of the thalamus, namely, functionally and topographically (review text with Figure 12). The functional aspects of the thalamus will be reviewed with color used to display the connections of the nuclei with the cortical areas (dorsolateral and medial aspects).

SPECIFIC RELAY NUCLEI

- Sensory:
  - **VPL**, ventral posterolateral nucleus: This nucleus receives input from the somatosensory systems of the body, mainly for discriminative touch and position sense, as well as the "fast" pain system for localization. The fibers relay to the appropriate areas of the post-central gyrus, areas 1, 2, and 3, the sensory homunculus. The hand, particularly the thumb, is well represented (see Figure 33, Figure 34, and Figure 36).
  - **VPM**, ventral posteromedial nucleus: The fibers to this nucleus are from the trigeminal system (TG), i.e., the face, and the information is relayed to the facial area of the post-central gyrus. The tongue and lips are well represented (see Figure 35 and Figure 36).
  - **MGB**, medial geniculate body (nucleus): This is the nucleus for the auditory fibers from the inferior colliculus, which relay to the transverse gyri of Heschl on the superior temporal gyri in the lateral fissure (see Figure 38 and Figure 39).
  - **LGB**, lateral geniculate body (nucleus): This is the relay nucleus for the visual fibers from the ganglion cells of the retina to the calcarine cortex. This nucleus is laminated with different layers representing the visual fields of the ipsilateral and contralateral eyes (see Figure 41A and Figure 41C).

- Motor:
  - **VA and VL**, ventral anterior and ventral lateral: Fibers to these nuclei originate in the globus pallidus and substantia nigra (pars reticulata) as well as the cerebellum, and are relayed to the motor and premotor areas of the cerebral cortex, as well as the supplementary motor cortex (see Figure 53 and Figure 57).

ASSOCIATION NUCLEI

- **DM**, dorsomedial nucleus: This most important nucleus relays information from many of the thalamic nuclei as well as from parts of the limbic system (hypothalamus and amygdala) to the prefrontal cortex (see Figure 77B).
- **AN**, anterior nuclei: These nuclei are part of the limbic system and relay information to the cingulate gyrus; they are part of the Papez circuit (see Figure 77A).
- **LD**, lateral dorsal nucleus: The function of this nucleus is not well established.
- **LP**, lateral posterior nucleus: This nucleus relays to the parietal association areas of the cortex; again it is not a well-known nucleus.
- **Pul, pulvinar**: This nucleus is part of the visual relay, but relays to visual association areas of the cortex, areas 18 and 19 (see Figure 41B).

NONSPECIFIC NUCLEI

- **IL, Mid, Ret**, intralaminar, midline, and reticular nuclei (not shown here, see Figure 12): These nuclei receive from other thalamic nuclei and from the ascending reticular activating system, as well as receiving fibers from the "slow" pain system; they relay to widespread areas.
- **CM**, centromedian nucleus: This nucleus is part of an internal loop receiving from the globus pallidus and relaying to the neostriatum, the caudate and putamen (see Figure 52).

There is definitely a processing of information in these nuclei of the thalamus, not simply a relay. On the sensory side, some aspects of a "crude" touch and particularly pain are located in the thalamus (see Figure 34). The nonspecific thalamic nuclei are part of the ascending reticular activating system (ARAS), which is required for consciousness (see Figure 42A and Figure 42B). The connection between the dorsomedial nucleus (DM) and the prefrontal cortex is known to be extremely important for the processing of limbic (emotional) aspects of behavior (discussed in Section D).

FIGURE 63: Thalamus: Nuclei and Connections
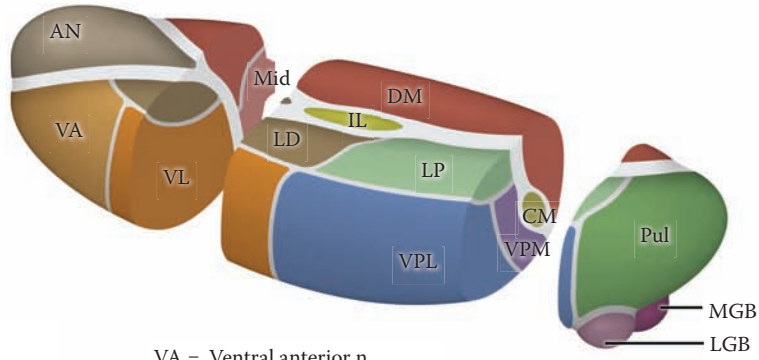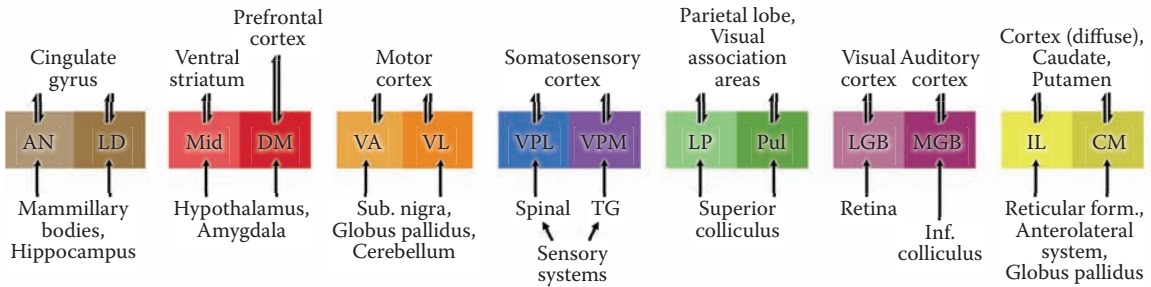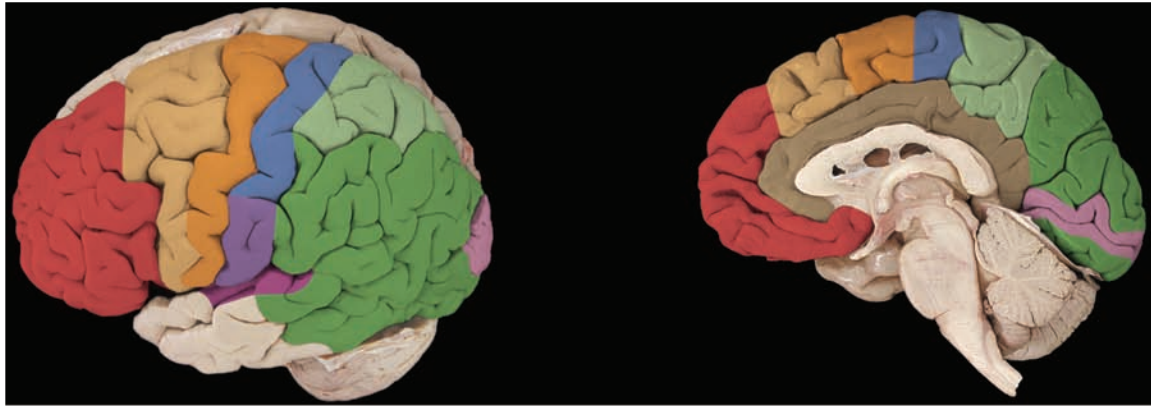
AN = Anterior nn.

LD = Lateral dorsal n.
LP = Lateral posterior n.
Pul = Pulvinar

DM = Dorsomedial n.
Mid = Midline nn.

VA = Ventral anterior n.
VL = Ventral lateral n.
VPL = Ventral posterolateral n.
VPM = Ventral posteromedial n.

LGB = Lateral geniculate body
MGB = Medial geniculate body

IL = Intralaminar nn.
CM = Centromedian n.

FIGURE 64A
BRAINSTEM HISTOLOGY

VENTRAL VIEW — SCHEMATIC

Study of the brainstem will be continued by examining its histological neuroanatomy through a series of cross-sections. Since it is well beyond the scope of the nonspecialist to know all the details, certain salient points have been selected, namely:

- The cranial nerve nuclei
- The ascending and descending tracts
- Certain brainstem nuclei that belong to the reticular formation
- Other select special nuclei

As has been indicated, the attachment of the cranial nerves to the brainstem is one of the keys to being able to understand this part of the brain (see Figure 6 and Figure 7). Wherever one sees a cranial nerve attached to the brainstem, one knows that its nucleus (or one of its nuclei) will be located at that level (see Figure 8A and Figure 8B). Therefore, if one visually recalls or "memorizes" the attachment of the cranial nerves, one has a key to understanding the brainstem. In the clinical setting, knowledge of which cranial nerve is involved is usually the main clue to localize a lesion in the brainstem.

Since the focus is on the cranial nerves, only a limited number of cross-sections will be studied. This diagram shows the ventral view of the brainstem, with the attached cranial nerves; the motor nuclei are shown on the right side (see Figure 8A), and the sensory cranial nerve nuclei are shown on the left side (see Figure 8B). The lines indicate the sections that will be depicted in the series to follow.

There are *eight* cross-sections that will be studied through the three parts of the brainstem; each is preceded by a photographic view of that part of the brainstem.

- Two through the midbrain
  - CN III, upper midbrain (superior colliculus level)
  - CN IV, lower midbrain (inferior colliculus level)
- Three through the pons
  - Upper pons (level for a special nucleus at this level)
  - CN V mid-pons (through the principal sensory and motor nuclei)
  - CN VI, VII, and part of VIII, the lower pons
- Three through the medulla
  - CN VIII (some parts), the upper medulla

- CN IX, X, and XII, the mid-medullary level
- Lower medulla, with some special nuclei

Two important points should be noted for the student-user of this atlas:

1. A small image of this view of the brainstem, both the ventral view and the sagittal view (see, for example, Figure 65A) will be shown with each cross-sectional level with the plane of the cross-section indicated.
2. These cross-sectional levels are the ones shown alongside the pathways in Section B (Functional Systems) of this atlas (see Figure 31).

HISTOLOGICAL STAINING

A variety of histological stains are available that can feature different normal and abnormal components of tissue. For the nervous system, there are many older stains and an ever-increasing number of newer stains using specific antibody markers, often tagged with fluorescent dyes. In general, the stains include those for:

- Cellular components, the cell bodies of neurons and glia (and cells lining blood vessels); these are general stains such as Hematoxylin & Eosin (H & E).
- The neurons, particularly the dendritic tree (including dendritic spines) and often the axons; the best known of these is the Golgi stain.
- Axonal fibers, either normal or degenerating.
- Glial elements (normal or reactive astrocytes).
- Myelin (normal or degenerating myelin).

The stain used for the histological sections in this atlas combines a cellular stain with a myelin stain; the combined stain is officially known as the Kluver-Barrera stain. Since the myelinated fibers are often compacted in certain areas, these tend to stand out clearly. The cellular neuronal areas are usually lightly stained as the cells are more dispersed, but the cell bodies can be visualized at higher magnification.

BLOOD SUPPLY

The vertebro-basilar system supplies the brainstem in the following pattern (see Figure 58 and Figure 61). Penetrating branches from the **basilar** artery supply nuclei and tracts that are adjacent to the midline; these are called the paramedian branches. The lateral territory of the brainstem, both tracts and nuclei, is supplied by one of the cerebellar **circumferential** arteries, posterior inferior, anterior inferior, and superior (see Figure 58).
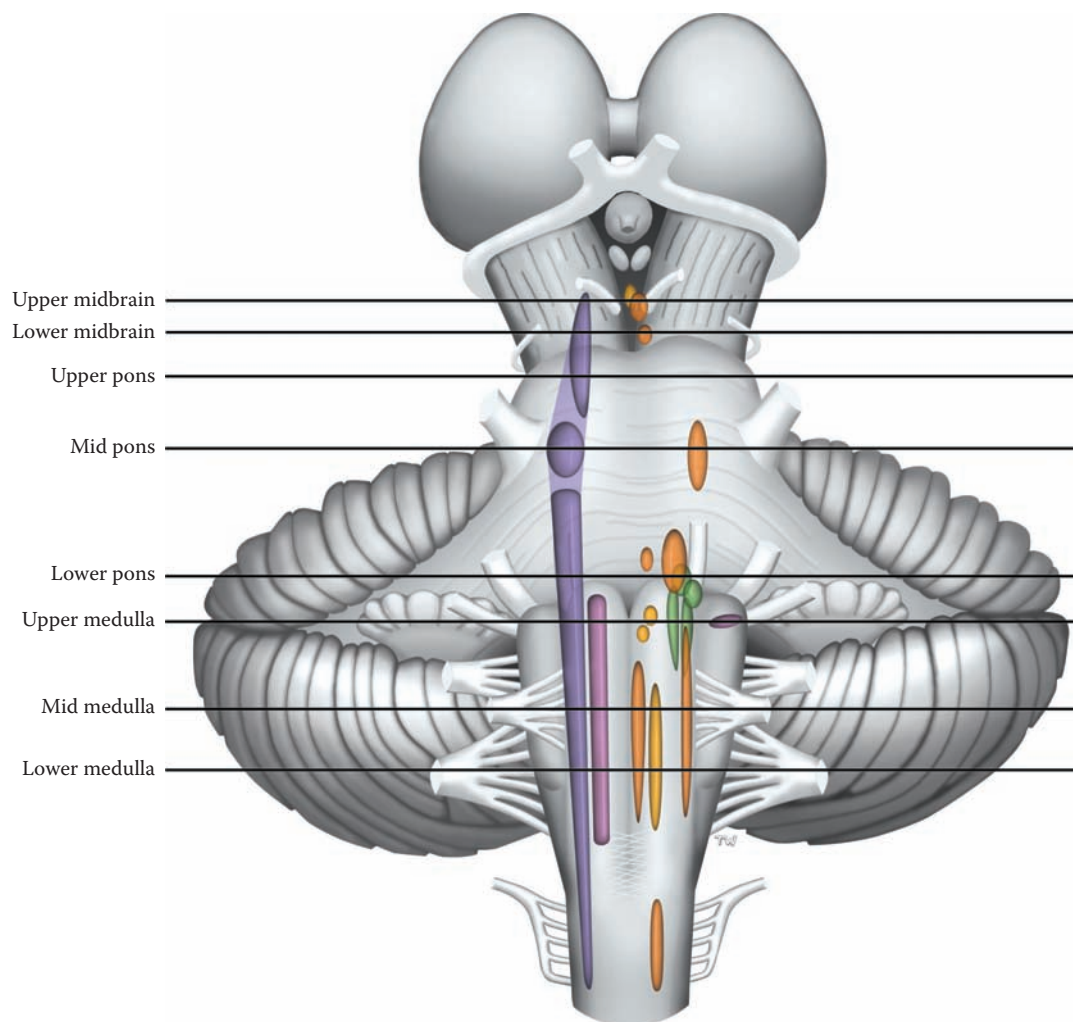
Upper midbrain
Lower midbrain
Upper pons
Mid pons
Lower pons
Upper medulla
Mid medulla
Lower medulla

FIGURE 64A: Brainstem Histology: Ventral View

FIGURE 64B
BRAINSTEM HISTOLOGY

SAGITTAL VIEW — SCHEMATIC

This is a schematic drawing of the brainstem seen in a midsagittal view (see Figure 17 and Figure 18). This view is being presented because it is one that is commonly used to portray the brainstem. The learner should try to correlate this view with the ventral view shown in the previous diagram. This schematic also will be shown in each of the cross-section diagrams, with the exact level indicated, in order to orient the learner to the plane of section through the brainstem.

The location of some nuclei of the brainstem can be visualized using this sagittal view, including the red nucleus in the upper midbrain, the pontine nuclei that form the "bulging" of the pons, and the inferior olivary nucleus of the medulla (not illustrated). Some of the cranial nerve attachments are shown as well but are not labeled.

Using this orientation, one can approach the description of the eight cross-sections in a systematic manner. This is sometimes referred to as the floor plan of the brainstem:

- **Ventral or basal**: The most anterior portion of each area of the brainstem contains some representation of the descending cortical fibers, specifically the cortico-bulbar, cortico-pontine, and cortico-spinal pathways (see Figure 45 and Figure 46). In the midbrain, the cerebral peduncles include all these axon systems. The cortico-bulbar fibers are given off to the various brainstem and cranial nerve nuclei. In the pons, the cortico-pontine fibers terminate in the pontine nuclei, which form the bulge known as the pons proper; the cortico-spinal fibers are dispersed among the pontine nuclei. In the medulla, the cortico-spinal fibers regroup to form the pyramids. The medulla ends at the point where these fibers decussate (see Figure 7).
- **Central**: The central portion of the brainstem is called the **tegmentum**. The reticular formation occupies the core region of the tegmentum (see Figure 42A and Figure 42B). This area contains virtually all the cranial nerve nuclei, and other nuclei including the red nucleus and the inferior olive, as well as the remaining tracts.
- **CSF**: The ventricular system is found throughout the brainstem (see Figure 20A, Figure 20B, and Figure 21). The brainstem level can often be identified according to the ventricular system that passes through this region, namely, the aqueduct in the midbrain region and the fourth ventricle lower down.
- **Dorsal or roof**: The four colliculi, which collectively form the tectum, are located behind (dorsal to) the aqueduct of the midbrain. The fourth ventricle separates the pons and medulla from the cerebellum. The upper part of the roof of the fourth ventricle is called the superior medullary velum (see Figure 10 and Figure 41B).

CLINICAL ASPECT

The information that is being presented in this series should be sufficient to allow a student to recognize the clinical signs that would accompany a lesion at a particular level, particularly as it involves the cranial nerves. Such lesions would also interrupt the ascending or descending tracts, and this information would assist in localizing the lesion. Specific lesions will be discussed with the cross-sectional levels.
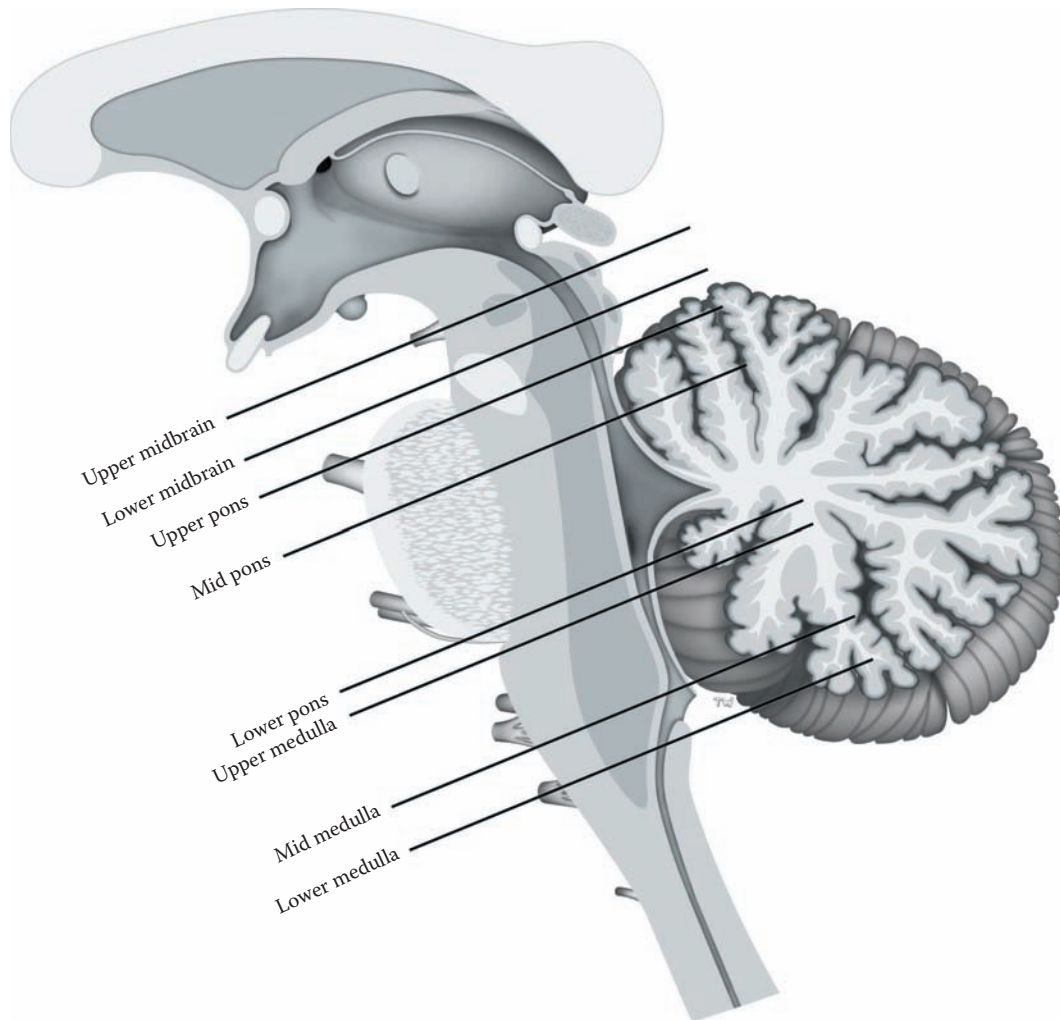
PLAN OF STUDY:

- A schematic of each section is presented in the upper figure, and the corresponding histological section of the human brainstem is presented below.
- The various nuclei of the brainstem have been colored differently, consistent with the color used in the tracts (see Section B of this atlas). This visual cataloging is maintained uniformly throughout the brainstem cross-sections (see page xviii).

The brainstem is being described starting from the midbrain downward through to the medulla for two reasons:

1. This order follows the numbering of the cranial nerves, from midbrain downward
2. This is the sequence that has been described for the fibers descending from the cortex

Others may prefer to start the description of the cross-sections from the medulla upward.

Note to the Learner: The presentation of the histology is the same on the accompanying CD-ROM, with the added feature that the structure to be identified is highlighted in both the schematic and histological section, at the same time. It is suggested that the learner review these cross-sections using the text together with the CD-ROM. The histological images of the brainstem will be more understandable after this combined approach.

Upper midbrain

Lower midbrain

Upper pons

Mid pons

Lower pons
Upper medulla

Mid medulla

Lower medulla

FIGURE 64B: Brainstem Histology: Sagittal View

THE MIDBRAIN
FIGURE 65, FIGURE 65A, AND FIGURE 65B

The midbrain is the smallest of the three parts of the brainstem. The temporal lobes of the hemispheres usually obscure its presence on an inferior view of the brain (see Figure 15A).

The midbrain area is easily recognizable from the anterior view in a dissected specimen of the isolated brainstem (see Figure 7). The massive cerebral peduncles are located most anteriorly. These peduncles contain axons that are a direct continuation of the fiber systems of the internal capsule (see Figure 26). Within them are found the pathways descending from the cerebral cortex to the brainstem (cortico-bulbar, see Figure 46 and Figure 48), to the cerebellum via the pons (cortico-pontine, see Figure 48 and Figure 55), and to the spinal cord (cortico-spinal tracts, see Figure 45 and Figure 48).

The tegmentum contains two special nuclei in the midbrain region — the substantia nigra and the red nucleus, both involved in motor control.

- The **substantia nigra** is found throughout the midbrain and is located behind the cerebral peduncles. It derives its name from the dark melanin-like pigment found (not in all species) within its neurons in a freshly dissected specimen, as seen in the present illustration (see also Figure 15B). The pigment is not retained when the tissue is processed for sectioning. Therefore, this nuclear area is clear (appearing white) in most photographs in atlases, despite its name. With myelin-type stains, the area will appear "empty"; with cell stains, the neuronal cell bodies will be visible. Its function is related to the basal ganglia (see Figure 52 and Figure 53).
- The **red nucleus** derives its name from the fact that this nucleus has a reddish color in a freshly dissected specimen, presumably due to its marked vascularity. The red nucleus is found at the superior collicular level. Its function is discussed with the motor systems (see Figure 47).

The reticular formation is found in the core area of the tegmentum, and is particularly important for the maintenance of consciousness (see Figure 42A and Figure 42B). The **periaqueductal gray,** surrounding the aqueduct, has been included as part of the reticular formation (see Figure 42B); this area participates as part of the descending control system for pain modulation (see Figure 43).

The aqueduct of the midbrain helps to identify this cross-section as the midbrain area (see Figure 21). Posterior to the aqueduct are the two pairs of colliculi, which can also be seen on the dorsal view of the isolated brainstem (see Figure 9A and Figure 10). The four nuclei together form the tectal plate, or tectum, also called the quadrigeminal plate.

The **pretectal region**, located in front of and somewhat above the superior colliculus, is the nuclear area for the pupillary light reflex (see Figure 41C).

FIGURE 65: UPPER MIDBRAIN (PHOTOGRAPHIC VIEW)

This is a photographic image, enlarged, of the sectioned midbrain. As shown in the upper left image, the brainstem was sectioned at the level of the cerebral peduncles; the corresponding level is shown on a medial view of the brain, indicating that the section is through the superior colliculus. Many of the structures visible on this "gross" specimen will be seen in more detail on the histological sections.

The distinctive features identifying this section as midbrain are:

- Anteriorly, the outline of the cerebral peduncles with the fossa in between.
- Immediately behind is a dark band, the substantia nigra, pars compacta, with pigment present in the cell bodies.
- A faint outline of the red nucleus can be seen in the tegmentum, which identifies this section as the superior collicular level.
- In the middle toward the back of the specimen is a narrow channel, which is the aqueduct of the midbrain, surrounded by the periaqueductal gray.
- The gray matter behind the ventricle is the superior colliculus at this level.

There are two levels presented for a study of the midbrain:

- Figure 65A: Upper midbrain, which includes CN III nucleus and the superior colliculus.
- Figure 65B: Lower midbrain, at the level of the CN IV nucleus and the inferior colliculus, and the decussation of the superior cerebellar peduncles.

Superior colliculus

Aqueduct of midbrain

Periaqueductal gray

Oculomotor nucleus
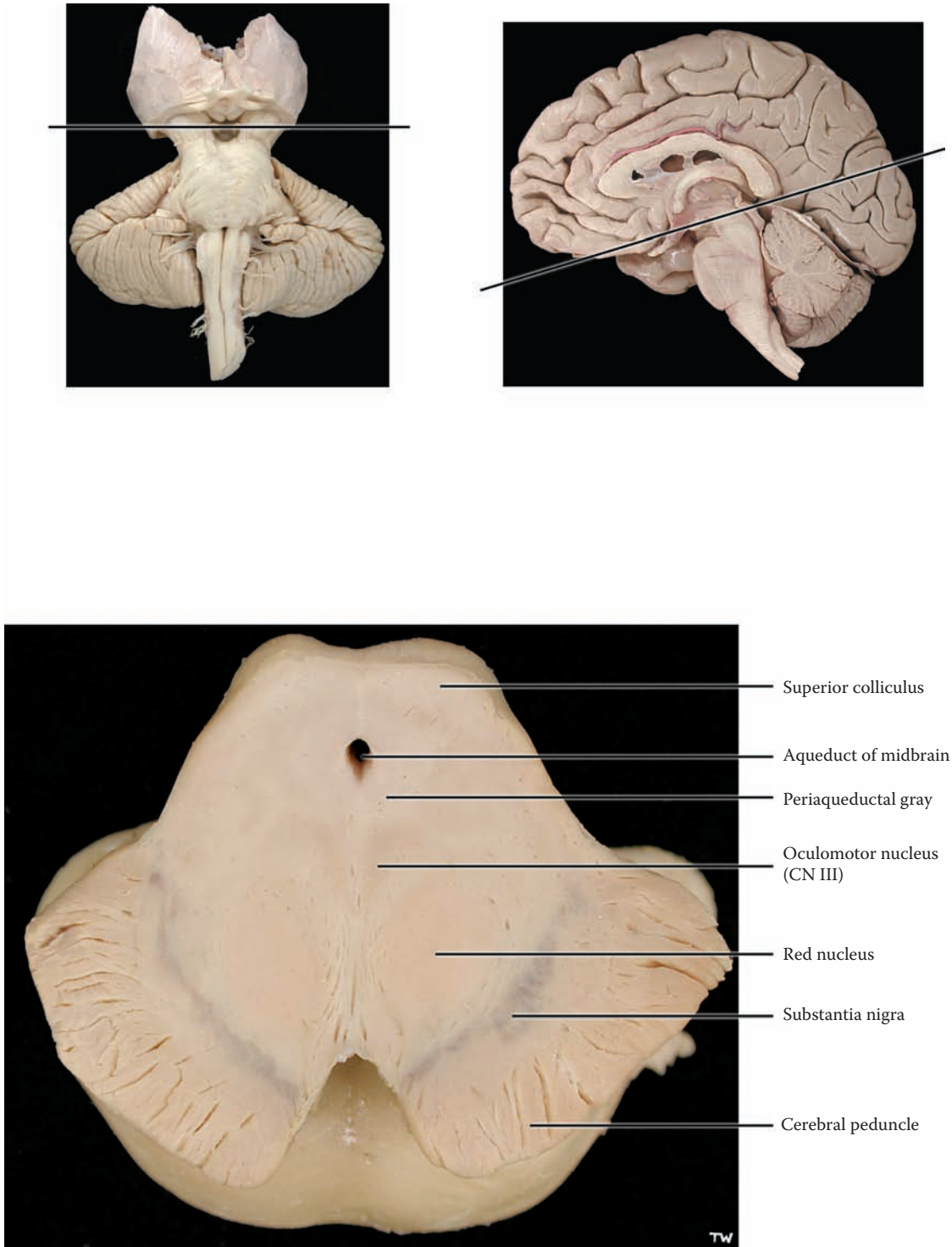(CN III)

Red nucleus

Substantia nigra

Cerebral peduncle

FIGURE 65: Brainstem Histology — Midbrain (upper — photograph)

FIGURE 65A
UPPER MIDBRAIN: CROSS-SECTION

The identifying features of this cross-section of the midbrain include the cerebral peduncle ventrally, with the substantia nigra posterior to it. The aqueduct is surrounded by the periaqueductal gray. The remainder of the midbrain is the tegmentum, with nuclei and tracts. Dorsally, behind the aqueduct, is a colliculus.

The descending fiber systems are segregated within the cerebral peduncles (see Figure 45, Figure 46, and Figure 48). The substantia nigra consists, in fact, of two functionally distinct parts — the pars compacta and the pars reticulata. The **pars reticulata** lies adjacent to the cerebral peduncle and contains some widely dispersed neurons; these neurons connect the basal ganglia to the thalamus as one of the output nuclei of the basal ganglia (similar to the globus pallidus internal segment, see Figure 53). The **pars compacta** is a cell-rich region, located more dorsally, whose neurons contain the melanin-like pigment. These are the dopaminergic neurons that project to the neostriatum (discussed with Figure 52). Loss of these neurons results in the clinical entity Parkinson's disease (discussed with Figure 52).

The red nucleus is located within the tegmentum; large neurons are typical of the ventral part of the nucleus. With a section that has been stained for myelin, the nucleus is seen as a clear zone. The red nucleus gives origin to a descending pathway, the rubro-spinal tract, which is involved in motor control (see Figure 47 and Figure 48).

The oculomotor nucleus (CN III) is quite large and occupies the region in front of the periaqueductal gray, near the midline; this identifies the level as upper midbrain with the superior colliculus. These motor neurons are large in size and easily recognizable. The parasympathetic portion of this nucleus is incorporated within it and is known as the Edinger-Westphal (EW) nucleus (see Figure 8A). The fibers of CN III pass anteriorly through the medial portion of the red nucleus and exit between the cerebral peduncles, in the interpeduncular fossa (see Figure 6 and Figure 7).

The ascending (sensory) tracts present in the midbrain are a continuation of those present throughout the brainstem. The medial lemniscus, the ascending trigeminal pathway, and the fibers of the anterolateral system incorporated with them (see Figure 36 and Figure 40) are located in the outer part of the tegmentum, on their way to the nuclei of the thalamus (see Figure 63).

The nuclei of the reticular formation are found in the central region of the brainstem (the tegmentum); they are functionally part of the ascending reticular activating system and play a significant role in consciousness (discussed with Figure 42A and Figure 42B). The periaqueductal gray surrounding the cerebral aqueduct is involved with the descending pathway for the modulation of pain (see Figure 43).

The superior colliculus is a subcortical center for certain visual movements (see Figure 41B). These nuclei give rise to a fiber tract, the tecto-spinal tract, a descending pathway that is involved in the control of eye and neck movements; it descends to the cervical spinal cord as part of the medial longitudinal fasciculus (MLF) (see Figure 51B).

The MLF stains heavily with a myelin-type stain and is found anterior to the cranial nerve motor nucleus, next to the midline, at this level as well as other levels of the brainstem. Also to be noted at this level is the brachium of the inferior colliculus, a part of the auditory pathway (see Figure 10, Figure 37, and Figure 38).

CLINICAL ASPECT

A specific lesion involving a thrombosis of the basilar artery may destroy much of the brainstem yet leave the inner part of the midbrain intact. Few people actually survive this cerebrovascular damage, but those that do are left in a suspended (rather tragic) state of living, known by the name **"locked-in" syndrome**. The patient retains consciousness, with intellectual functions generally intact, meaning that they can think and feel as before. However, usually, all voluntary movements are gone, except perhaps for some eye movements, or occasionally some small movements in the hands and fingers. This means that they require a respirator to breathe and 24-hour total care. There may also be a loss of all sensations, or some sensation from the body may be retained.

Superior colliculus

Brachium of the
inferior colliculus

Anterolateral system
Medial lemniscus

Edinger-Westphal
nucleus

Oculomotor
nucleus

Oculomotor nerve (CN III)

Aqueduct of midbrain

Periaqueductal gray

Reticular formation

MLF

Red nucleus

Substantia nigra

Parieto-, temporo- and
occipito-pontine fibers

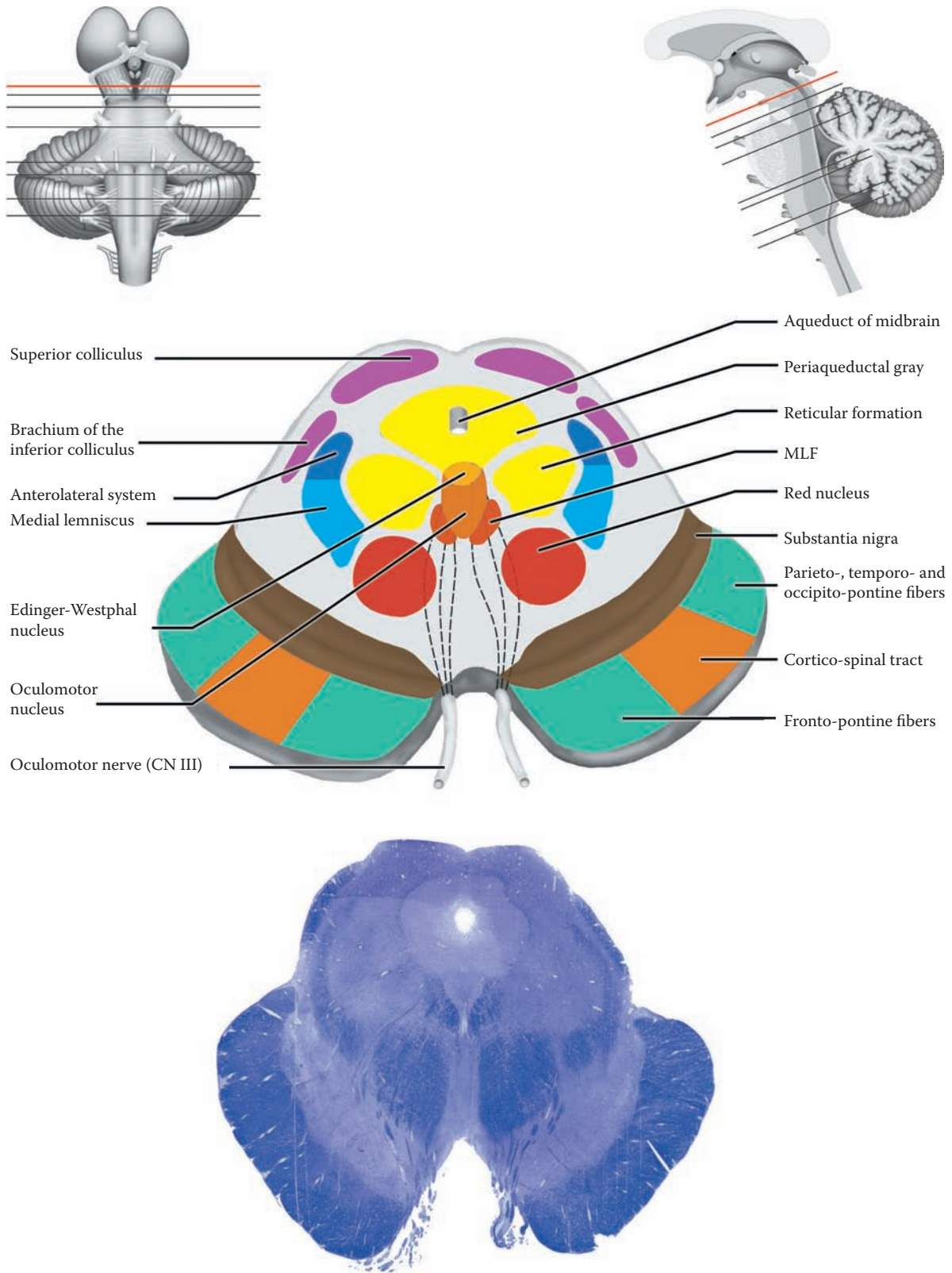Cortico-spinal tract

Fronto-pontine fibers

FIGURE 65A: Brainstem Histology — Upper Midbrain

FIGURE 65B
LOWER MIDBRAIN:
CROSS-SECTION

This cross-section includes the cerebral peduncles, still located anteriorly and the substantia nigra located immediately behind these fibers. The unique feature in the lower midbrain is the decussation (crossing) of the superior cerebellar peduncles, which occupies the central area of the section; this identifies the section as the inferior collicular level. Posteriorly the aqueduct is surrounded by the periaqueductal gray, and behind the aqueduct is the inferior colliculus. Often, the cross-section at this level includes some of the pontine nuclei. (as is seen in the histological section below). Therefore, one may see a somewhat confusing mixture of structures.

The arrangement of the fibers in the cerebral peduncle is the same as found in the upper midbrain. The tegmentum contains the ascending tracts, the medial lemniscus, the trigeminal pathway, and the anterolateral fibers (system), which are situated together at the outer edge of the lower midbrain (see Figure 40).

In sections through the lower levels of the midbrain, there is a brief appearance of a massive fiber system (as seen with a myelin-type stain) occupying the central region of the lower midbrain. These fibers are the continuation of the superior cerebellar peduncles, which are crossing (decussating) at this level (see Figure 10 and Figure 40). The fibers are coming from the deep cerebellar nuclei (the intracerebellar nuclei), mainly the dentate nucleus, and are headed for the ventral lateral nucleus of the thalamus, and then on to the motor cortex (discussed with Figure 57). Some of the fibers that come from the intermediate deep cerebellar nucleus will synapse in the red nucleus.

The nuclei of the reticular formation found in the central region (the tegmentum) at this level are function-ally part of the ARAS and play a significant role in consciousness (see Figure 42A and Figure 42B). Between the cerebral peduncles is a small nucleus, the interpeduncular nucleus, which belongs with the limbic system. The periaqueductal gray surrounding the aqueduct of the midbrain is involved with pain and also with the descending pathway for the modulation of pain (see Figure 43).

The nucleus of CN IV, the trochlear nucleus, is located in front of the periaqueductal gray, next to the midline. Because it supplies only one extra-ocular muscle, it is a smaller nucleus than the oculomotor nucleus. CN IV heads dorsally and will exit from the brainstem below the inferior colliculus (see Figure 48), on the posterior aspect of the brainstem. The MLF lies just anterior to the trochlear nucleus. Some unusually large round cells are often seen at the edges of the periaqueductal gray; these cells are part of the mesencephalic nucleus of the trigeminal nerve, CN V (see Figure 8B).

The lateral lemniscus, the ascending auditory pathway, is still present at this level, and its fibers are terminating in the inferior colliculus, a relay nucleus in the auditory pathway (see Figure 37 and Figure 38). After synapsing here, the fibers are relayed to the medial geniculate nucleus via the brachium of the inferior colliculus, seen at the upper midbrain level (previous illustration).

CLINICAL ASPECT

The presence of the pain and temperature fibers that are found at this level at the outer edge of the midbrain has prompted the possibility, in very select cases, to surgically sever the sensory ascending pathways at this level. This highly dangerous neurosurgical procedure would be done particularly for cancer patients who are suffering from intractable pain. Nowadays it would only be considered as a measure of last resort. Pain control is currently managed through the use of drugs, either as part of palliative care or in the setting of a pain "clinic," accompanied by other measures.

Brachium of the
inferior colliculus

Inferior colliculus

Lateral lemniscus

Mesencephalic
nucleus of CN V

Anterolateral system

Medial lemniscus

Trochlear nucleus

Interpeduncular
nucleus

Aqueduct of midbrain

Periaqueductal gray

Reticular formation

MLF

Decussation of
the superior
cerebellar peduncles

Substantia nigra

Parieto-, temporo- and
occipito-pontine fibers

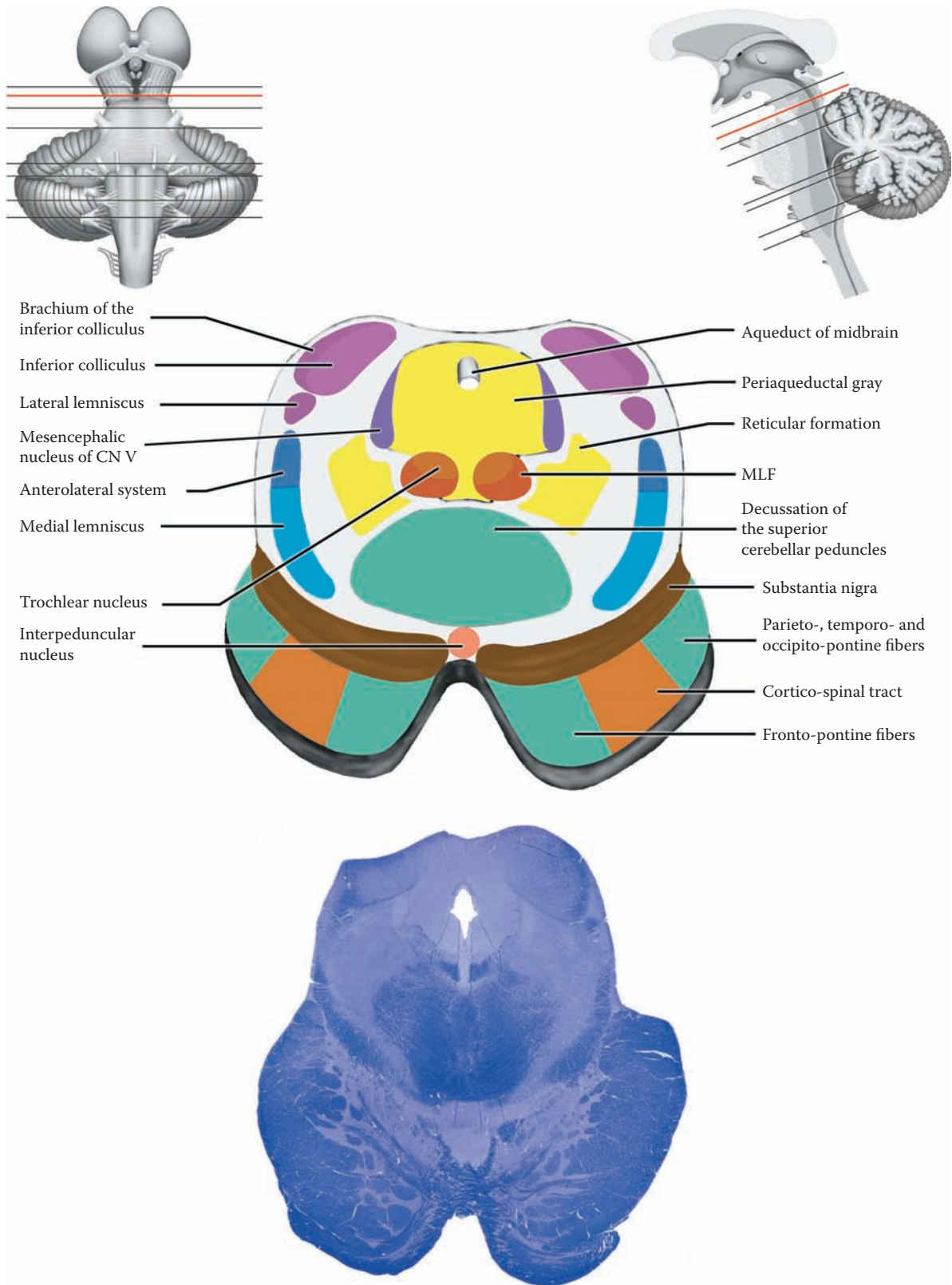Cortico-spinal tract

Fronto-pontine fibers

FIGURE 65B: Brainstem Histology — Lower Midbrain

THE PONS
FIGURE 66, FIGURE 66A,
FIGURE 66B, AND FIGURE 66C

The pons is characterized by its protruding anterior (ventral) portion, the pons proper, also called the basilar portion of the pons, with the basilar artery lying on its surface (see Figure 15A and Figure 58). This area contains the pontine nuclei, the site of relay of the cortico-pontine fibers (see Figure 48); the ponto-cerebellar fibers then cross and enter the cerebellum via the middle cerebellar peduncle (see Figure 55). Intermingled with the pontine nuclei are the dispersed fibers, which belong to the cortico-spinal system (see Figure 45 and Figure 48).

Behind the pons proper is the tegmentum, the region of the brainstem that contains the cranial nerve nuclei, most of the ascending and descending tracts, and the nuclei of the reticular formation. The cranial nerves attached to the pons include the trigeminal (CN V) at the mid-pontine level, and the abducens (CN VI), the facial (CN VII), and part of CN VIII (the vestibulocochlear) at the lowermost pons; the fibers of VII form an internal loop over the abducens nucleus in the pons (see Figure 48). The fibers of CN VII and CN VIII are located adjacent to each other at the cerebello-pontine angle (see Figure 6, Figure 7, and Figure 8A).

The ascending tracts present in the tegmentum are those conveying sensory information from the body and face. These include the medial lemniscus and the antero-lateral fibers (system). The medial lemniscus shifts its position in its course through the brainstem (see Figure 40), moving from a central to a lateral position. The ascending trigeminal pathways join with the medial lemniscus in the upper pons. The lateral lemniscus (auditory) is also located in the tegmentum.

One of the distinctive nuclei of the pons is the locus ceruleus, a pigment-containing nucleus located in the upper pontine region (to be discussed with Figure 66A). The nuclei of the reticular formation of the pons have their typical location in the tegmentum (see Figure 42A and Figure 42B). Their role in the motor systems has been described with the reticular formation, as well as giving rise to descending tracts (see Figure 49A and Figure 49B).

The fourth ventricle begins in the pontine region as a widening of the aqueduct and then continues to enlarge so it is widest at about the level of the junction between the pons and medulla (see Figure OA, Figure 20A, Figure 20B, and Figure 21). This ventricle separates the pons and medulla anteriorly from the cerebellum posteriorly. There is no pontine nucleus dorsal to the fourth ventricle; the cerebellum is located above (posterior to) the roof of the ventricle.

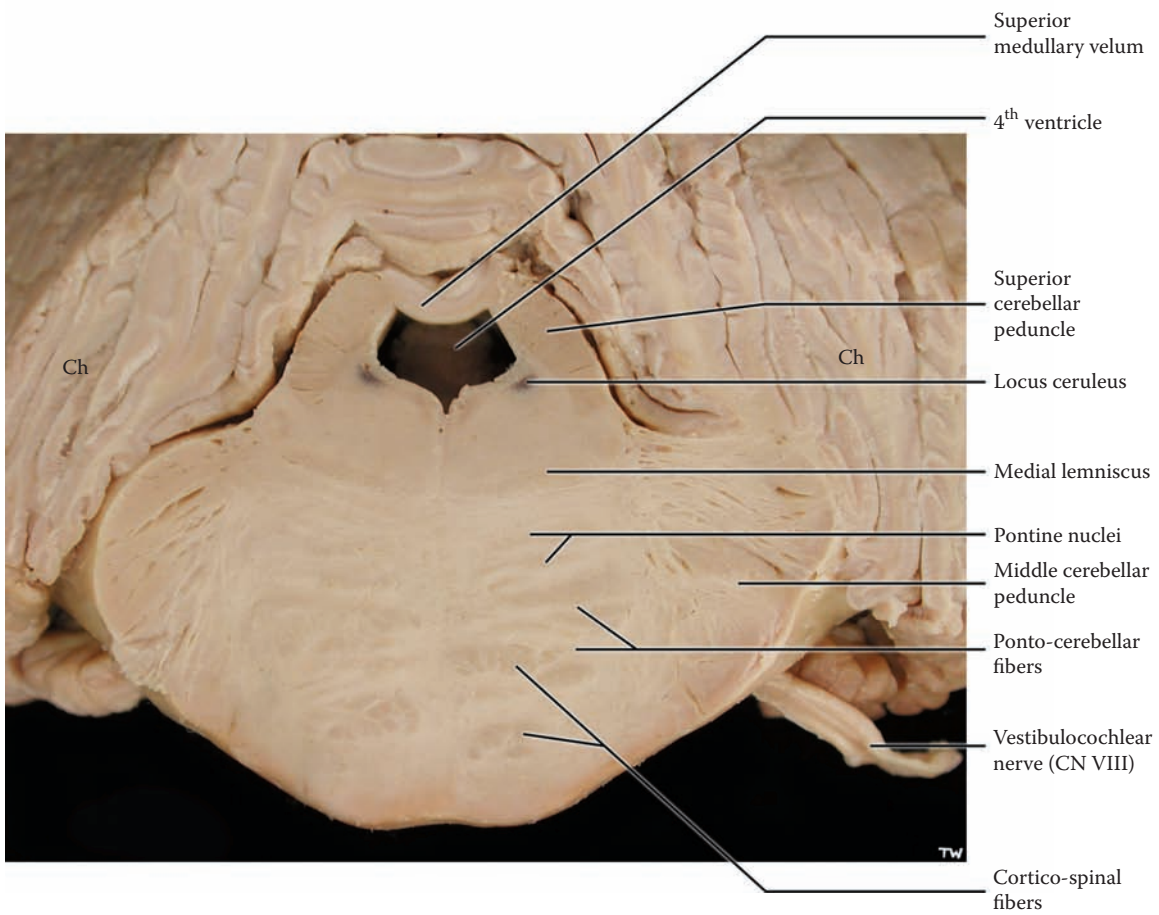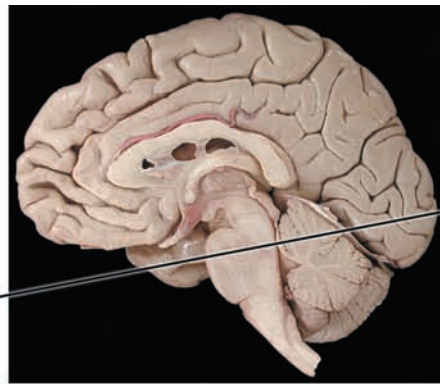## FIGURE 66: UPPER PONS (PHOTOGRAPHIC VIEW)

This is a photographic image, enlarged, of the pontine region, with the cerebellum attached. The section is done at the level of the upper pons, as indicated in the upper images of the ventral view of the brainstem and in the midsagittal view.

The unique nucleus present at this level is the locus ceruleus, a small nucleus whose cells have pigment, much like those of the substantia nigra, pars compacta (see Figure 65). As with that nucleus, the pigment is lost during histological processing.

The ventral region has the distinctive appearance of the pontine nuclei, with the cortico-spinal and cortico-pontine fibers dispersed among them. The pontine tegmentum seems quite compressed. The space in the middle of the tissue section is the fourth ventricle, as it begins to widen. Behind the ventricle is a small area of white matter, called the superior medullary velum (see Figure 10 and Figure 41B). The thin folia of the cerebellum are easily recognized, with an inner strip of white matter bounded on either side by the thin gray matter of the cerebellar cortex.

The pons is to be represented by three sections:

- Figure 66A: The upper pons, at the level of the locus ceruleus.
- Figure 66B: The mid (middle) pons, at the level of the attachment of the trigeminal nerve. It includes the massive middle cerebellar peduncles.
- Figure 66C: The lower pons, just above the junction with the medulla. This lowermost level has the nuclei of cranial nerves VI, VII, and parts of both divisions of CN VIII.

Ch = Cerebellar hemisphere

FIGURE 66: **Brainstem Histology** — Pons (upper — photograph)

FIGURE 66A
UPPER PONS:
CROSS-SECTION

This level is presented mainly to allow an understanding of the transition of midbrain to pons. This particular section is taken at the uppermost pontine level, where the trochlear nerve, CN IV, exits (below the inferior colliculus, see Figure 7). This is the only cranial nerve that exits posteriorly; its fibers cross (decussate) before exiting (see Figure 48).

Anteriorly, the pontine nuclei are beginning to be found. Cortico-pontine fibers will be terminating in the pontine nuclei. From these cells, a new tract is formed that crosses and projects to the cerebellum forming the middle cerebellar peduncle. The cortico-spinal fibers become dispersed between these nuclei and course in bundles between them (see Figure 45 and Figure 48).

The ascending tracts include the medial lemniscus and anterolateral system (somatosensory from the body, see Figure 33, Figure 34, and Figure 40), the ascending trigeminal pathway (see Figure 35 and Figure 40) and the lateral lemniscus (auditory, see Figure 37). The fibers of the trigeminal system that have crossed in the pons (discriminative touch from the principal nucleus of V), and those of pain and temperature (from the descending nucleus of V) that crossed in the medulla join together in the upper pons with the medial lemniscus (see Figure 35, Figure 36, and Figure 40). The medial lemniscus is located midway between its more central position inferiorly, and the lateral position found in the midbrain (see Figure 40). In sections stained for myelin, it has a somewhat "comma-shaped" configuration. The auditory fibers are located dorsally, just before terminating in the inferior colliculus in the lower midbrain (see Figure 38 and Figure 40). Centrally, the cerebral aqueduct is beginning to enlarge, becoming the fourth ventricle. The MLF is found in its typical location ventral to the fourth ventricle, next to the midline.

The nuclei of the reticular formation are located in the tegmentum (see Figure 42A and Figure 42B). The special nucleus at this level, the locus ceruleus, is located in the dorsal part of the tegmentum not too far from the edges of the fourth ventricle. The nucleus derives its name from its bluish color in fresh specimens, as seen in the photographic image in the previous illustration. As explained, the pigment is lost when the tissue is processed for histology. The locus ceruleus is usually considered part of the reticular formation (as discussed with Figure 42B) because of its widespread connections with virtually all parts of the brain. It is also unique because noradrenaline is its catecholamine neurotransmitter substance.

The superior cerebellar peduncle is found within the tegmentum of the pons. These fibers carry information from the cerebellum to the thalamus and the red nucleus. The fibers, which are the axons from the deep cerebellar nuclei, leave the cerebellum and course in the roof of the fourth ventricle (the superior medullary velum, see Figure 10 and Figure 40). They then enter the pontine region and move toward the midline, finally decussating in the lower midbrain (see Figure 57 and Figure 65B).

The uppermost part of the cerebellum is found at this level. One of the parts of the vermis, the midline portion of the cerebellum, the lingula, is identified. This particular lobule is a useful landmark in the study of the cerebellum and was identified when the anatomy of the cerebellum was explained (see Figure 54).

ADDITIONAL DETAIL

Several very large neurons belonging to the mesencephalic nucleus of the trigeminal may be found near the edges of the fourth ventricle (see Figure 8B). This small cluster of cells may not be found in each and every cross-section of this particular region.

Decussation of CN IV

Mesencephalic
nucleus of CN V

Lateral lemniscus

Anterolateral system

Medial lemniscus

Trochlear nerve (CN IV)

Cortico-spinal tract

Lingula of cerebellum

4th ventricle

Locus ceruleus

Superior cerebellar
peduncle

MLF

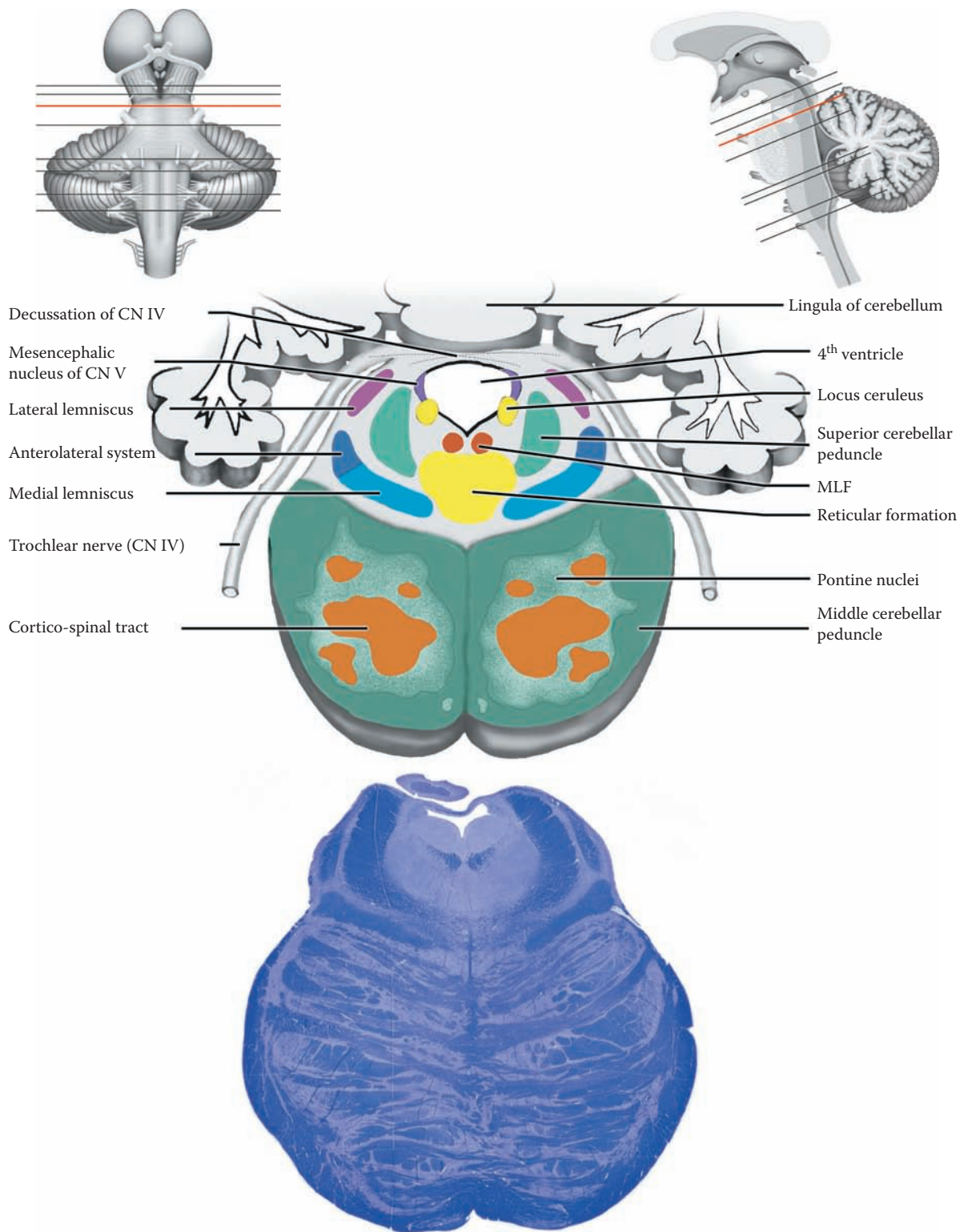Reticular formation

Pontine nuclei

Middle cerebellar
peduncle

FIGURE 66A: Brainstem Histology — Upper Pons

FIGURE 66B
MID-PONS: CROSS-SECTION

This section is taken through the level of the attachment of the trigeminal nerve. Anteriorly, the pontine nuclei and the bundles of cortico-spinal fibers are easily recognized. The pontine cells (nuclei) and their axons, which cross and then become the middle cerebellar peduncle, are particularly numerous at this level (see Figure 55). The cortico-spinal fibers are seen as distinct bundles that are widely dispersed among the pontine nuclei at this level (see Figure 45 and Figure 48).

The trigeminal nerve enters and exits the brainstem along the course of the middle cerebellar peduncle. CN V has several nuclei with different functions (see Figure 8B and Figure 35). This level contains only two of its four nuclei: the principal (or main) sensory nucleus and the motor nucleus. The principal (main) sensory nucleus subserves discriminative (i.e., two-point) touch sensation and accounts for the majority of fibers; the face area is extensively innervated, particularly the lips, and also the surface of the tongue. The motor nucleus supplies the muscles of mastication and usually is found as a separable nerve as it exits alongside the large sensory root. Within the pons, these nuclei are separated by the fibers of CN V; the sensory nucleus (with smaller cells) is found more laterally, and the motor nucleus (with larger cells) more medially.

The ascending fiber systems are easily located at this cross-sectional level. The medial lemniscus has moved away from the midline, as it ascends (see Figure 40). The anterolateral fiber system has become associated with it by this level. In addition, the ascending trigeminal pathway joins with the medial lemniscus. The lateral lemniscus is seen as a distinct tract, lying just lateral to the medial lemniscus. The MLF is found in its typical location anterior to the fourth ventricle.

The core area of the tegmentum is occupied by the nuclei of the reticular formation. Some of the nuclei here are called the oral portion of the pontine reticular formation (see Figure 42B). This "nucleus" contributes fibers to a descending medial reticulo-spinal tract, which is involved in the indirect voluntary pathway for motor control and plays a major role in the regulation of muscle tone (discussed with Figure 49B).

The fourth ventricle has become quite wide at this level. The superior cerebellar peduncles are found at its edges, exiting from the cerebellum and heading toward the midbrain (red nucleus) and thalamus. The thin sheet of white matter that connects these peduncles is called the superior medullary velum (see Figure 10). The cerebellum, which is quite large at this level, is situated behind the ventricle. The lingula of the cerebellum is again labeled and is sometimes seen actually intruding into the ventricular space.

ADDITIONAL DETAIL

The superior cerebellar peduncles and the superior medullary velum can be located in a specimen (such as the one shown in Figure 9A), a dorsal view of the isolated brainstem. These structures would be found below the inferior colliculi, just below the exiting fibers of CN IV dorsally.

Note on the cerebellum: The cerebellum is usually not included in the histological sections of the pons because of the technical difficulty of sectioning such a large fragment of tissue, transferring the section through the various staining solutions, and mounting the section on large slides.

Superior medullary
velum

Sensory n. CN V

Motor n. CN V

Lateral lemniscus

Anterolateral system

Medial lemniscus

Trigeminal
nerve (CN V)

Cortico-spinal fibers

Lingula of
cerebellum

Superior cerebellar
peduncle

4th ventricle

MLF

Reticular formation
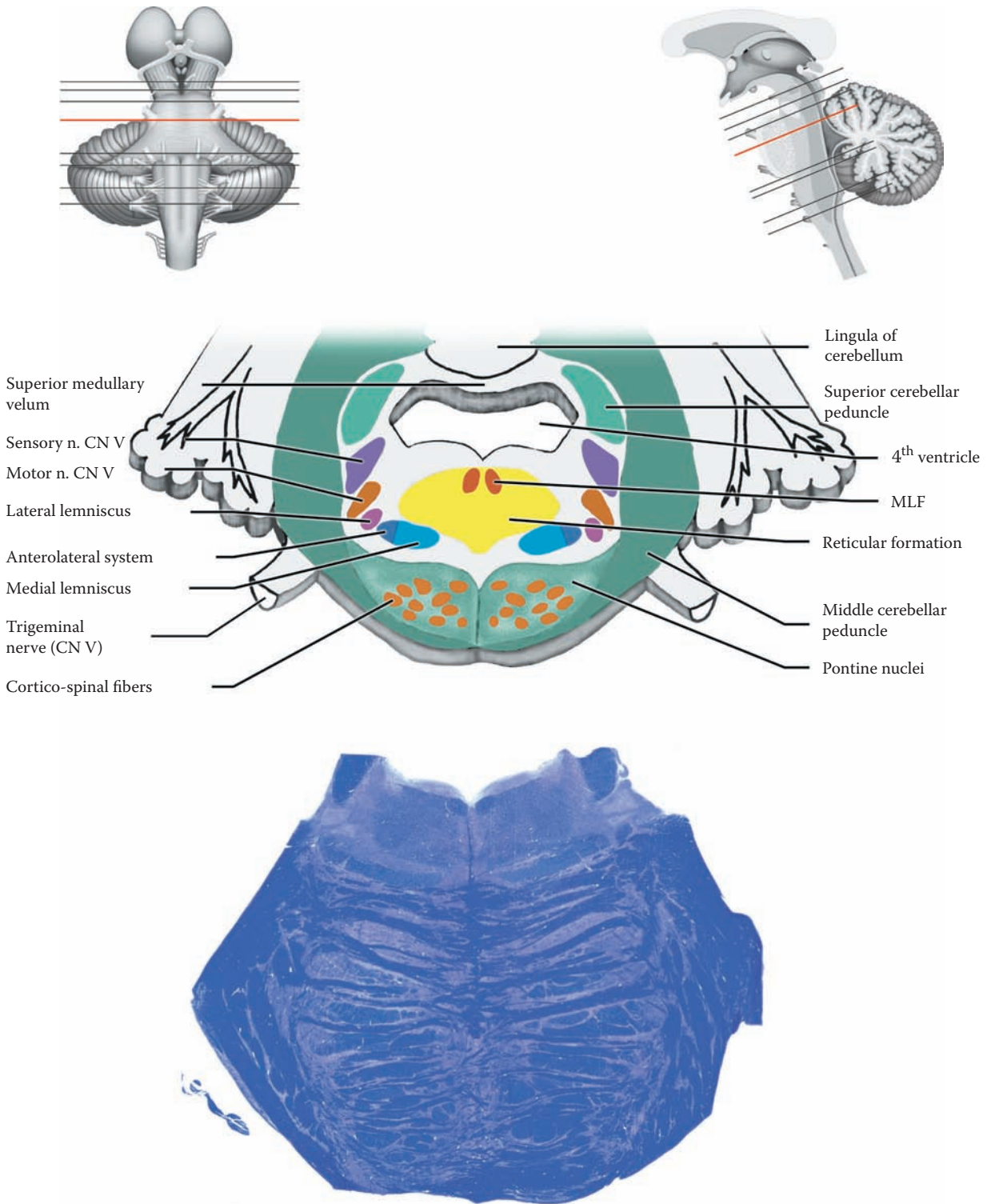
Middle cerebellar
peduncle

Pontine nuclei

FIGURE 66B: Brainstem Histology — Mid-Pons

FIGURE 66C
LOWER PONS:
CROSS-SECTION

This section is very complex because of the number of nuclei related to the cranial nerves located in the tegmental portion, including CN V, VI, VII, and VIII. Some of the tracts are shifting in position or forming. Anteriorly, the pontine nuclei have all but disappeared, and the fibers of the cortico-spinal tract are regrouping into a more compact bundle, which will become the pyramids in the medulla (below).

CN V: The fibers of the trigeminal nerve carrying pain and temperature, that entered at the mid-pontine level, form the descending trigeminal tract, also called the spinal tract of V; medial to it is the corresponding nucleus (see Figure 8B). The descending fibers synapse in this nucleus as this pathway continues through the medulla, cross, and then ascend (see Figure 35), eventually joining the medial lemniscus in the upper pons (see Figure 36).

CN VI: The abducens nucleus, motor to the lateral rectus muscle of the eye (see Figure 8A), is located in front of the ventricular system. The MLF is found just anterior to these nuclei, near the midline. Some of the exiting fibers of CN VI may be seen as the nerve emerges anteriorly, at the junction of the pons and medulla.

CN VII: The motor neurons of the facial nerve nucleus, supplying the muscles of facial expression, are located in the ventrolateral portion of the tegmentum. As explained, the fibers of CN VII form an internal loop over the abducens nucleus (see Figure 48). The diagram is drawn as if the whole course of this nerve is present in a single section, but only part of this nerve is found on an actual section through this level of the pons.

CN VIII — Cochlear division: CN VIII enters the brainstem slightly lower, at the ponto-cerebellar angle (see Figure 6 and Figure 7). The auditory fibers synapse in the dorsal and ventral cochlear nuclei, which will be seen in the medulla in a section just below this level (see also Figure 8B). The two distinctive parts of this nerve at this histological level are the crossing fibers, which form the trapezoid body, and the superior olivary complex (see Figure 37 and Figure 40). After one or more synapses, the fibers then ascend and form the lateral lemniscus, which actually commences at this level.

CN VIII — Vestibular division: Of the four vestibular nuclei (see Figure 51A and Figure 51B), three are found at this level. The lateral vestibular nucleus, with its giant-size cells, is located at the lateral edge of the fourth ventricle; this nucleus gives rise to the lateral vestibulospinal tract (see Figure 50). The medial vestibular nucleus is also present at this level, an extension from the medullary region. There is also a small superior vestibular nucleus in this region. The latter two nuclei contribute fibers to the MLF, relating the vestibular sensory information to eye movements (discussed with Figure 51B).

The tegmentum of the pons also includes the ascending sensory tracts and the reticular formation. The medial lemniscus, often somewhat obscured by the fibers of the trapezoid body, is situated close to the midline but has changed its orientation from that seen in the medullary region (see Figure 40; see also cross-sections of the medulla, Figure 67B and Figure 67C). The anterolateral system is too small to be identified. The nuclei of the reticular formation include the caudal portion of the pontine reticular formation, which also contributes to the pontine reticulo-spinal tract (see Figure 49B).

The fourth ventricle is very large but often seems smaller because the lobule of the cerebellar vermis, called the nodulus (part of the flocculonodular lobe, refer to Figure 54), impinges upon its space. The MLF is found anterior to it, near the midline.

The lowermost part of the middle cerebellar peduncle can still be identified at this level. Also present is the inferior cerebellar peduncle, which entered the cerebellum at a lower level (see Figure 7); it is found more internally within the cerebellum. The intracerebellar (deep cerebellar) nuclei are also found at this cross-sectional level and are located within the white matter of the cerebellum (discussed with Figure 56A and Figure 56B).

Nodulus of cerebellum

Vestibular nn.:
 Medial
 Superior
 Lateral

Spinal t. CN V
Spinal n. CN V

Abducens n.

Anterolateral system
Medial lemniscus

Trapezoid body

Abducens nerve (CN VI)

Cortico-spinal fibers

Fastigial n.
Globose n.
Emboliform n.
Dentate n.

4th ventricle

Cerebellar peduncles:
 Inferior
 Middle

MLF
Reticular formation

Facial n.
Facial nerve (CN VII)

Vestibulocochlear
nerve (CN VIII)
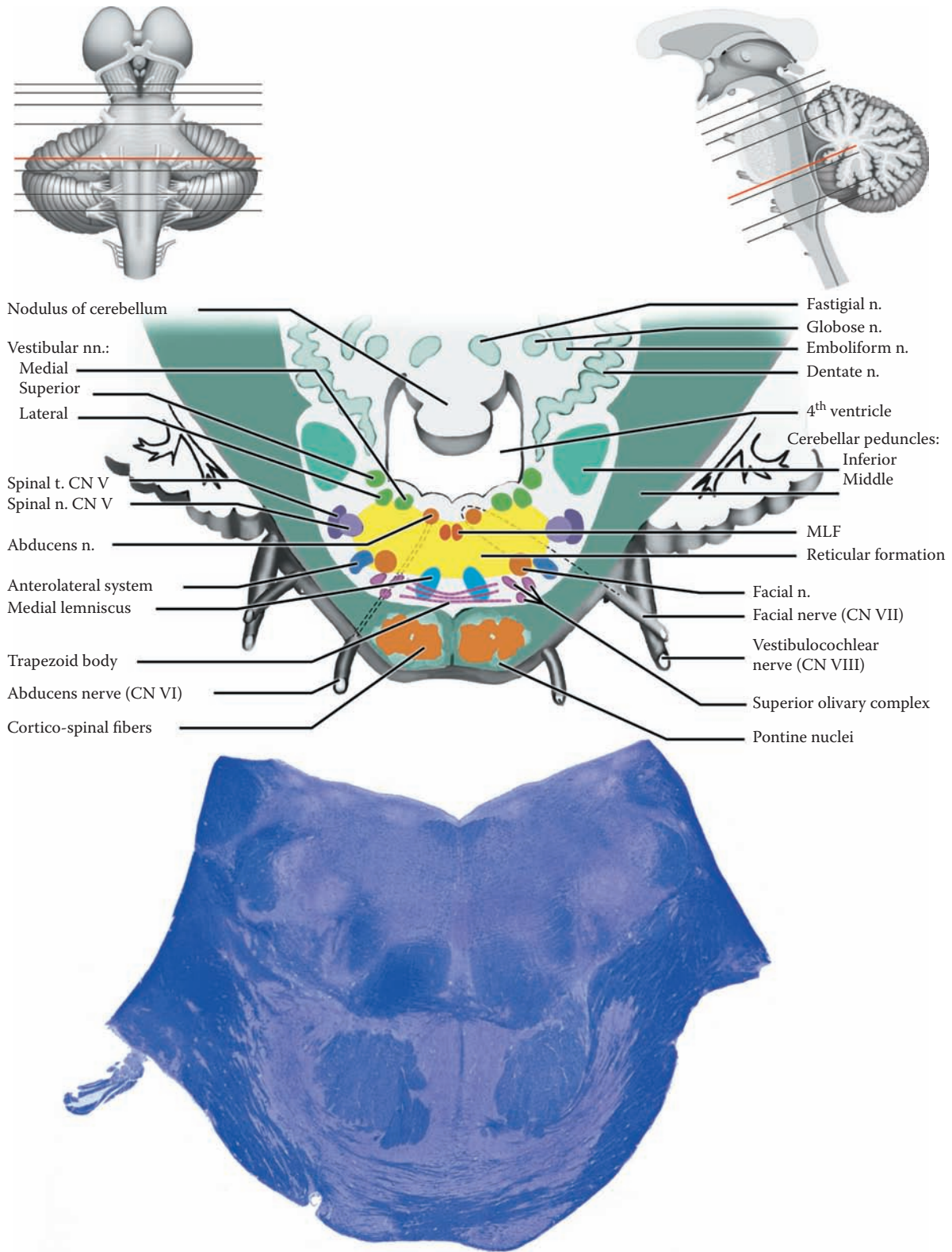
Superior olivary complex

Pontine nuclei

FIGURE 66C: Brainstem Histology — Lower Pons

THE MEDULLA
FIGURE 67, FIGURE 67A,
FIGURE 67B, AND FIGURE 67C

This part of the brainstem has a different appearance from the midbrain and pons because of the presence of two distinct structures: the pyramids and the inferior olivary nucleus.

The pyramids, located ventrally, are an elevated pair of structures located on either side of the midline (see Figure 6 and Figure 7). They contain the cortico-spinal fibers that have descended from the motor areas of the cortex and now emerge as a distinct bundle (see Figure 45 and Figure 48). Most of its fibers cross (decussate) at the lowermost part of the medulla. The inferior olive (nucleus) is a prominent structure that has a distinct scalloped profile when seen in cross-section. It is so large that it forms a prominent bulge on the lateral surface of the medulla (see Figure 6 and Figure 7). Its fibers relay to the cerebellum (see Figure 55).

The tegmentum is the area of the medulla that contains the cranial nerve nuclei, the nuclei of the reticular formation, the ascending tracts, and two special nuclei, the inferior olivary nucleus (discussed above) and the dorsal column nuclei (dorsally).

Cranial nerves IX, X, and XII are attached to the medulla and have their nuclei here; part of CN VIII is also represented in the uppermost medulla. The most prominent nucleus of the reticular formation in this region is the nucleus gigantocellularis (see Figure 42A and Figure 42B); the descending fibers form the lateral reticulo-spinal tract (see Figure 49B).

Included in the tegmentum are the two ascending tracts, the large medial lemniscus and the small anterolateral system, both conveying the sensory modalities from the opposite side of the body. The spinal trigeminal tract and nucleus, conveying the modalities of pain and temperature from the ipsilateral face and oral structures, is also found throughout the medulla. The solitary nucleus and tract, which subserve both taste and visceral afferents, are likewise found in the medulla. The MLF is still a distinct tract in its usual location (see Figure 51B).

The nuclei gracilis and cuneatus, the relay nuclei for the dorsal column tracts, are found in the lower part of the medulla, on its dorsal aspect (discussed with Figure 67C). The fourth ventricle lies behind the tegmentum, separating the medulla from the cerebellum (see Figure 20B). The roof of this (lower) part of the ventricle has choroid plexus (see Figure 21). CSF escapes from the fourth ventricle via the various foramina located here, and then flows into the subarachnoid space, the cisterna magna (see Figure 18 and Figure 21).

FIGURE 67: MID-MEDULLA
(PHOTOGRAPHIC VIEW)

This is a photographic image, enlarged, at the middle level of the medulla, with the cerebellum attached. This specimen shows the principal identifying features of the medulla, the pyramids ventrally on either side of the midline and the more laterally placed inferior olivary nucleus, with its scalloped borders.

Between the olivary nuclei, on either side of the midline, are two dense structures, the medial lemniscus. The other dense tract that is recognizable in this specimen is the inferior cerebellar peduncle located at the outer posterior edge of the medulla. Other tracts and cranial nerve nuclei, including the reticular formation, are found in the central region of the medulla, the tegmentum.

The space behind is the fourth ventricle, narrowing in its lower portion (see Figure 20B). There is no "roof" to the ventricle in this section, and it is likely that the plane of the section has passed through the median aperture, the foramen of Magendie (see Figure 21).

The cerebellum remains attached to the medulla, with the prominent vermis and the large cerebellar hemispheres. The cerebellar lobe adjacent to the medulla is the tonsil (see Figure 18; discussed with Figure 9B). The extensive white matter of the cerebellum is seen, as well as the thin outer layer of the cerebellar cortex.

The medulla is to be represented by three sections:

- Figure 67A: The upper medullary level typically includes CN VIII (both parts) and its nuclei.
- Figure 67B: This section through the mid-medulla includes the nuclei of cranial nerves IX, X, and XII.
- Figure 67C: The lower medullary section is at the level of the dorsal column nuclei, the nuclei gracilis and cuneatus.
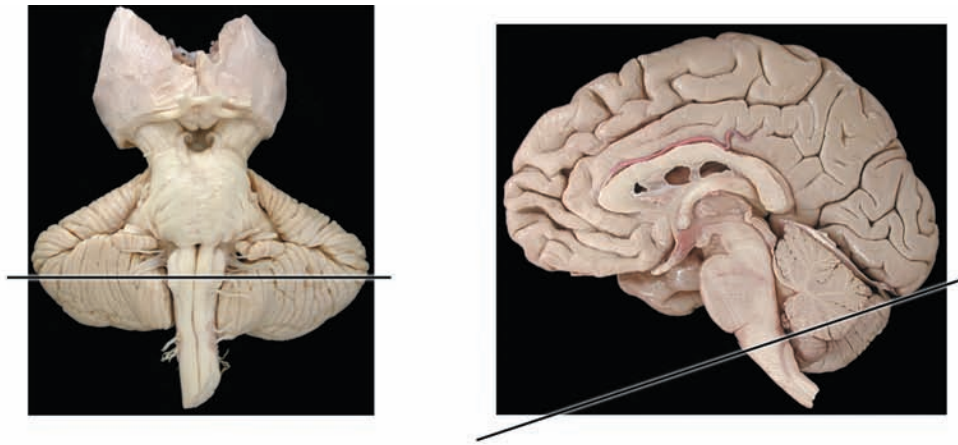
Ch = Cerebellar hemisphere

FIGURE 67: Brainstem Histology — Medulla (mid — photograph)

FIGURE 67A
UPPER MEDULLA:
CROSS-SECTION

This section has the characteristic features of the medullary region, namely the pyramids anteriorly with the inferior olivary nucleus situated just laterally and behind.

The cortico-spinal voluntary motor fibers from areas 4 and 6 go through the white matter of the hemispheres, funnel via the internal capsule (posterior limb), continue through the cerebral peduncles of the midbrain and the pontine region, and emerge as a distinct bundle in the medulla within the pyramids. The cortico-spinal tract is often called the pyramidal tract because its fibers form the pyramids (discussed with Figure 45).

The medial lemniscus is the most prominent ascending (sensory) tract throughout the medulla, carrying the modalities of discriminative touch, joint position, and vibration (see Figure 33 and Figure 40). The tracts are located next to the midline, oriented in the anteroposterior (ventrodorsal) direction (see Figure 40), just behind the pyramids; they will change orientation and shift more laterally in the pons. Dorsal to them, also along the midline, are the paired tracts of the MLF, situated in front of the fourth ventricle. The anterolateral tract, conveying pain and temperature, lies dorsal to the olive, although it is not of sufficient size to be clearly identified (see Figure 34 and Figure 40). Both the medial lemniscus and the anterolateral system are carrying fibers from the opposite side of the body at this level. The descending nucleus and tract of CN V are present more laterally, carrying fibers (pain and temperature) from the ipsilateral face and oral structures, before decussating (see Figure 35 and Figure 40).

The other prominent tract in the upper medullary region is the inferior cerebellar peduncle. This tract is conveying fibers to the cerebellum, both from the spinal cord and from the medulla, including the inferior olivary nucleus (discussed with Figure 55).

The VIIIth nerve enters the medulla at its uppermost level, at the cerebello-pontine angle, passing over the inferior cerebellar peduncle. The nerve has two nuclei along its course, the ventral and dorsal cochlear nuclei (see Figure 8B). The auditory fibers synapse in these nuclei and then go on to the superior olivary complex in the lower pons region. The crossing fibers are seen in the lowermost pontine region as the trapezoid body (see Figure 37 and Figure 40).

The vestibular part of the VIIIth nerve is represented at this level by two nuclei, the medial and inferior vestibular nuclei (see Figure 51A). Both these nuclei lie in the same position as the vestibular nuclei in the pontine section, adjacent to the lateral edge of the fourth ventricle. The inferior vestibular nucleus is distinct because of the many axon bundles that course through it. The vestibular nuclei contribute fibers to the MLF (discussed with Figure 51B).

The solitary nucleus is found at this level, surrounding a tract of the same name. This nucleus is the synaptic station for incoming taste fibers (mainly with CN VII, also with CN IX), and for visceral afferents entering with CN IX and X from the GI tract and other viscera. The solitary nucleus and tract are situated just beside (anterior to) the vestibular nuclei.

The core area is occupied by the cells of the reticular formation (see Figure 42A and Figure 42B). The most prominent of its nuclei at this level is the gigantocellular nucleus (noted for its large neurons), which gives rise to the lateral reticulo-spinal tract (see Figure 49B). The other functional aspects of the reticular formation should be reviewed at this point, including the descending pain system from the nucleus raphe magnus (discussed with Figure 43).

The fourth ventricle is still quite large at this level. The lower portion of its roof has choroid plexus (see Figure 20A and Figure 21); a fragment of this is present with the histological section, although the roof is torn. Behind the ventricle is the cerebellum, with the vermis (midline) portion and the cerebellar hemispheres. The dentate nucleus, the largest of the intracerebellar nuclei, is present at this level. Again, the cerebellum has not been processed with the histological specimen.

Dentate n.

Vermis of cerebellum

Choroid plexus

4th ventricle

Medial vestibular n.

Inferior vestibular n.

Inferior cerebellar
peduncle

Dorsal cochlear n.

Ventral cochlear n.

Solitary n.
Solitary t.

Spinal t. CN V

Spinal n. CN V

MLF

Anterolateral system

Medial lemniscus

Reticular formation

Vestibulocochlear
nerve (CN VIII)
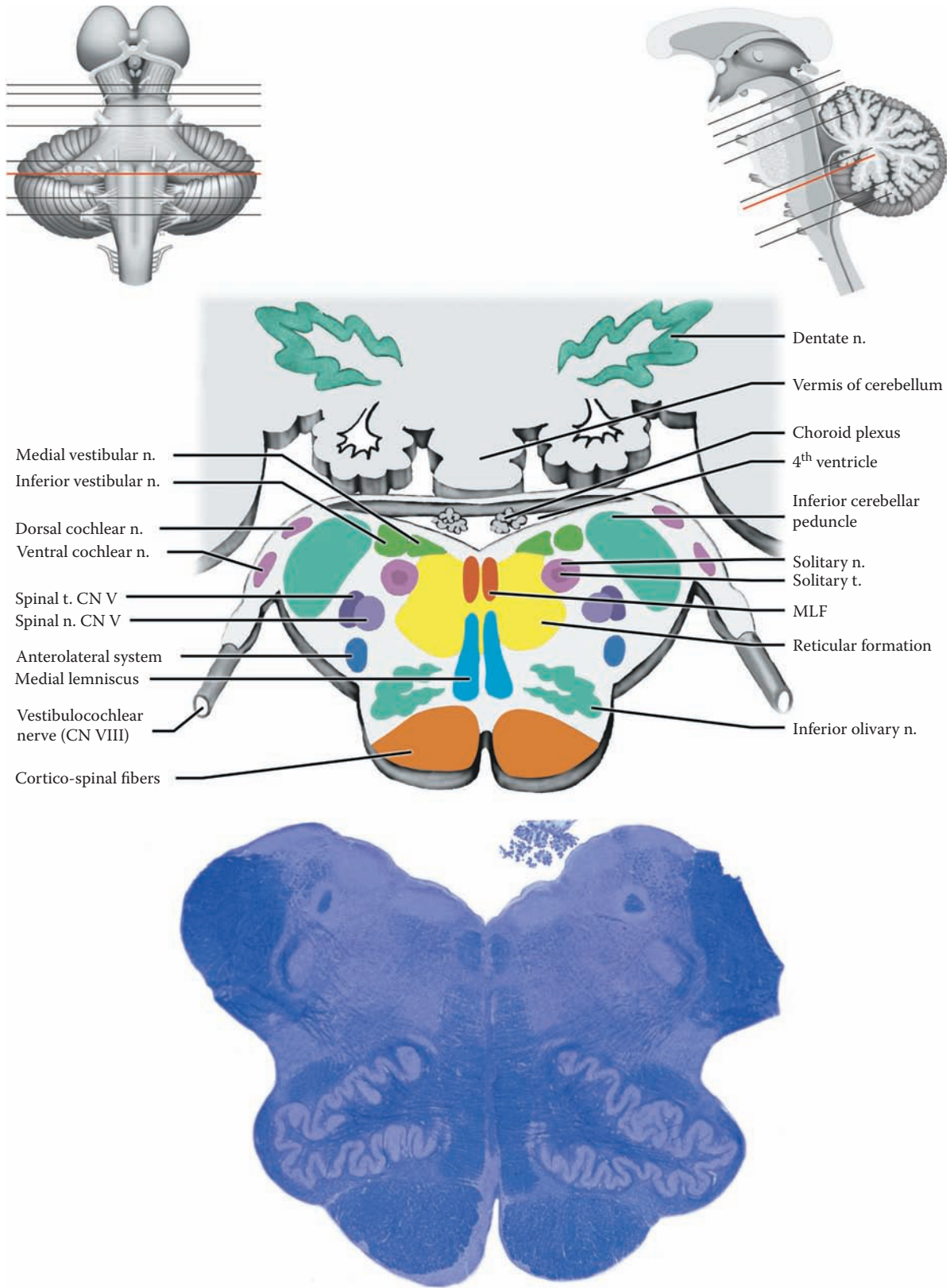
Inferior olivary n.

Cortico-spinal fibers

FIGURE 67A: Brainstem Histology — Upper Medulla

FIGURE 67B
MID-MEDULLA:
CROSS-SECTION

This cross-sectional level is often presented as "typical" of the medulla. The pyramids and inferior olive are easily recognized anteriorly.

The medial lemniscus occupies the area between the olives, on either side of the midline (see Figure 40). The MLF lies behind (dorsal) the medial lemniscus, also situated adjacent to the midline. The fibers of the anterolateral system are situated dorsal to the olive. The descending nucleus and tract of the trigeminal system have the same location as seen previously in the lateral aspect of the tegmentum.

The hypoglossal nucleus (CN XII) is found near the midline and in front of the ventricle; its fibers exit anteriorly, between the pyramid and the olive (see Figure 6 and Figure 7). CN IX and CN X are attached at the lateral aspect of the medulla (see Figure 6 and Figure 7). Their efferent fibers are derived from two nuclei (indicated by the dashed lines): the dorsal motor nucleus, which is parasympathetic, and the nucleus ambiguus, which is motor to the muscles of the pharynx and larynx (see Figure 8A). The dorsal motor nucleus lies adjacent to the fourth ventricle just lateral to the nucleus of XII. The nucleus ambiguus lies dorsal to the olivary nucleus; in a single cross-section only a few cells of this nucleus are usually seen, making its identification difficult (i.e., "ambiguous") in actual sections. The taste and visceral afferents that are carried in these nerves synapse in the solitary nucleus, which is located in the posterior aspect of the tegmentum, surrounding the tract of the same name.

The reticular formation occupies the central core of the tegmentum; the nucleus gigantocellularis is located in this part of the reticular formation (see Figure 42B). These cells give rise to a descending tract, the lateral reticulospinal tract as part of the indirect voluntary motor system (see Figure 49B); there is also a strong influence on the excitability of the lower motor neuron, influencing the stretch reflex and muscle tone.

The inferior cerebellar peduncle is found at the lateral edge of this section, posteriorly, carrying fibers to the cerebellum (see Figure 55). The fourth ventricle is still a rather large space, behind the tegmentum, with the choroid plexus attached to its roof in this area; often the ventricle appears "open," likely because this thin tissue has been torn. There is no cerebellar tissue posteriorly since the section is below the level of the cerebellum (see the sagittal schematic accompanying this figure).

CLINICAL ASPECT

Vascular lesions in this area of the brainstem are not uncommon. The midline area is supplied by the paramedian branches from the vertebral artery (see Figure 58). The structures included in this territory are the corticospinal fibers, the medial lemniscus, and the hypoglossal nucleus.

The lateral portion is supplied by the posterior inferior cerebellar artery, a branch of the vertebral artery (see Figure 58, Figure 59A, and Figure 61), called **PICA** by neuroradiologists. This artery is prone to infarction for some unknown reason. Included in its territory are the cranial nerve nuclei and fibers of CN IX and X, the descending trigeminal nucleus and tract, fibers of the anterolateral system, and the solitary nucleus and tract, as well as descending autonomic fibers. The inferior cerebellar peduncle or vestibular nuclei may also be involved. The whole clinical picture is called the **lateral medullary syndrome** (of Wallenberg).

Interruption of the descending autonomic fibers gives rise to a clinical condition called **Horner's syndrome**. In this syndrome, there is loss of the autonomic sympathetic supply to one side of the face, ipsilaterally. This leads to ptosis (drooping of the upper eyelid), a dry skin, and constriction of the pupil. The pupillary change is due to the competing influences of the parasympathetic fibers, which are still intact. Other lesions elsewhere that interrupt the sympathetic fibers in their long course can also give rise to Horner's syndrome.

Note to the Learner: It is instructive to work out the clinical symptomatology of both of these vascular lesions, using a drawing, indicating which function is lost with each of the tracts or nucleus involved in the lesion, and which side of the body would be affected.

Inferior vestibular n.

Accessory cuneate n.

Dorsal motor n.

Hypoglossal n.

Spinal t. CN V

Spinal n. CN V

Vagus nerve (CN X)

Anterolateral system

Medial lemniscus

Cortico-spinal fibers

Hypoglossal nerve (CN XII)

Choroid plexus

4th ventricle

Solitary n.

Solitary t.

Inferior cerebellar peduncle

N. ambiguus
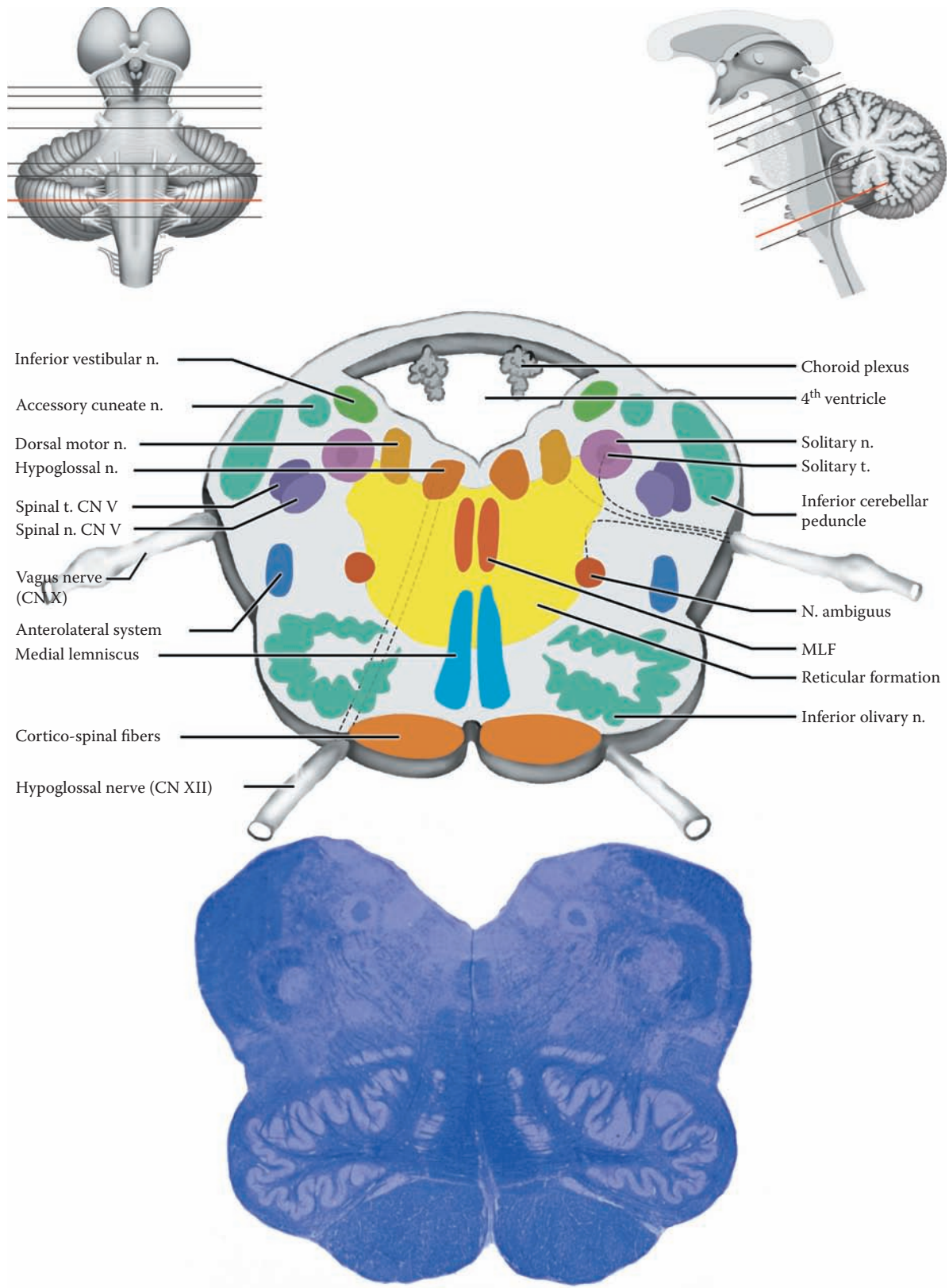
MLF

Reticular formation

Inferior olivary n.

FIGURE 67B: Brainstem Histology — Mid-Medulla

FIGURE 67C
LOWER MEDULLA:
CROSS-SECTION

The medulla seems significantly smaller in size at this level, approaching the size of the spinal cord below. The section is still easily recognized as medullary because of the presence of the pyramids anteriorly (the cortico-spinal tract) and the adjacent inferior olivary nucleus.

The tegmentum contains the cranial nerve nuclei, the reticular formation and the other tracts. The nuclei of CN X and CN XII, as well as the descending nucleus and tract of V, are present as before (as in the mid-medullary section, see Figure 67B). The MLF and anterolateral fibers are also in the same position. The solitary tract and nucleus are still found in the same location. The internal arcuate fibers are present at this level; these are the fibers from the nuclei gracilis and cuneatus, which cross (decussate) to form the medial lemniscus (see below). These fibers usually obscure visualization of the nucleus ambiguus. Finally, the reticular formation is still present.

The dorsal aspect of the medullary tegmentum is occupied by two large nuclei: the nucleus cuneatus (cuneate nucleus) laterally, and the nucleus gracilis (gracile nucleus) more medially. These are found on the dorsal aspect of the medulla (see Figure 9B and Figure 40). These nuclei are the synaptic stations of the tracts of the same name that have ascended the spinal cord in the dorsal column (see Figure 33, Figure 68, and Figure 69). The gracilis is mainly for the upper limb and upper body; the cuneatus carries information from the lower body and lower limb. The fibers relay in these nuclei and then move through the medulla anteriorly as the internal arcuate fibers, cross (decussate), and form the medial lemniscus on the opposite side (see Figure 40). At this level, the medial lemniscus is situated between the olivary nuclei and dorsal to the pyramids, and is oriented anteroposteriorly.

Posteriorly, the fourth ventricle is tapering down in size, giving a "V-shaped" appearance to the dorsal aspect of the medulla (see Figure 20B). It is common for the ventricle roof to be absent at this level. This is likely accounted for by the presence of the foramen of Magendie, where the CSF escapes from the ventricular system into the subarachnoid space (see Figure 21). Posterior to this area is the cerebello-medullary cistern, otherwise known as the cisterna magna (see Figure 2, Figure 18, and Figure 21).

One special nucleus is found in the "floor" of the ventricle at this level, the **area postrema**. This forms a little bulge that can be appreciated on some sections. The nucleus is part of the system that controls vomiting, and it is often referred to as the vomiting "center." It is interesting to note that this region lacks a blood-brain barrier, allowing this particular nucleus to be "exposed" directly to whatever is circulating in the blood stream. It likely connects with the nuclei of the vagus nerve, which are involved in the act of vomiting.

ADDITIONAL DETAIL

The accessory cuneate nucleus is found at this level, as well as at the mid-medullary level. This nucleus is a relay for some of the cerebellar afferents from the upper extremity (see Figure 55). The fibers then go to the cerebellum via the inferior cerebellar peduncle. The inferior cerebellar peduncle has not yet been formed at this level.

Cross-sections through the lowermost part of the medulla may include the decussating cortico-spinal fibers, i.e., the pyramidal decussation (see Figure 40); this would therefore alter significantly the appearance of the structures in the actual section.

Gracilis t.
Gracilis n.
Cuneatus t.
Cuneatus n.
Dorsal motor n.
Hypoglossal n.
Spinal t. CN V
Spinal n. CN V
Vagus nerve (CN X)
Internal arcuate fibers
Anterolateral system
Medial lemniscus
Cortico-spinal fibers
Hypoglossal nerve (CN XII)

Foramen of Magendie
4th ventricle
Area postrema
Accessory cuneate n.
Solitary n.
Solitary t.
MLF
N. ambiguus
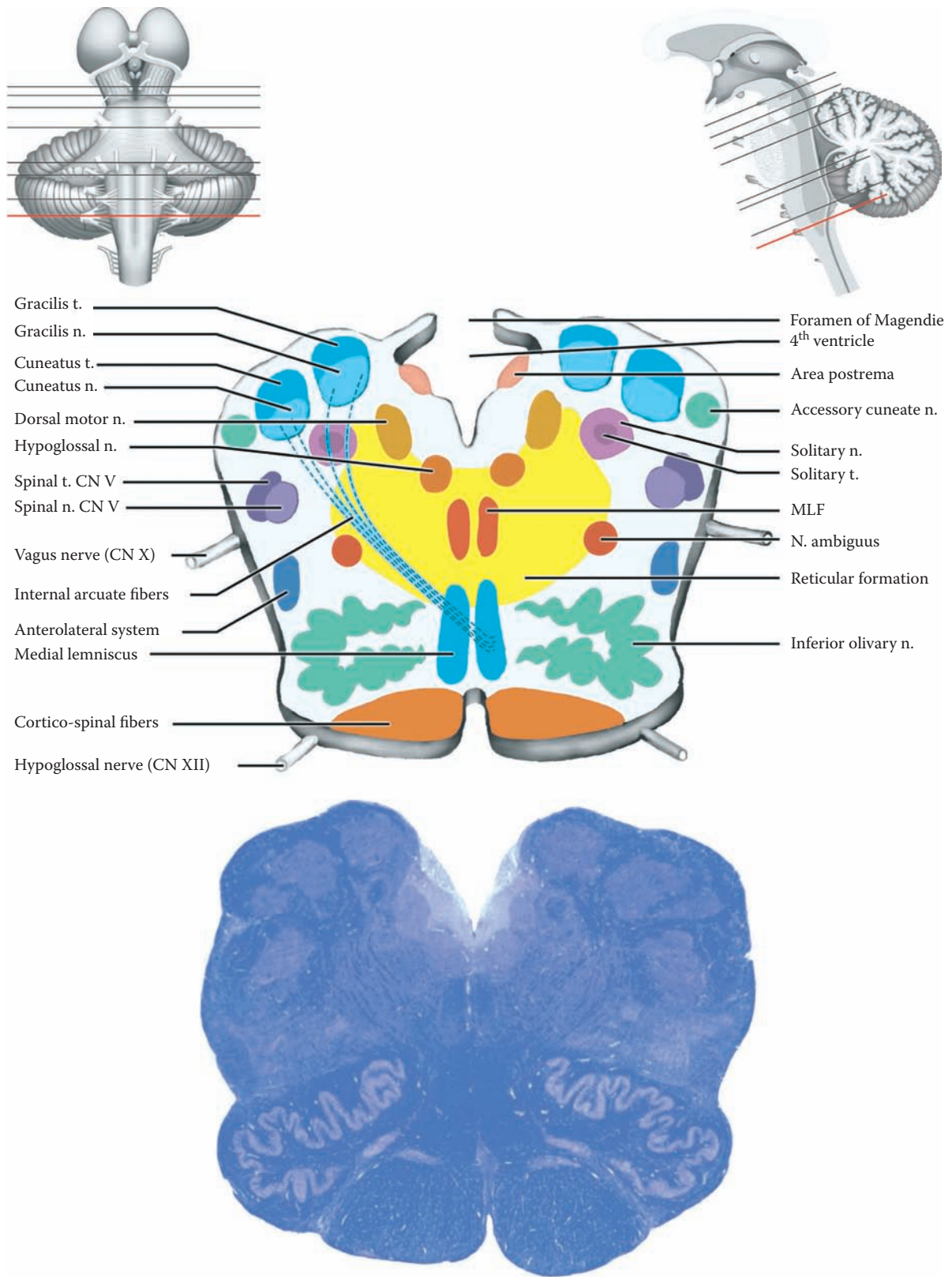Reticular formation
Inferior olivary n.

FIGURE 67C: Brainstem Histology – Lower Medulla

FIGURE 68
SPINAL CORD:
CROSS-SECTIONS

UPPER ILLUSTRATION: NUCLEI

This diagram shows all the nuclei of the gray matter of the spinal cord — both sensory and motor (see Figure 4, Figure 32, and Figure 44).

LOWER ILLUSTRATION: TRACTS: C8 LEVEL

The major tracts of the spinal cord are shown on this diagram, with the descending tracts on the left side and the ascending ones on the right side. In fact, both sets of pathways are present on both sides. Some salient features of each will be presented.

DESCENDING TRACTS

- **Lateral cortico-spinal**, from the cerebral (motor) cortex (see Figure 45 and Figure 48): These fibers for direct voluntary control supply mainly the lower motor neurons in the lateral ventral horn to control fine motor movements of the hand and fingers. This pathway crosses in the lowermost medulla.
- **Anterior (ventral) cortico-spinal**, also from the motor cortex (see Figure 45): These fibers, which do not cross in the pyramidal decussation, go to the motor neurons that supply the proximal and axial musculature.
- **Rubro-spinal**, from the red nucleus (see Figure 47 and Figure 48): This tract crosses at the level of the midbrain. Its role in human motor function is not certain.
- **Medial and lateral reticulo-spinal tracts,** from the pontine and medullary reticular formation, respectively (see Figure 49A and Figure 49B): These pathways are the additional ones for indirect voluntary control of the proximal joints and for posture, as well as being important for the control of muscle tone.
- **Lateral vestibulo-spinal,** from the lateral vestibular nucleus (see Figure 50): Its important function is participating in the response of the axial muscles to changes in gravity. This pathway remains ipsilateral.
- **Medial longitudinal fasciculus** (MLF, see Figure 51B): This mixed pathway is involved in the response of the muscles of the eyes and of the neck to vestibular and visual input. It likely descends only to the cervical spinal cord level.

ASCENDING TRACTS

- **Dorsal column tracts**, consisting at this level of both the fasciculus cuneatus and fasciculus gracilis (see Figure 33 and Figure 40): These are the pathways for discriminative touch sensation, joint position and "vibration" from the same side of the body, with the lower limb fibers medially (gracile) and the upper limb pathway laterally (cuneate).
- **Anterolateral system**, consisting of the anterior (ventral) spino-thalamic and lateral spino-thalamic tracts (see Figure 34): These pathways carry pain and temperature, as well as crude touch information from the opposite side of the body, with the lower limb fibers more lateral and the upper limb fibers medial.
- **Spino-cerebellar tracts**, anterior (ventral) and posterior (dorsal) (reviewed with the cerebellum, see Figure 54 and Figure 55): These convey information from the muscle spindles and other sources to the cerebellum.

SPECIAL TRACT

The dorsolateral fasciculus, better known as the tract of Lissauer (see Figure 32), carries intersegmental information, particularly relating to pain afferents.

CLINICAL ASPECT

The functional aspects of each of these tracts should be reviewed at this time by noting the loss of function that would be found following a lesion of the various pathways.

An acute injury to the cord, such as severing of the cord following an accident, will usually result in a complete shutdown of all spinal cord functions, called **spinal shock** (discussed with Figure 5). After a period of about 3–4 weeks, the spinal cord reflexes will return. In a matter of weeks, due to the loss of all the descending influences on the spinal cord, there is an increase in the reflex responsiveness (hyperreflexia) and a marked increase in tone (spasticity), along with the Babinski response (discussed with Figure 49B).

A classic lesion of the spinal cord is the **Brown-Sequard syndrome**, which is a lesion of one-half of the spinal cord on one side. Although rare, this is a useful lesion for the learner to review the various deficits, sensory and motor, that would be found after such a lesion. In particular, it helps the learner understand which side of the body would be affected because of the various crossing of the pathways (sensory and motor) at different levels.
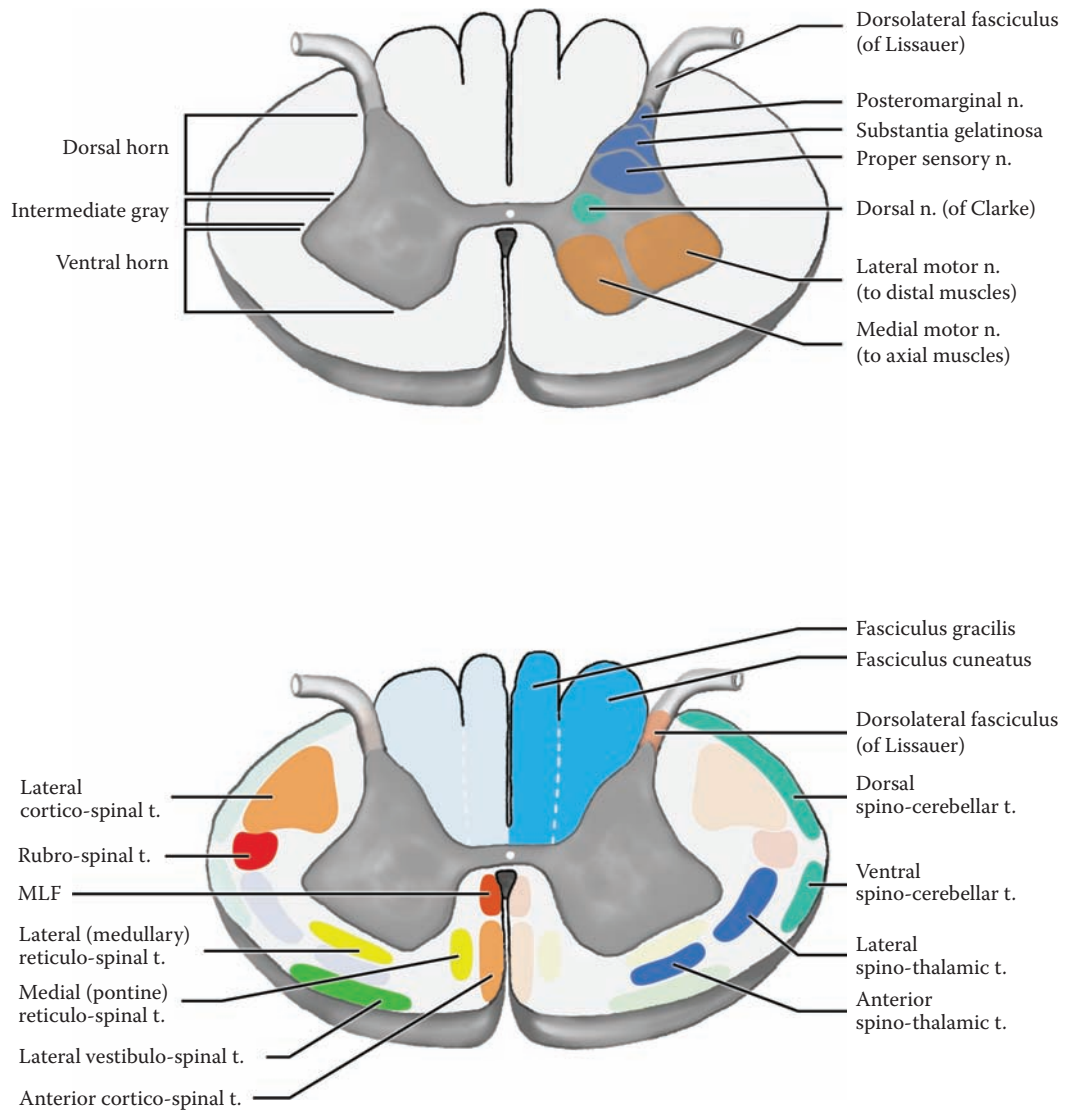
Dorsolateral fasciculus
(of Lissauer)

Posteromarginal n.
Substantia gelatinosa
Proper sensory n.

Dorsal horn

Intermediate gray

Ventral horn

Dorsal n. (of Clarke)

Lateral motor n.
(to distal muscles)

Medial motor n.
(to axial muscles)

Fasciculus gracilis
Fasciculus cuneatus

Dorsolateral fasciculus
(of Lissauer)

Lateral
cortico-spinal t.

Rubro-spinal t.

MLF

Lateral (medullary)
reticulo-spinal t.

Medial (pontine)
reticulo-spinal t.

Lateral vestibulo-spinal t.

Anterior cortico-spinal t.

Dorsal
spino-cerebellar t.

Ventral
spino-cerebellar t.

Lateral
spino-thalamic t.

Anterior
spino-thalamic t.

FIGURE 68: Spinal Cord — Nuclei and Tracts

FIGURE 69
SPINAL CORD:
CROSS-SECTIONAL VIEWS — HISTOLOGICAL

The spinal cord was introduced in the orientation section of this atlas (Section A, see Figure 1–Figure 5). The organization of the nervous tissue in the cord has the gray matter inside, in a typical "butterfly" or "H-shaped" configuration, with the white matter surrounding (see Figure 1, Figure 4, and Figure 5). The functional aspects of the spinal cord were presented in Section B, including the nuclei and connections for the afferent fibers (sensory, see Figure 32), and the efferent circuits with some reflexes (motor, see Figure 44).

The white matter surrounding the gray matter is divided by it into three areas: the dorsal, the lateral, and the anterior areas. These zones are sometimes referred to as funiculi (singular funiculus). Various tracts are located in each of these three zones, some ascending and some descending, which were reviewed (see previous illustration).

The following are cross-sectional views of various levels of the spinal cord, stained with a myelin and cell stain.

CERVICAL LEVEL — C8

This is a cross-section of the spinal cord through the cervical enlargement. This level has been used in many of the illustrations of the various pathways (in Section B). Since the cervical enlargement contributes to the formation of the brachial plexus to the upper limb, the gray matter ventrally is very large because of the number of neurons involved in the innervation of the upper limb, particularly the muscles of the hand. The dorsal horn is likewise large, because of the amount of afferents coming from the skin of the fingers and hand.

The white matter is comparatively larger at this level because:

- All the ascending tracts are present and are carrying information from the lower parts of the body as well as the upper limb.
- All the descending tracts are fully represented, as many of the fibers will terminate in the cervical region of the spinal cord. In fact, some of them do not descend to lower levels.

Various layers of meninges are seen in these cross-sections, as well as dorsal and ventral roots in the sub-arachnoid (CSF) space.

THORACIC LEVEL — T6

The thoracic region of the spinal cord presents an altered morphology because of the decrease in the amount of gray matter. There are fewer muscles and less dense innervation of the skin in the thoracic region. The gray matter has, in addition, a lateral horn, which represents the sympathetic preganglionic neurons. The lateral horn is present from T1 to L2.

LUMBAR LEVEL — L3

This cross-sectional level of the spinal cord has been used in the various illustrations of the pathways in Section B of this atlas. This cross-section is similar in appearance to the cervical section, because both are innervating the limbs. There is, however, proportionately less white matter at the lumbar level. The descending tracts are smaller because many of the fibers have terminated at higher levels. The ascending tracts are smaller because they are conveying information only from the lower regions of the body.

The sacral region of the spinal cord is the smallest in size and is therefore easy to recognize (not shown). The white matter is quite reduced in size. There is still a fair amount of gray matter because of the innervation of the pelvic musculature.

This region of the spinal cord, roughly the conus medullaris (see Figure 2A), also contains the preganglionic parasympathetic neurons of the autonomic nervous system. These neurons innervate the bowel and the bladder.

BLOOD SUPPLY

The anterior spinal artery, the main blood supply to the spinal cord, comes from branches from each of the vertebral arteries that join (see Figure 58); it descends in the midline (see Figure 2B) and supplies the ventral horn and the anterior and lateral group of tracts, including the lateral cortico-spinal pathway. The posterior spinal arteries supply the dorsal horn and the dorsal columns.

CLINICAL ASPECT

The blood supply to the spinal cord was reviewed with Figure 2B; it is known that this blood supply is marginal, particularly in the mid-thoracic region. The learner is encouraged to work out the clinical symptomatology following lesions of the spinal cord at various levels.
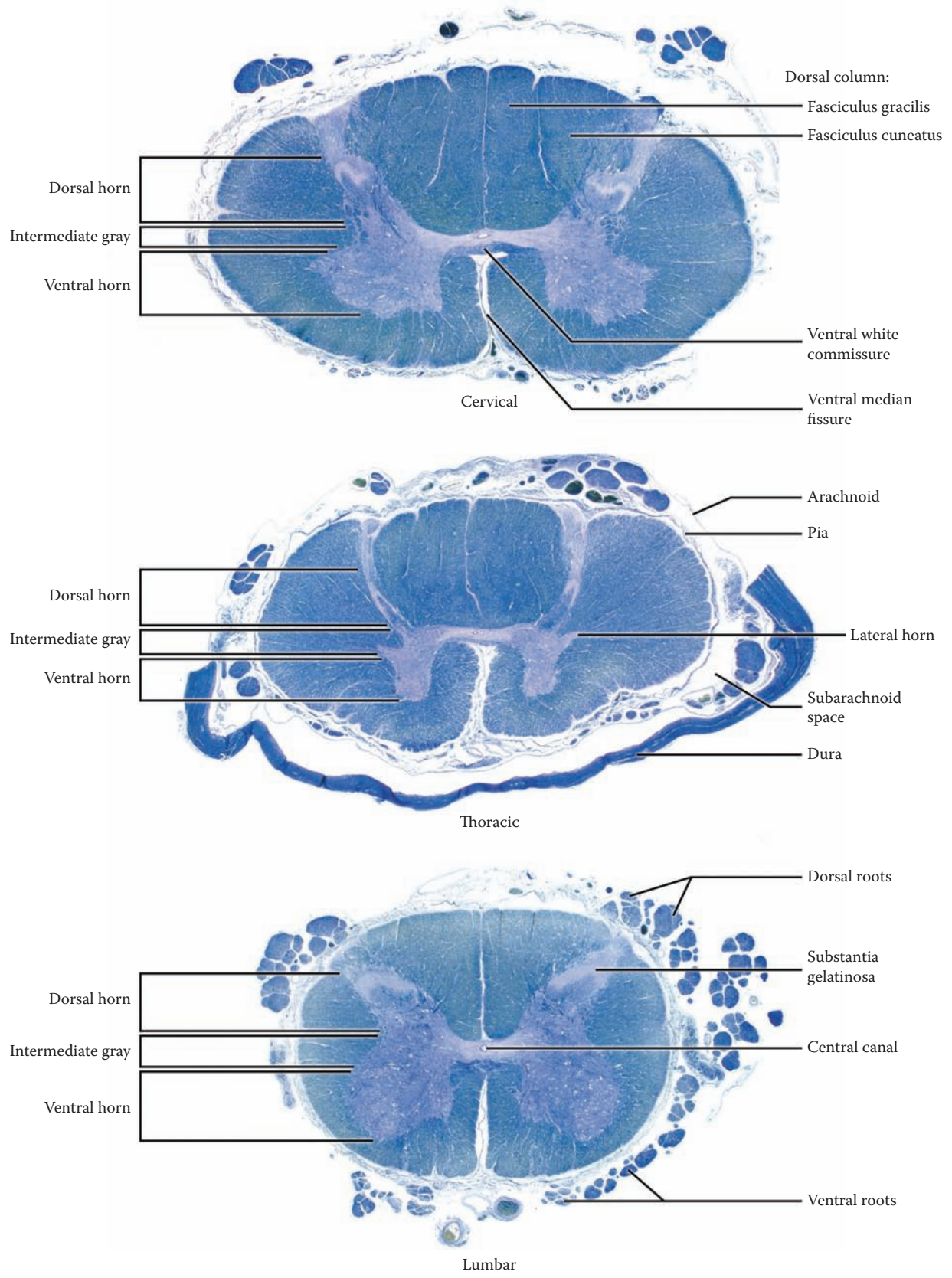
Dorsal column:

Fasciculus gracilis

Fasciculus cuneatus

Dorsal horn

Intermediate gray

Ventral horn

Ventral white
commissure

Ventral median
fissure

Cervical

Arachnoid

Pia

Dorsal horn

Intermediate gray

Ventral horn

Lateral horn

Subarachnoid
space

Dura

Thoracic

Dorsal roots

Substantia
gelatinosa

Dorsal horn

Intermediate gray

Central canal

Ventral horn

Ventral roots

Lumbar

FIGURE 69: Spinal Cord Histology — Cross-Sections