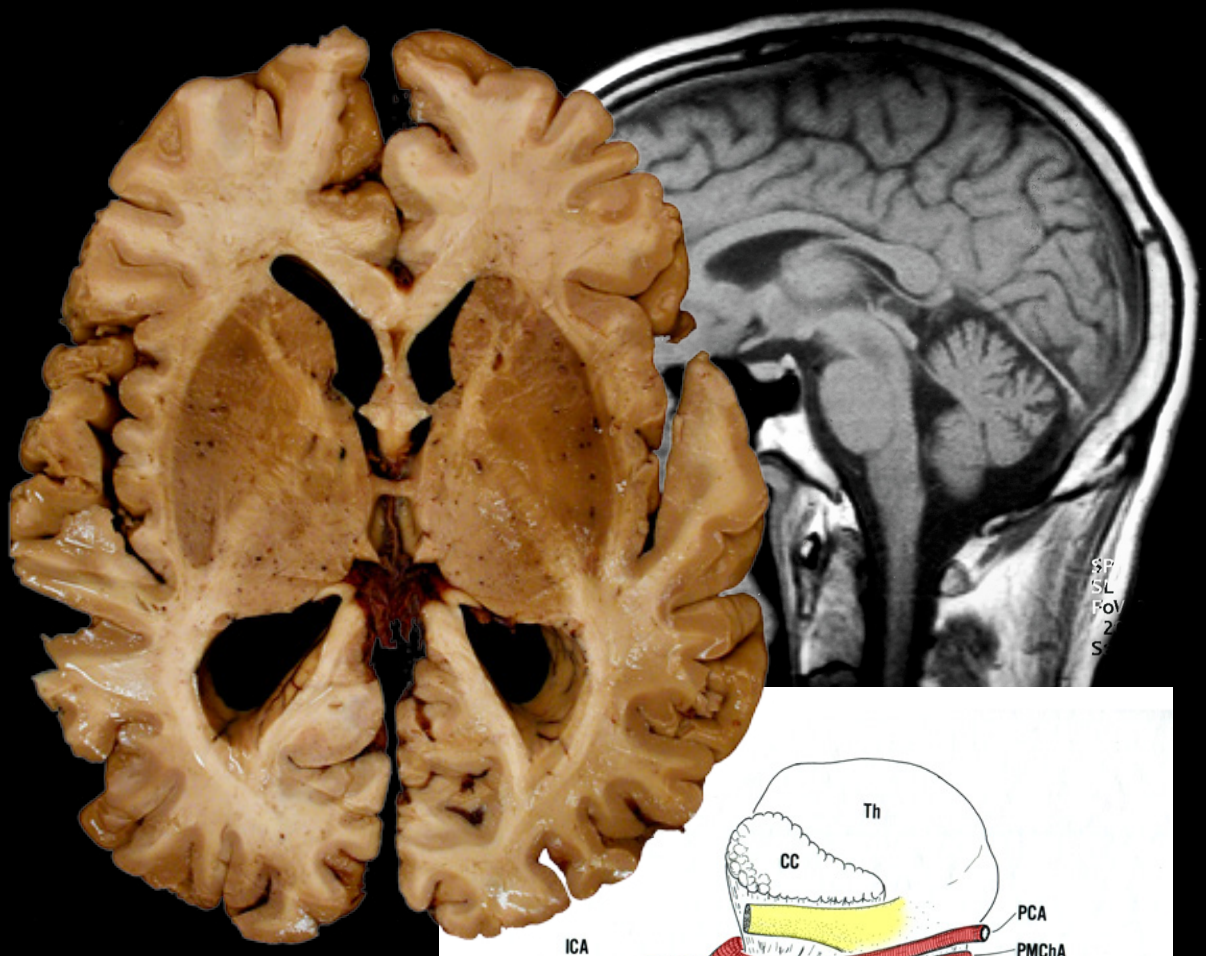
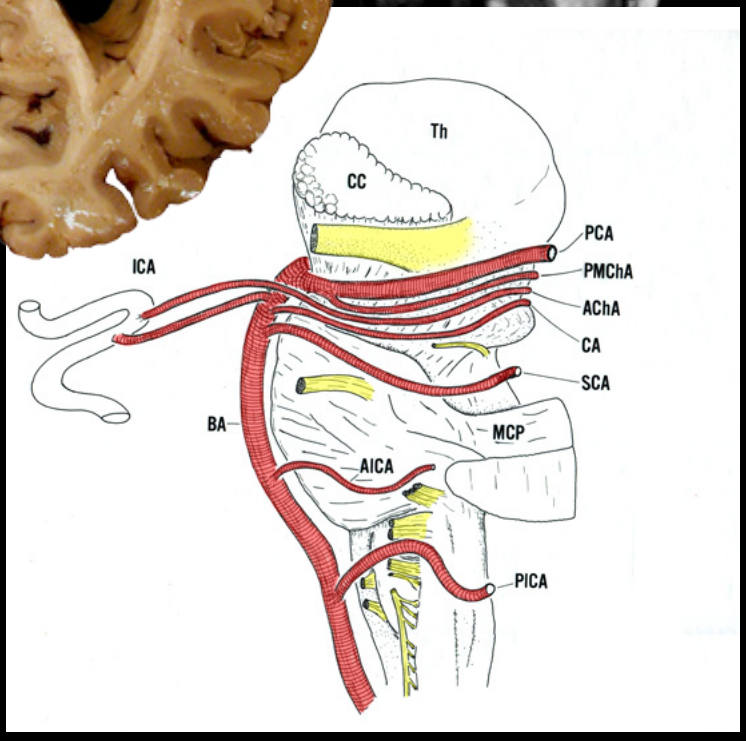
Medical Neuroanatomy:

A Problem-Oriented Approach





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Chapter 1
Introduction to Gross Brain Anatomy

▶ INTRODUCTION

Of all the organ systems in the body, the central nervous system has the most varied topography and structure. Encased in a bony vault that limits its expansion during development, the tissue of the central nervous system forms numerous convoluted surface folds. From these intricate structures, the brain and spinal cord, arise the complexities of human reflexive, emotive and motivational behavior. Damage to these intricate structures results in significant behavioral and physiological deficits in humans. The primary goal of this manual is to approach an understanding of nervous sytem functions by studying the deficits in human performance that result from neurologic damage.

Embryologic studies have demonstrated that the adult central nervous system can be divided into a hierarchy of functional levels (Moore and Persaud, 1998; also see Figure 1-11). Each level in the developmental hierarchy is contained within one of three meningeal compartments: supratentorial, infratentorial, or vertebral (Table 1-1). At any level on the neuraxis, alterations in structure due to vascular accidents, mass occupying events (e.g., tumors or abscesses), or degenerative processes amongst others can occur. These events, which generally are destructive to neural tissue, have been referred to as lesions. When a lesion occurs in the nervous system, the patient presents neurologic signs and symptoms that represent specific clues to the location of the damage. Treatment and need for long term care is based, to a great degree, on the localization of the injury. Associating specific neurologic clinical signs with lesions of specific levels of the neuraxis requires knowledge of the neuroanatomy of a given area and of what happens when the brain attempts to work with damaged structures (Damasio and Damasio, 1989). Knowledge of the meningeal compartments and their contents can assist in localizing the general region of neurologic damage in a patient.

This chapter is focused on two goals. First, it examines the major neural structures contained within each meningeal compartment, associating them with their general functions. Second, a general scheme of cerebral vascularization is described. Ultimately we seek to integrate these two items together such that you can associate the loss of a specific artery to the clinical presentation of the patient. Although at this point you may not fully understand the function of structures presented in this chapter, gaining familiarity with their location will greatly benefit you in the remaining chapters of this manual. In keeping with the overall goal of the text, our exploration will be done in the context of a case study involving

damage to the human neuraxis.

GENERAL OBJECTIVES

The major objective of Chapter One is simply an overview of central nervous system anatomy in relation to its surrounding meningeal compartments and a general outline to the cerebral vascular anatomy. It is not intended for memorization at this time. A general knowledge of this material will be helpful in organizing material presented in later sections. The specific objectives of this chapter are as follows:

1. To describe the nervous system in terms of its six major levels of organization and function (Table 1-1)
2. To learn general types of clinical defects resulting from damage in each of the six major levels in the neuraxis
3. To understand the distribution of cerebral blood vessels and to know where extravasated blood accumulates in the cerebral vault

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each one will be followed by a list of questions that can best be answered using knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before attempting to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After you are familiar with the material, re-examine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources, such as specialty texts, a medical dictionary or clinical instructors.

MATERIALS

1. One complete human brain and spinal cord
2. One brain sectioned in the mid-sagittal plane

Embryonic Structure	Adult Structure	Meningeal Compartment
Spinal Cord	Spinal Cord	Vertebral Compartment
Myelencephalon	Medulla	Infratentorial Compartment
Metencephalon	Pons	Infratentorial Compartment
Metencephalon	Cerebellum	Infratentorial Compartment
Mesencephalon	Midbrain	Infratentorial Compartment
Diencephalon	Thalamus	Supratentorial Compartment
Telencephalon	Cerebral Hemispheres	Supratentorial Compartment

Table 1-1 The major levels of the central nervous system, their embryonic origin, and the meningeal compartment in which they are contained in adult life.

Chapter One Topics:

Case Study 1-1

DISCUSSION

Meninges - Coverings of the Brain and Spinal Cord

Meningeal Layers
- Dura
- Arachnoid
- Pia

Meningeal Compartments
- Supratentorial Compartment
- Infratentorial Compartment
- Vertebral Compartment

Central Nervous System Organization
- Spinal Cord
- Medulla
- Pons
- Cerebellum
- Midbrain
- Thalamus
- Cerebrum

Cerebral Vasculature
- Anterior Circulation
- Posterior Circulation

Intracranial Hemorrhages
- Epidural Hemorrhage
- Subdural Hemorrhage
- Intracerebral Hemorrhage

Summary

Reference List

Case Study 1-1

Chief complaint
A 74-year-old retired lawyer was brought into a small community clinic in northern Maine complaining of a pain on the right side of his head and weakness on the left side of his body.

History of chief complaint
He had had mild hypertension for several years but was otherwise in excellent health. He had been in Maine on a hunting trip for the previous 3 days. On the day of admission he had been walking back to camp in a heavy snowfall when he suddenly developed pain behind the right ear, along with weakness of the left side of his body, greatest in his arm, and a dysarthria. He was brought immediately to the clinic, where a Physician Assistant examined him. He was observed to be afebrile, to have a pulse rate of 88 beats per minute, regular breathing at a rate of 16 respirations per minute and blood pressure of 200/112 mmHg. He was awake, oriented, and followed commands. His speech was slurred, but meaningful. He complained of a steady, moderately severe pain above and behind the right ear. His head and eyes deviated moderately to the right at rest, and there was a notable left homonymous hemianopsia.

Review of Systems
The patient denied any recent history of trauma, headaches, or dizzy periods. He admitted to consuming one to two bottles of beer each evening on the hunting trip, but denied consistent use of alcohol in his daily life. He also denied the use of any illicit drugs and was not taking any prescription medications. Otherwise the ROS was unremarkable.

Physical Examination on Presentation

He was able to track a moving object with his eyes throughout the full visual field on the right and just past the midline to the left, but could not volitionally follow a traget into the the remainder of the left visual field; however, with the doll's head maneuver, his eyes could be directed into the left visual hemisphere. The pupils were unequal, the right being 2 mm and the left, 3 mm; both reacted to light. His speech was dysarthric, but speech content was meaningful. Sensation was reduced in the left side of the face and cornea. There was a moderately severe, flaccid left hemiparesis interrupted intermittently by clonic movements of the leg and tonic flexor movements of the left arm. Stretch reflexes on the left side were reduced, but the plantar response was extensor. A patchy diminution of primary sensory modalities was present on the left arm.

Follow-up

Within an hour of admission, the patient was having periodic decorticate posturing on the left side. The right plantar response had become extensor. He gradually lost consciousness; within 4 hours of admission he was unresponsive except to noxious stimuli. At first, painful stimuli produced extensor responses on the left but decorticate responses on the right; however, this pattern finally transformed into bilateral extensor posturing, slightly more pronounced on the left than on the right. By this time, the right pupil had dilated and fixed in an oval shape, being 7 mm vertically and 3 mm horizontally. Minimal oculomotor responses could be elicited to cold caloric stimulation, and the patient was hyperventilating. Blood pressure had risen to 235/150 mmHg.

One hour after entering the clinic, preparations were begun for emergency transfer to Bangor, Maine, the closest major medical center, however, due to the snowstorm air travel was impossible and ground transportation was slow. Treatment with mannitol was started, and during the next hour the patient's condition stabilized, except that the right pupil became round and regained a minimal reaction to light. In route to Bangor, the patient's blood pressure dropped to 160/60 mmHg, he began to vomit, and his temperature rose to 39.6 degrees centigrade. He began to sweat profusely, and within 6 hours of initial presentation at the clinic, the decerebrate responses had become less intense, the pupils were fixed, slightly irregular at 3 to 4 mm in diameter and unequal, oculocephalic responses were absent, and respiration was quiet and shallow.

Within 8 hours of admission to the clinic (2 hours into the trip to Bangor), respiration was ataxic, the pupils remained slightly unequal, with no oculovestibular responses; and the patient was diffusely flaccid but had bilateral extensor plantar responses and mild flexor response in the legs to noxious stimulation of the soles of his feet. He died 30 minutes later while still in route.

Questions:

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem; is the onset of neurologic findings acute or insidious. Is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is involved with the lesion in this patient

▶ DISCUSSION

Meninges – Coverings of the Brain and Spinal Cord

The tissue of the central nervous system is contained within a bony vault called the cranium and vertebral canal. Between nervous tissue and bone can be found three general layers of protective coverings or meninges (Figure 1-1). A rich vascular supply perfuses the tissue within the cranial vault. Abnormal accumulation of fluids such as extravasated blood, either between meningeal layers (epidural, subdural, or subarachnoid) or within the nervous tissue itself (intracerebral) will increase the pressure within the cranial vault or vertebral canal. This increased pressure can compromise function in surrounding neural tissue.

CLINICAL DISCUSSION: Increased intracranial pressure (ICP) can be diffuse in origin such as in overall swelling of the brain from infectious and inflammatory processes or expansion of the ventricles secondary to overproduction or insufficient removal of cerebral spinal fluid. Conversely, increased ICP can be focal in origin consequent to a hemorrhagic vascular event, an abscess or a tumor. Although the initial clinical presentation can differ based on the origin of the pathology – focal or diffuse – ultimate cardinal manifestations of increased ICP are diffuse in nature including headache, nausea and vomiting, ocular palsies, papilledema, visual changes and mental status changes such as irritability, drowsiness, obtundation and coma (Adams, Victor et al., 1997).

Dura

The dura mater is a tough outer covering of dense irregular connective tissue surrounding the brain and spinal cord. The cerebral dura is divided into two layers. The outer dura forms the periosteum (also termed endosteum) of the cranial vault (Figure 1-1 and 1-2). The outer layer of dura is also continuous through the foramen magnum and the cranial sutures with the periosteum on the external surface of the cranium (Figure 1-1). The inner or meningeal dura for the most part is fused with the outer layer; however, in specific regions it separates to create venous sinuses such as the superior sagittal sinus (Figure 1-1). The falx cerebri and tentorium cerebelli are both formed by the fusion of meningeal dural sheets derived from the inner border of the venous sinuses (Figure 1-1).

In the vertebral canal the organization of the dural sheaths differ from that of the cranial vault. The outer dural layer or periosteal layer becomes the periosteum of the vertebral bodies; the inner layer of dura continues into the vertebral canal as the meningeal or spinal dura surrounding the spinal cord (Figure 1-3). An epidural space exists between these two layers. This space is occupied by fat and an elaborate plexus of veins termed the epidural plexus of Batson. As the cranial and spinal nerves exit the dural sac and pass through the intervertebral foramen (Figure 1-3), they acquire sheaths derived from meningeal dura termed the epineurium.

CLINICAL DISCUSSION: The epidural space and its tortuous, valveless venous plexus represent an area of venous potential stasis where blood-borne pathogens and tumor cells can seed. A resultant epidural abscess or epidural metastatic growth can eventually compress the dural sac and its enclosed spinal cord or spinal roots or compress a spinal nerve as it enters the intervertebral foramen. Compression of the spinal cord is termed a **myelopathy**, while compression of the spinal roots is a **rhizopathy** or **radiculopathy**, and compression of a spinal nerve, a **neuropathy**. Typical manifestations of a myelopathy involve intense pain at the level of the lesion with sensory and motor loss expressed below the level of the lesion (Brazis, Masdeu et al., 1996a). Conversely, rhizotomies and neuropathies present with sensory or motor deficits at or around the segmental level of the lesion.

Anytime a patient presents with slowly evolving signs of spinal cord compression (myelopathy), epidural abscess or epidural tumor secondary to metastatic spread should be in the differential.

Arachnoid

The arachnoid can be divided into two layers, the outer of which is a delicate membrane located internal to and adhered to the inner dura (Haines, Harkey et al., 1993). A potential space exists between these two layers of tissue but it appears to be fused during life. Many bridging veins cross this space (Figures 1-1 and 1-4). During a traumatic event, the dura moves with the cranium and the arachnoid moves with the brain. The shearing forces developed between these two meningeal layers can rupture some of the bridging veins, initiating a subdural hematoma. The inner layer of arachnoid consists of many delicate trabeculae that extend through the subarachnoid space to reach the pial surface. Blood vessels traverse the inner portion of the arachnoid supported by the labyrinthine trabecular network. It is around the arachnoid trabeculae that cerebrospinal fluid (CSF) circulates. The internal border of the CSF compartment is the pial layer.

Pia

The pia is a thin, smooth layer of connective tissue closely adherent to the surface of the brain and spinal cord (Figure 1-5). Its inner surface is fused to the end-feet of astrocytes (small supporting cells contained within the brain and spinal cord) and thus is closely adhered to the central nervous system.

CLINICAL DISCUSSION: The area under the arachnoid membrane, termed the subarachnoid space, contains cerebrospinal fluid. The large cerebral arteries pass through this space. Rupture of a cerebral artery in the subarachnoid space produces a subarachnoid hemorrhage (SAH). Since extravasated blood is an irritant to the meninges, SAHs often present with an extremely painful headache.

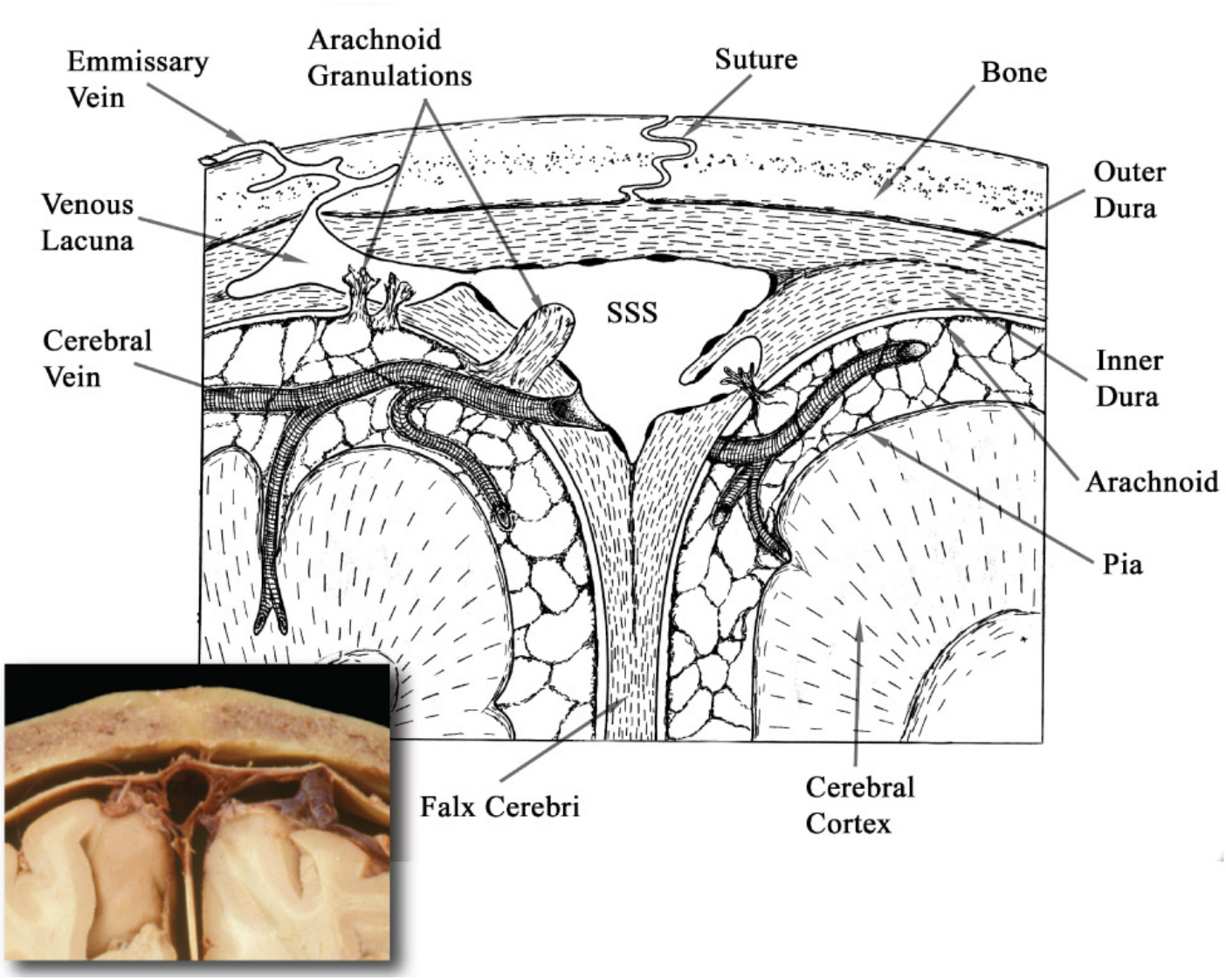


Figure 1-1 A diagram of a midline, coronal section taken through the head illustrating the three layers of meninges and the bony cranium. Note the split in the dura as the outer layer adheres to the cranial bones and the inner layer joins together to form the superior sagittal sinus (SSS). The position of the bridging (cerebral) veins as they pass from the cerebrum through the meninges to the sinus makes them vulnerable to rupture. (Figure modified from Parent, A. Carpenter's Human Neuroanatomy, Williams and Wilkins, Baltimore, 1996.)

Infection or inflammation of the spinal arachnoid is termed spinal arachnoiditis. This condition is characterized by opacification and thickening of the spinal arachnoid membrane. Ultimately, adhesions can form that interfere with spinal cord and spinal root function. A burning, stinging or aching pain and impaired reflexes are the cardinal manifestations of arachnoiditis. Weakness and muscle atrophy can also occur, but are less frequent (Adams, Victor, and Ropper, 1997).

Meningeal Compartments

Major folds in the dura help delineate several meningeal compartments in the cranial vault and vertebral column (Figure 1-8 and Figure 1-9). The falx cerebri divides the cranial cavity into left and right supratentorial compartments and the tentorium cerebelli separates the supratentorial from the infratentorial compartments. The foramen magnum marks the transition from the compartments of the cranial vault to the vertebral compartment.

Thin opaque sheets of pia, called denticulate ligaments, extend outward from the lateral margin of the spinal cord and attach to the dura (Figure 1-6 and Figure 1-7). As such, denticulate ligaments serve to anchor the cord within the dural sac and are a surgical landmark separating the dorsal and ventral roots of the spinal cord. The most superior denticulate ligament extends upward through the foramen magnum to attach to the inner wall of the occipital bone.

In the vertebral canal, the organization of the dural sheath changes. The outer dural layer of the cranial vault represents the periosteum

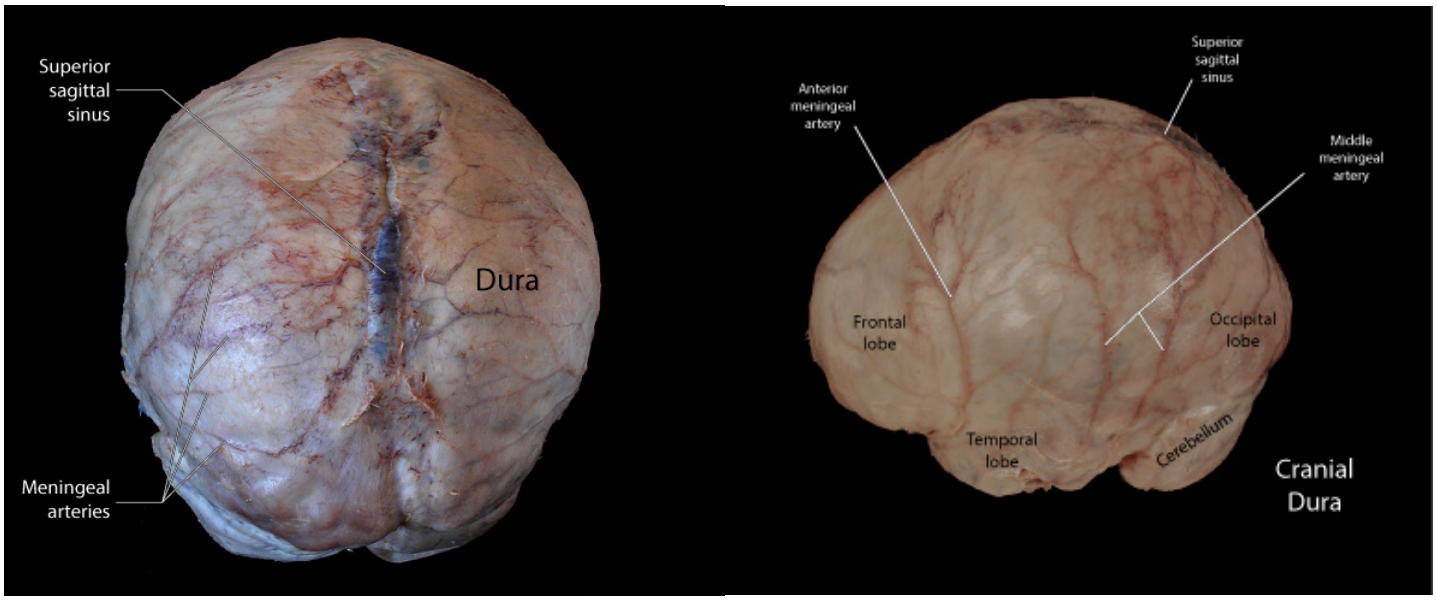


Figure 1-2 A superior view (left) and lateral view (right) of the dural coverings of the brain. In this specimen the bony calverium and head where dissected away from the dural sac leaving the sac with the brain contained within. On the left the superior sagittal sinus is seen in dark blue while on the right image the meningeal arteries are present.

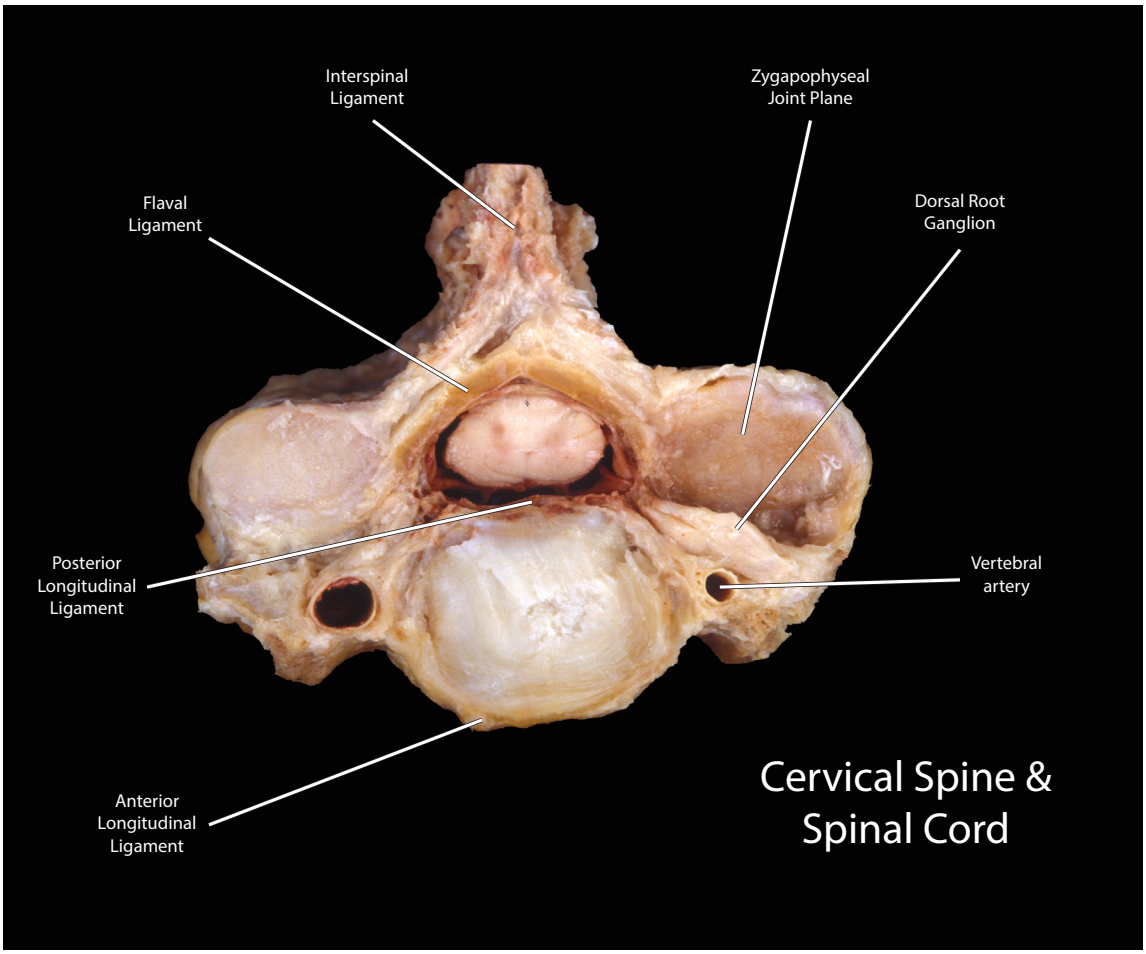


Figure 1-3 The cervical vertebral column. The column was separated at the C3-C4 disc. This image is a superior view of the C3/C4 disc and the superior articular processes of C4. The cervial spinal cord is seen in the center of the vertebral canal and the C4 spinal roots and dorsal root ganglia are present in the intervertebral foramina. Also note the position of the vertebral artery with respect to the dorsal root ganglion.

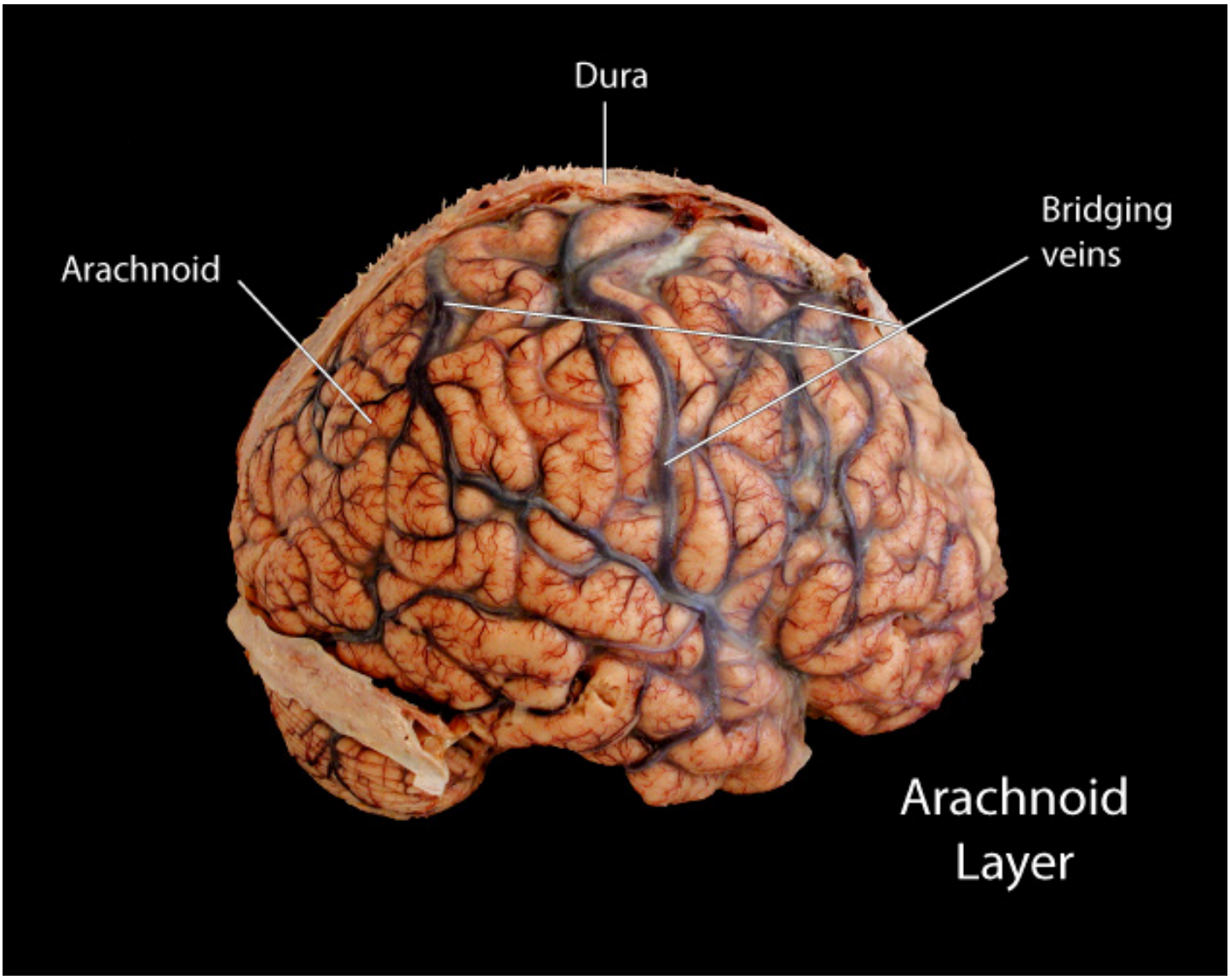


Figure 1-4 The arachnoid layers and associated bridging veins. The arachnoid is a thin membranous velum of connective tissue that surrounds the brain and spinal cord. Numerous vessels are contained between the arachnoid membrane and the pia.

of the vertebral canal and, as such, surrounds the bony elements of the vertebral column. A thickened lip of outer dura wraps around the edge of the foramen magnum to fuse with the periosteum of the outer cranium. Only the meningeal dural layer of the cranial vault is continuous with the spinal dura through the foramen magnum. An epidural space containing an important venous plexus (Batson's plexus of veins) and adipose tissue separates the vertebral periosteum from spinal dura (Batson, 1940; Batson, 1957). As the roots of the cranial and spinal nerves exit the dural sac they become peripheral nerves and acquire sheaths of meningeal dura, called the epineurium.

Supratentorial Compartment

The floor of the supratentorial compartment includes the orbital plate of the frontal bone and the wings of the sphenoid bone in the anterior cranial fossa (Figure 1-8), the squamae and anterior petrous wall of the temporal bone in the middle cranial fossa, and tentorium cerebelli. It is bound laterally and superiorly by the calvarium (made up of the squamae of the frontal, parietal, temporal, and occipital bones). Medially, the falx cerebri divides this compartment into two partitions. The supratentorial compartment contains the cerebral hemispheres, subcortical nuclei, and thalamus.

CLINICAL DISSCUSSION: A mass-expanding lesion in one of the supratentorial compartments will tend to push the brain toward the midline and under the falx cerebri. Axial plane, radiological imaging of the head using either computed tomography (CT) or magnetic resonance imaging (MRI) will demonstrate the falx to be curved rather than straight with the concave side of the curve facing the expanding compartment. Attempted movement of the cerebral hemisphere under the falx, an event termed herniation, can do significant damage to its medial aspect, especially where it contacts the sharpened border of the falx.

Vertebral Compartment

The foramen magnum is the rostral boundary of the vertebral compartment (Figure 1-9). Caudally, this meningeal compartment ex-

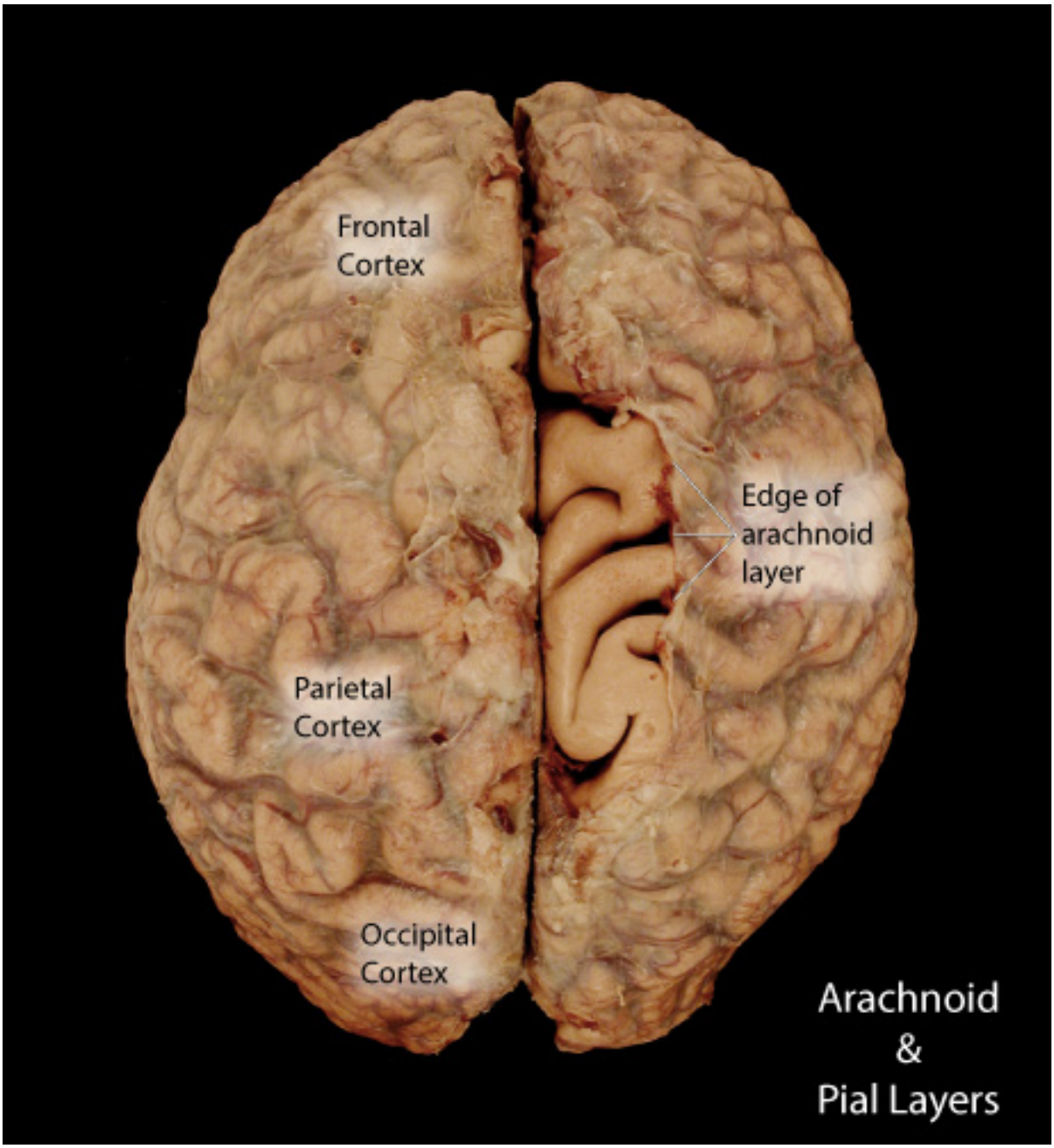


Figure 1-5 The arachnoid layer covers most of the surface of this brain with the exception of a small window cut in the arachnoid to expose the underlying pia.

tends downward to the second sacral vertebra where the dural sac fuses with the periosteum of the sacral canal. The lateral walls of the vertebral compartment extend to the entrance of the intervertebral foramina, where the dura fuses with the spinal roots, forming the epineurium of the peripheral nerve. Between the foramen magnum and vertebral level S2, the anterior surface of the spinal dura is intermittently adhered to the posterior longitudinal ligament of the vertebral canal. Occasional straps of dura extend from the posterior surface of the dural sac to pass through the epidural space and attach to the periosteum of the vertebral canal. These dural adhesions and straps have been implicated as a source of spinal axial pain (Parke and Watanabe, 1990) and sciatica (Spencer, Irwin et al., 1983) in the lumbar region. The spinal cord and the dorsal and ventral spinal roots are contained within the vertebral compartment. The dorsal root ganglia are located within the intervertebral foramina at each vertebral level. The intermingling of fibers from dorsal and ventral roots to form the spinal nerve also occurs in the intervertebral foramen, at a point just distal to the dorsal root ganglion.

CLINICAL DISCUSSION: Infection and inflammation of the meninges is termed meningitis. This process can involve an aseptic inflammation or it can result from an infection of bacterial or viral nature. Common bacterial agents are Streptococcus pneumoniae, Neisseria meningitides, group B streptococcus, Listeria monocytogenes, and Haemophilus influenzae. Of these, Group B streptococcus was the predominant pathogen among newborns, N. meningitidis among children 2 to 18 years old, and S. pneumoni-

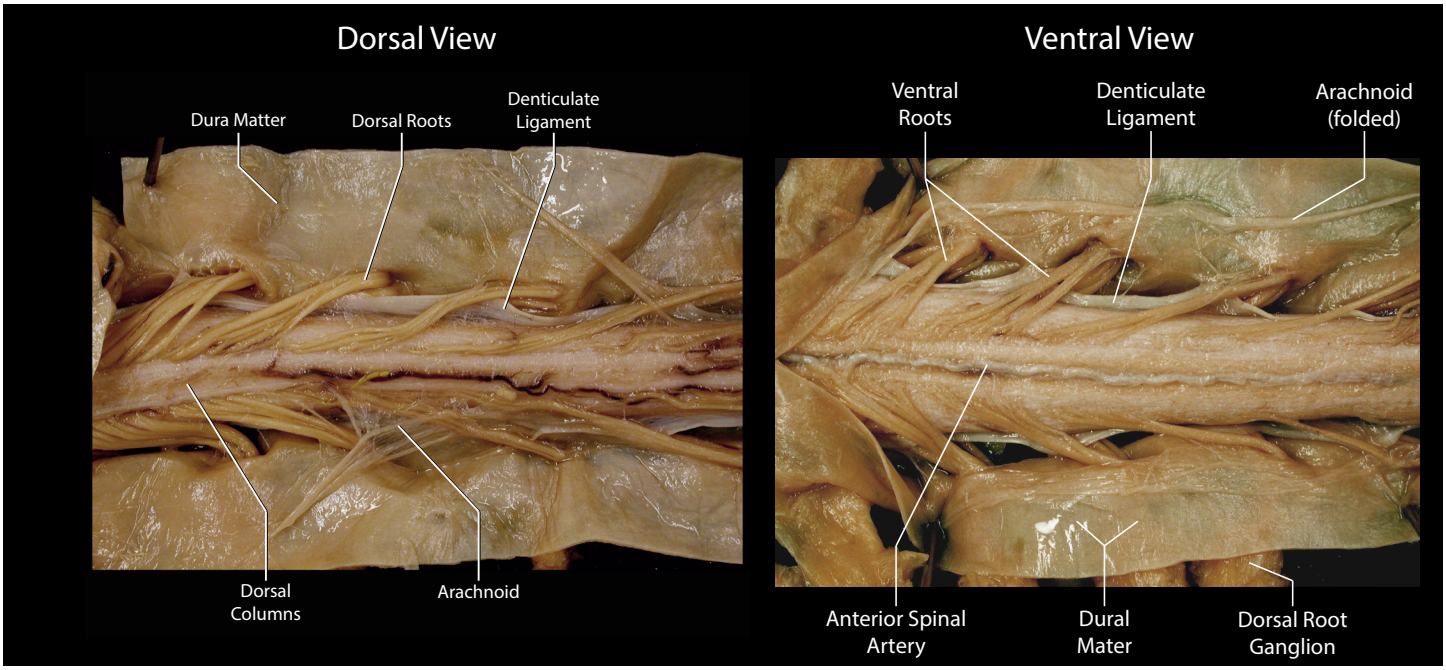


Figure 1-7 The spinal cord. In the dorsal view of the spinal cord (left) the dorsal rootlets are seen gathering together to form spinal roots. As the spinal roots pass over the edge of the denticulate ligament, they join with the ventral roots to slip into the lateral recess of the dural sac. The lateral recess leads into the intervertebral foramen. The dorsal root ganglion will be located at the distal end of the lateral recess approximately midway along the intervertebral foramen. The ventral view illustrates the ventral rootlets and the anterior spinal artery.

ae among adults (Schuchat, Robinson et al., 1997). The infection usually involves the meningeal membranes and the underlying cerebrospinal fluid. Outstanding clinical signs and symptoms of meningitis include headaches, stiff neck and mental status changes. Increased intracranial pressure is a significant concern in bacterial meningitis (Quagliarello and Scheld, 1992). Diagnosis is usually accomplished by sampling the CSF through a lumbar puncture and culturing the removed fluids. Axial plane imaging can sometimes reveal a thickening of the meningeal membranes.

Central Nervous System Organization

The brain and spinal cord contain an enormous three-dimensional network of synaptic connections between neurons. In an excellent, but somewhat dated article, Nauta and Feirtag succinctly review the general features of central nervous system organization (Nauta and Feirtag, 1979). At first glance, attempting to understand this organization appears overwhelming. However, guiding principles, established through phylogeny, can help sort out nervous system structure and function. One of these principles, although not perfect, states that the major components of the brain develop in a hierarchic array; each level of the hierarchy supplements and influences, but does not replace, those below it (Sarnat and Netsky, 1981).

The hierarchy of the CNS begins when the peripheral nerve roots enter the spinal cord. The spinal cord, in the vertebral compartment, forms the first level of processing in the central nervous system (Figure 1-11). As the spinal cord passes through the foramen magnum it transitions rapidly into the brainstem; this transformation is termed the cervicomedullary junction. The brainstem is located in the posterior cranial fossa or infratentorial compartment and is divided into three regions: medulla, pons and midbrain. Mounted on the dorsal aspect of the brainstem and also contained within the posterior cranial fossa, is the cerebellum, which means little cerebrum (or little brain). Rostrally, the midbrain passes through the incisor tentorium to become the thalamus and hypothalamus. Lateral and slightly rostral to the thalamus sit two large masses of neurons termed the corpus striatum (not visible on a midsagittal section). Finally, draped over the thalamus and corpus striatum, is the massive cerebrum the largest structure of the central nervous system. It is covered with a thin layer of cells termed the cerebral cortex.

A list of the general levels and their location by meningeal compartment is presented in Table 1-1. In this chapter, each level in the central nervous system will be briefly examined and a general statement concerning the neurologic deficits that occur when that level is damaged will be presented. It is important to familiarize yourself with these general deficits, since later chapters will give a more detailed treatment of the lesion-induced clinical findings.

CLINICAL DISCUSSION: Each compartment of the nervous system contains unique structures. Careful examination of the patient and their neurologic findings can allow localization of the lesion to specific compartments and in some cases to a specific structure in a compartment. Importantly, using the compartments as a frame of reference allows for more accurate ordering of imaging studies to confirm your diagnosis. For this reason, it is critical to associate specific neurologic findings with specific structures in each compartment.

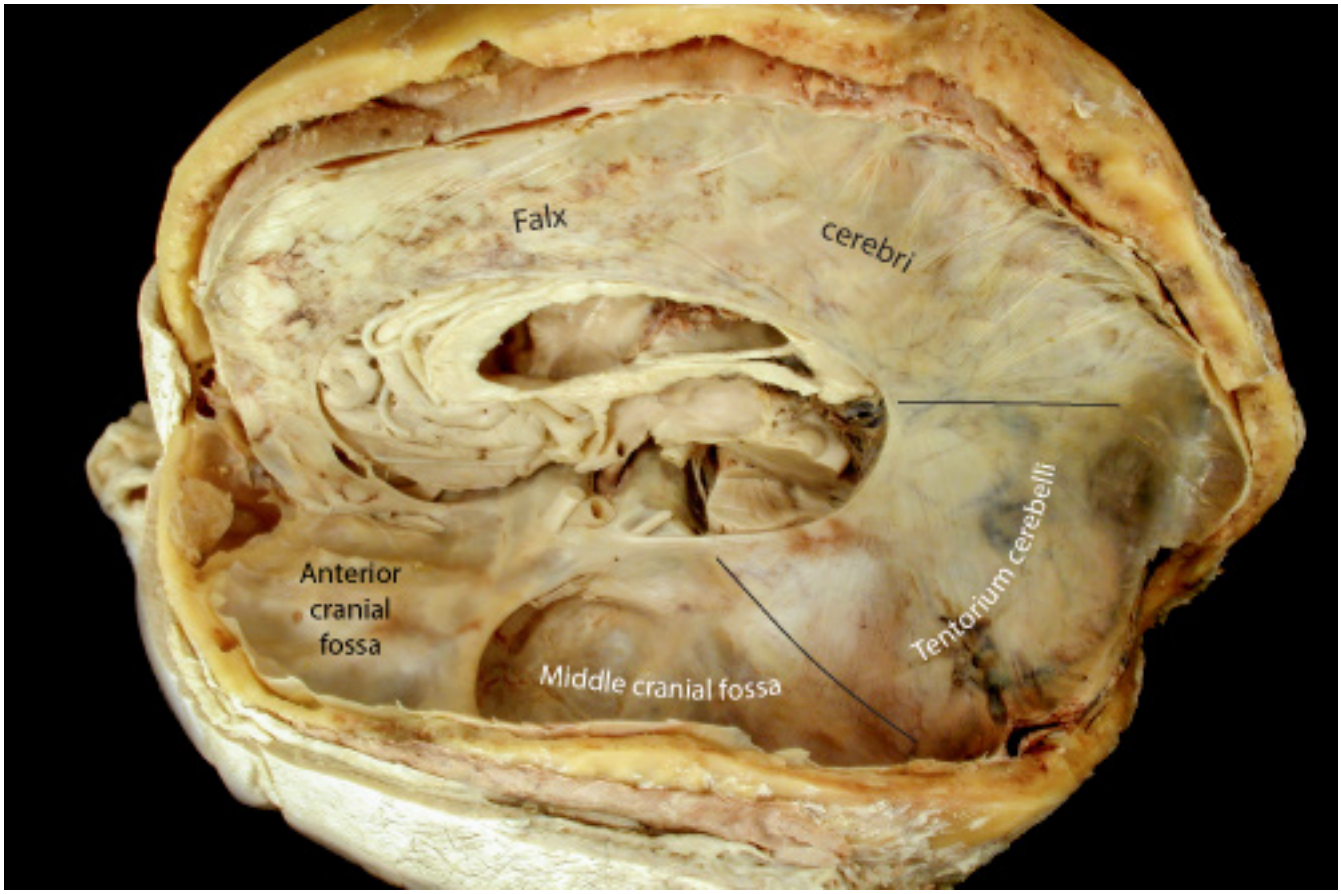


Figure 1-8 An oblique lateral view into the cranial cavity illustrating the continuity between the falx cerebri and the tentorium cerebelli. The black lines mark the approximate borders of the tentorium. Note the sharp edge of the inferior surface of the falx that continues to form the free border of the tentorium. This sharp edge can be very damaging to the brain when it is driven onto that edge by swelling or a mass expanding lesion.

Spinal Cord

The spinal cord is an elongated column of nervous tissue extending ventrally from the base of the brainstem to the upper lumbar portion of the vertebral canal. The cord is contained within the vertebral meningeal compartment and transmits somatic sensory information collected from peripheral nerves to the brain. It also transmits descending instructions from the cerebral cortex and brainstem to individual segmental levels of the spinal cord.

Each spinal segment represents that region of the cord serviced bilaterally by the roots arising from a pair of spinal nerves (Figure 1-12). The spinal nerves enter the vertebral canal by passing through the narrow intervertebral foramina. Within the foramen lies the dorsal root ganglion; here the spinal nerve separates into dorsal (sensory) and ventral (motor) roots. As the roots leave the intervertebral foramen and enter the spinal canal they fan out, forming rootlets. The latter join the cord over the space of approximately one inch (Figure 1-6 and Figure 1-7), a value that decreases in the lower sacral and coccygeal regions of the spinal cord. The entry zone for an individual root constitutes a spinal segment.

Sensory (or afferent) axons enter the spinal cord over the dorsal root, while motor (or efferent) axons leave the cord over the ventral root (Figure 1-6). Cell bodies for the sensory axons are found in the dorsal root ganglion. Each ganglion is located in the dorsal root at its junction with the ventral root in the intervertebral foramen (Figure 1-3). At each segmental level, a cross section of the spinal cord will reveal an H-shaped core of gray matter surrounded by vertical columns of white matter. The ventral gray, or ventral horn, contains motoneurons that innervate skeletal muscle fibers and associated interneurons that communicate with other segmental levels; the dorsal gray matter, or dorsal horn, contains neurons (termed tract cells) that establish communication with the brain and associated interneurons and is also used for communication with other portions of the spinal cord. The surrounding white matter contains ascending sensory and descending motor tracts.

The spinal cord has two enlargements – cervical and lumbosacral – to house the neural circuitry necessary to service the upper and lower extremities, respectively. The narrowing of the cord in its thoracic portion reflects the reduced skin sensitivity and reduced muscle mass of this body region (fewer neurons are needed to manage this region of spinal cord). Distal to the lumbar enlargement, the cord tapers into the conus medullaris and ends in a thin thread termed the filum terminale. Since the spinal cord is shorter than its housing, the vertebral column, the cord ends at approximately vertebral level L2. Consequently, the lumbar and sacral nerve roots must course considerable distances along the vertebral canal

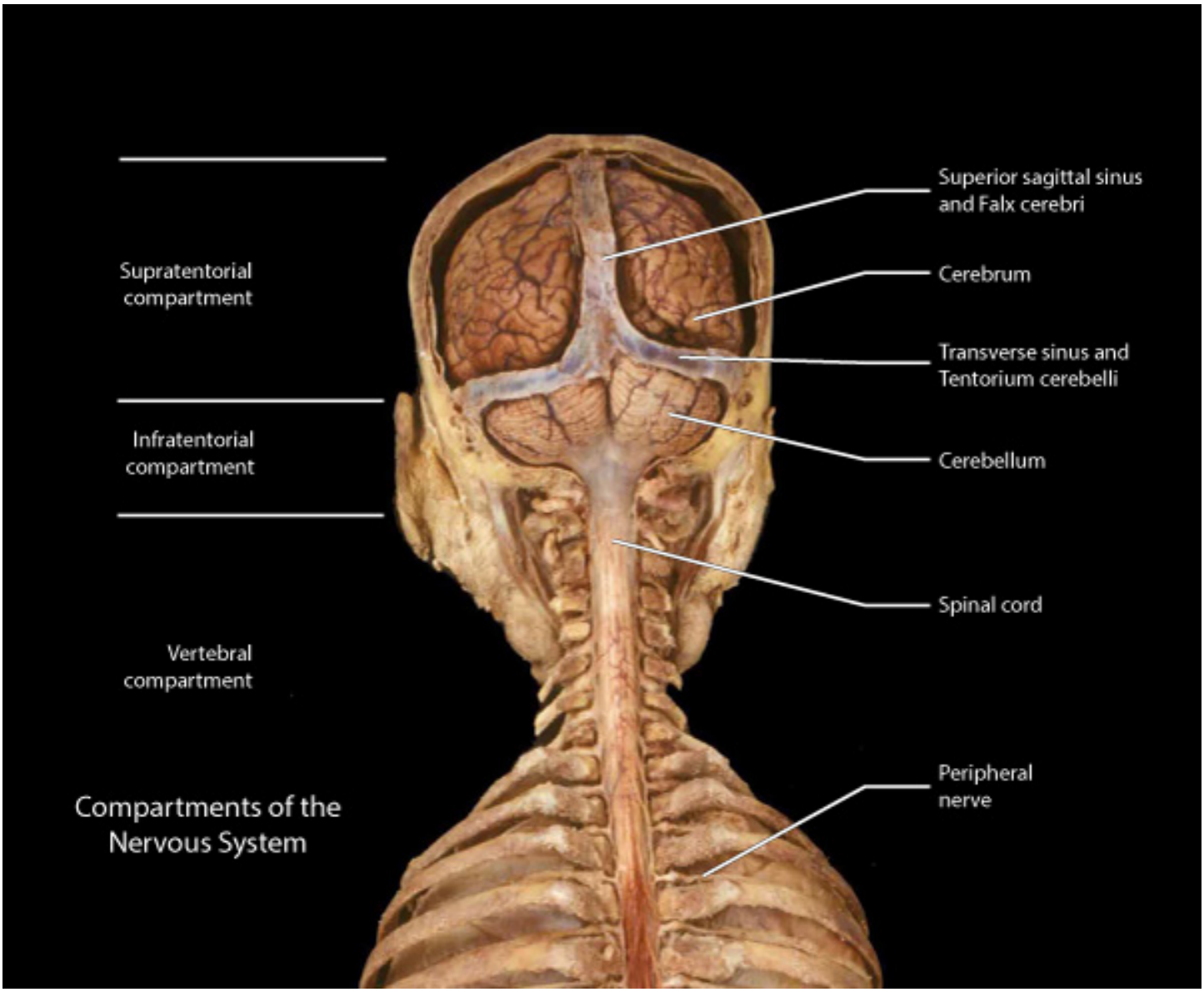


Figure 1-9 The meningeal compartments of the nervous system. The posterior aspect of the calverium has been removed and the vertebral column laminectomized. The dura has been excised leaving the dural sinuses. The arachnoid has been left in place. The intervertebral foramina have been opened to expose the dorsal root ganglia and the spinal nerves. Each of the four major compartments of the nervous system are visible.

before reaching their appropriate intervertebral foramina. This arrangement gives these nerve roots the appearance of a horse's tail, termed the cauda equina.

The primary function of the spinal cord is to receive sensory information from the environment and to 1) relay this information upward to the brainstem and thalamus and 2) generate protective reflexes that are sent to the skeletal muscle of the body through the ventral roots and spinal nerves.

CLINICAL DISCUSSION: Injury of the spinal roots, termed rhizopathy, either in the vertebral compartment or as they exit the intervertebral foramina into the periphery, can lead to a radicular (root) distribution of altered sensory experience and weakness (Brazis, Masdeu et al., 1996b). The altered sensory experience can be in the form of altered sensation presenting as either decreased (hypoesthesia) sensitivity or increased sensitivity (hyperesthesia), an abnormal quality of sensation (paresthesias), or flank pain (Spence, 1984). The areas affected reflect the afferent distribution of the specific root or peripheral nerve injured. Spinal nerve injuries can either be mononeuropathies (isolated spinal nerve), polyneuropathies (numerous bilaterally symmetrical spinal nerves) or mononeuropathy multiplexes (multiple, non-symmetric spinal nerve involvement).

Injury to the spinal cord can result in three general categories of deficit. Sensory and motor loss form the first category and are considered objective neurological findings since they can be quantified. Incontinence of bladder and bowel are the second and rep-

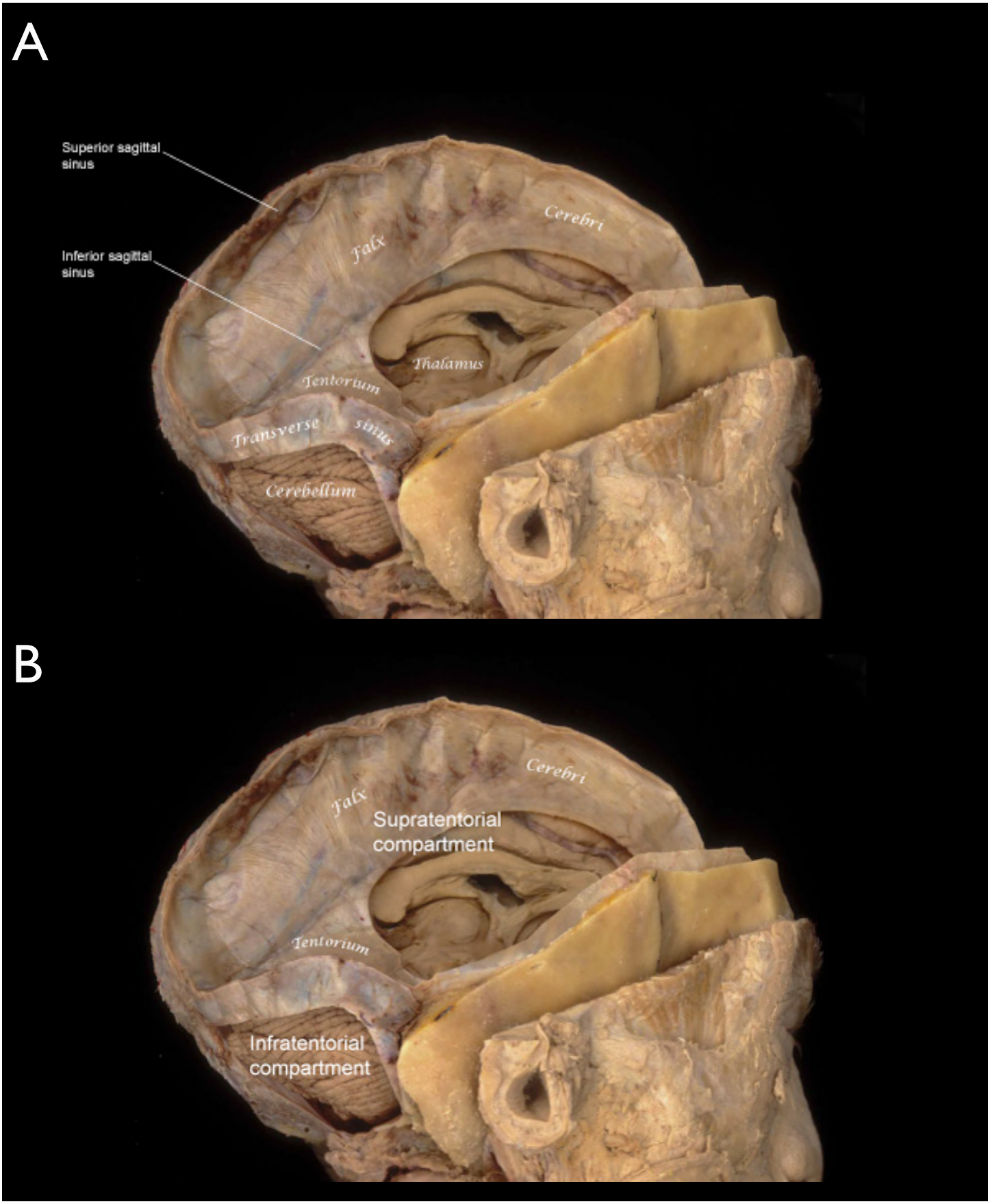


Figure 1-10 A lateral view of the head illustrating the supratentorial and infratentorial compartments. The calverium and occipital bone were removed and the dura was excised leaving the dural sinuses, falx and tentorium. The right cerebral hemisphere was also removed. The supratentorial compartment lies above the tentorium and contains the cerebral hemisphere. The infratentorial compartment lies under the tentorium and houses the cerebellum and brainstem.

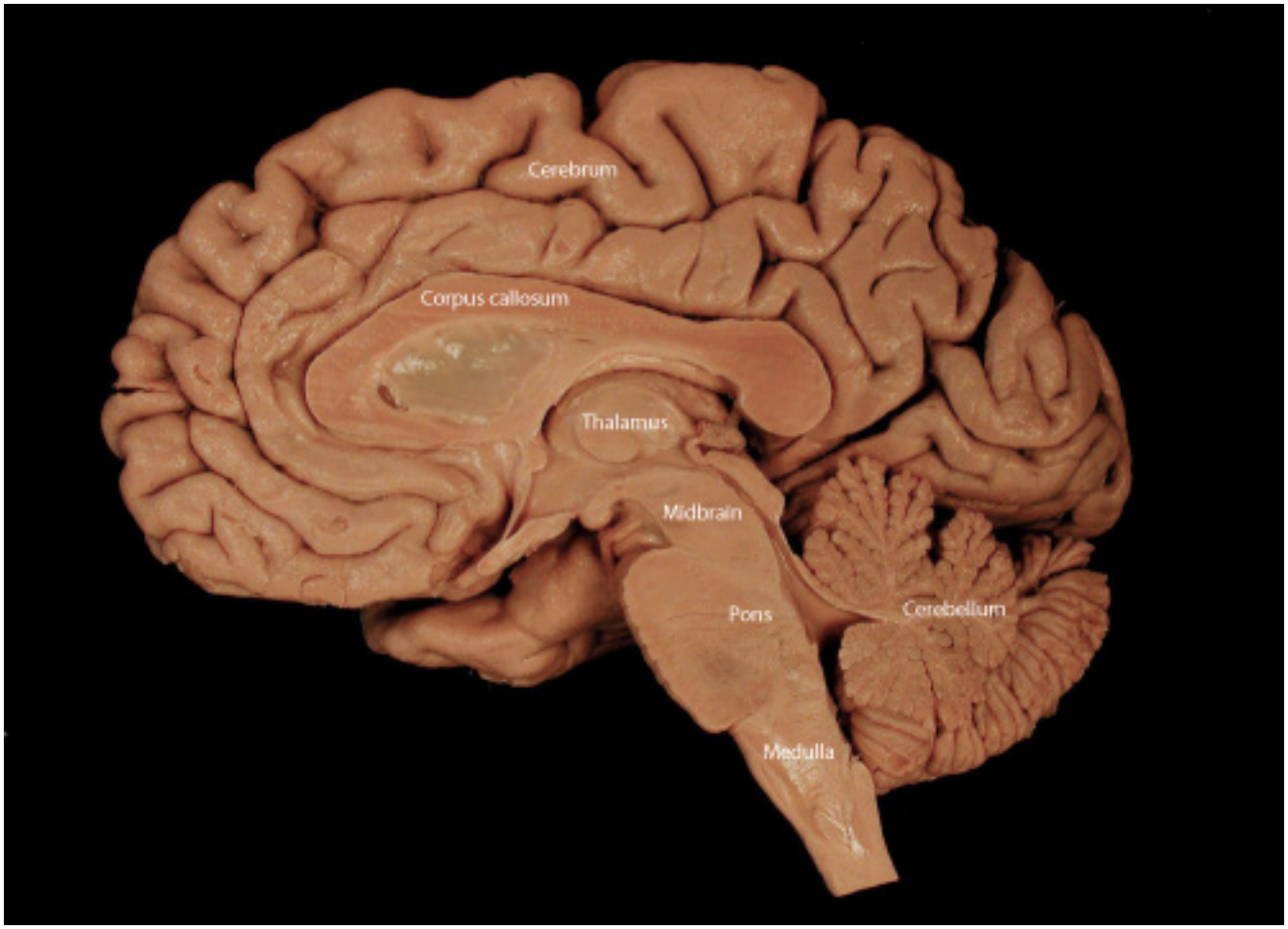


Figure 1-11 This is a sagittal view of the bisected brain. The brainstem extends upward from the foramen magnum to embed in the ventral aspect of the cerebrum. Posteriorly the cerebellum is attached to the brainstem while anteriorly the brainstem lies on the clivus of the basicranium. The brainstem is divided into three, embryologically defined regions - the medulla, pons and midbrain. The thalamus, located at the rostral end of the brainstem, is considered to be part of the cerebrum.

resents a loss of function in the autonomic nervous system. The third cardinal manifestation of spinal cord injury is pain that can be of a very intense nature and constant in duration, unrelated to any peripheral stimuli (Woolsey and Young, 1991). This latter situation is the most debilitating aspect of spinal injury.

Transection of the ascending or sensory tracts in the spinal cord can lead to loss of pain (to peripheral stimulation) and temperature sensation, discriminative touch, and proprioception. In general, the loss of sensation consequent to cord damage is broadly distributed, occurring at or below the segmental level of the lesion (termed a level-down pattern) and can involve a complete loss of function. Compare this pattern to the restricted band-like or segmental loss of function that results when a specific root or peripheral nerve is lesioned. In a spinal cord injury, the horizontal line across the body, below which sensory functions are diminished, is referred to as a "sensory level." Irritation, as opposed to transection, of sensory tracts in the spinal cord can present with painful paresthesias instead of sensory loss (DeMyer, 1979). Intense pain approximately at the segmental level of the spinal cord injury is a common occurrence, especially if the injury is due to vertebral fracture, spinal hemorrhage or infarction, intervertebral disk herniation, epidural abscess, tumor, or a degenerative disease such as spondylosis or syringomyelia (Woolsey and Young, 1991).

Damage to the motoneurons of individual spinal segments can present as weakness and flaccidity expressed in the muscles innervated from that segment. Typically the tendon reflexes are diminished or absent. Damage to descending fiber tracts from suprasegmental structures can result in weakness and spasticity for muscles innervated by motoneurons located below the level of the lesion, typically the tendon reflexes below the level of the lesion are hyper-reactive (see Chap. 2 for further discussion of this concept).

Complete destruction of the brain above the spinal cord leads to a state of flaccid paralysis – all muscle tone and reflexes are lost. Such a state was seen in the terminal stages of the patient in Case 1-1. He lost all muscle tone in his body shortly before dying.

Medulla

The medulla is located in the infratentorial compartment and represents the most caudal portion of the brainstem (Figure 1-13, Figure 1-14 and Figure 1-15). Distally it forms the spinomedul-

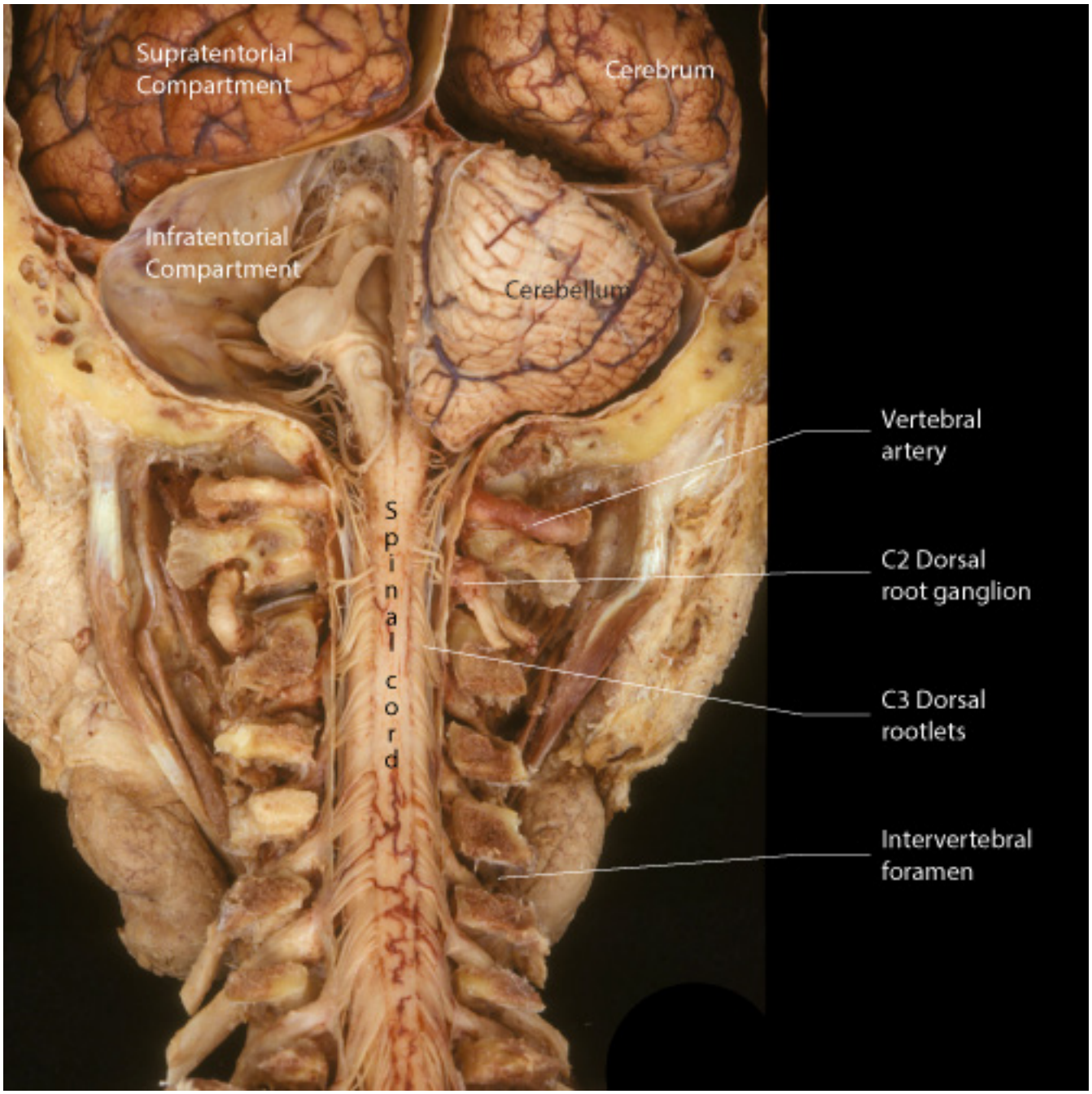


Figure 1-12 This is a posterior view of the central nervous system following the removal of the posterior aspect of the cranium and laminectomizing the vertebral canal. One half of the cerebellum has been removed to reveal the brainstem. The cervical intervertebral foramina have been opened to expose the intervertebral canal.

lary or cervicomedullary junction with the spinal cord and rostrally it joins the pons at the pontomedullary junction. The medulla contains ascending sensory tracts to the cerebrum and cerebellum and descending motor tracts to the spinal cord, as well as the central nuclei related to the eighth, ninth, tenth, and twelfth cranial nerves. Portions of the trigeminal nuclei (fifth cranial nerve) extend inferiorly from the pons to pass through the medulla. Two longitudinal ridges along the midline characterize the ventral surface of the medulla; these are the pyramids containing corticospinal fibers (Figure 1-14). Lateral to each pyramid at the rostral end of the medulla is a tubercle called the olive, which marks the location of the massive inferior olivary nucleus. The hypoglossal nerve exits the brainstem between the olivary tubercle and the pyramid. The glossopharyngeal and vagus nerves leave the brainstem dorsal to the olivary tubercle and the vestibulocochlear nerve exits the brainstem at the pontomedullary junction.

The salient features of the dorsal surface of the medulla (Figure 1-13) are the gracile and cuneate tubercles along the inferior portion of the fourth ventricle. These tubercles are located at the superior end of the gracile and cuneate fiber tracts, respectively, and mark the site of two large, sensory nuclei in the brainstem, the nucleus gracilis and cuneatus. The walls of the fourth ventricle approximate themselves inferiorly to form

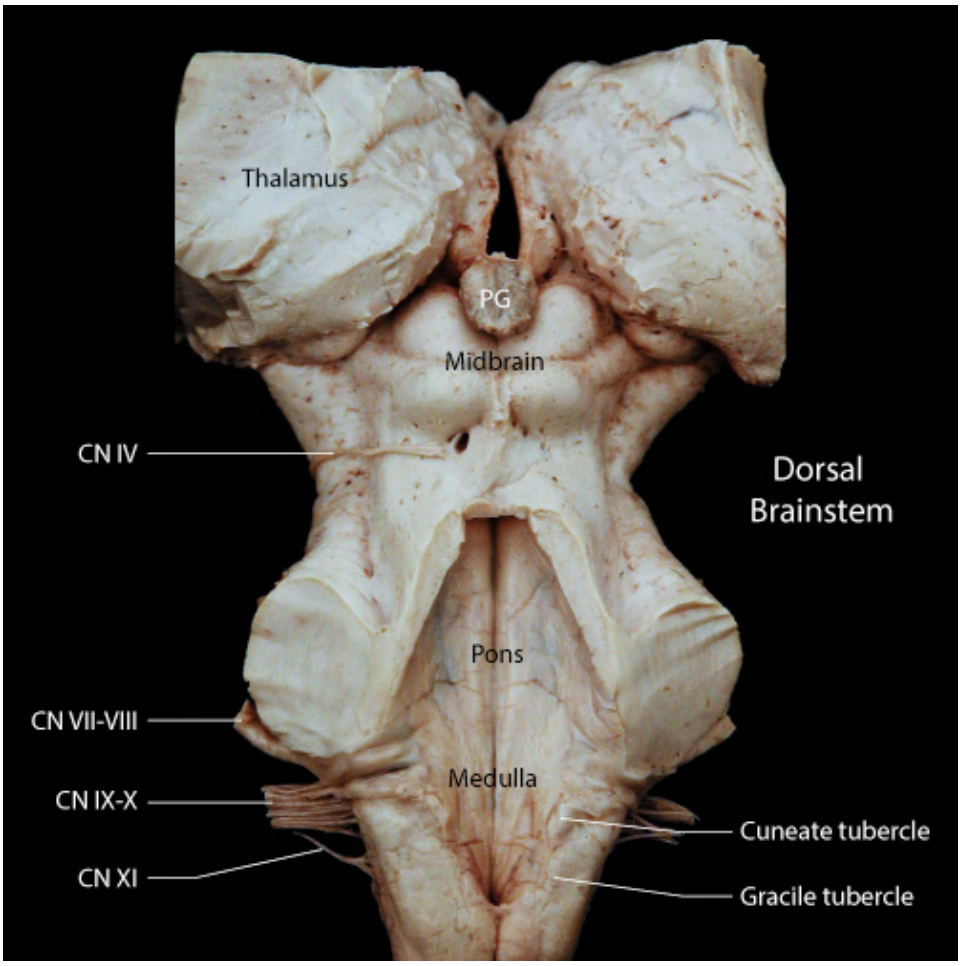


Figure 1-13 A dorsal view of the brainstem

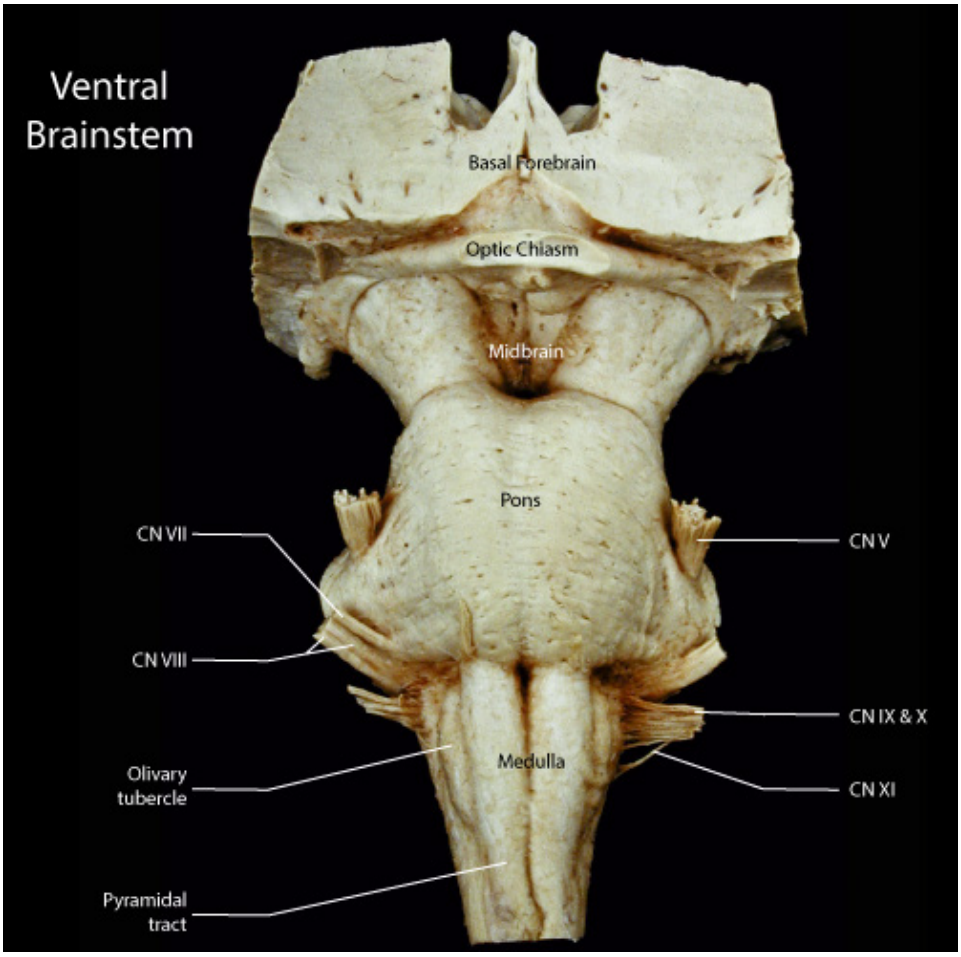


Figure 1-14 A ventral view of the brainstem

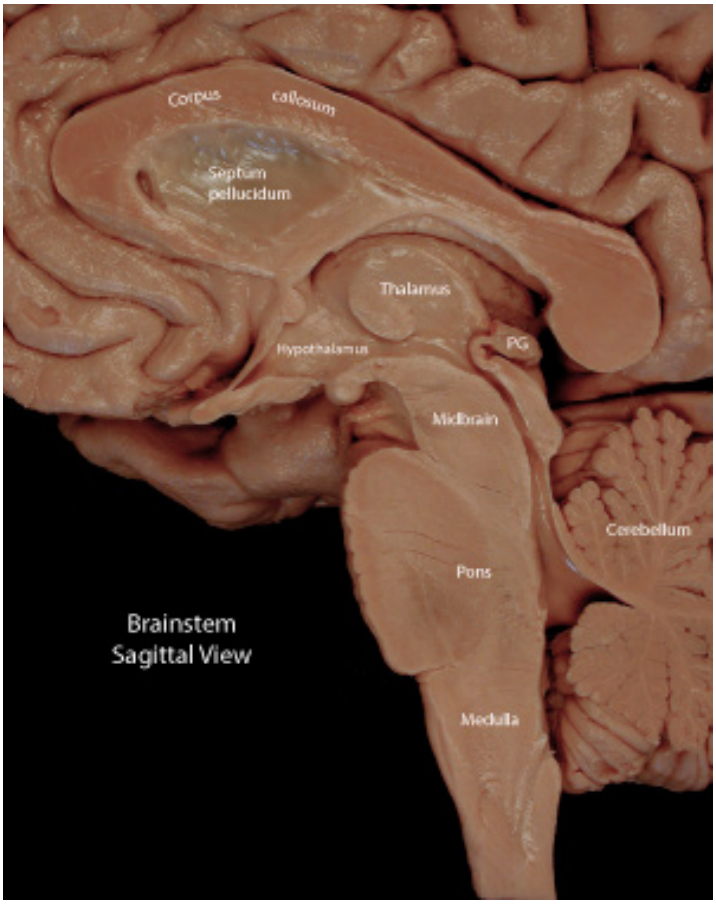


Figure 1-15 A sagittal view of the brainstem in a bisected brain illustyrating the embryologic regions of the brainstem.

the obex, a surgical landmark. At the lateral extremes of the fourth ventricle, and lying on the surface of the eighth cranial nerve, is the dorsal cochlear nucleus – a component of the auditory system.

The core of the medulla (as well as the pons and midbrain) is composed of the reticular formation. Its complex neuronal circuits are involved in the control of cardiovascular tone (Andresen and Kunze, 1994) and respiratory rate (Von Euler, 1986), pharyngeal and laryngeal musculature, gastrointestinal secretions and mobility, modulation of pain and emesis (Blessing, 1997) (also see Chapter 3).

CLINICAL DISCUSSION: Large lesions of the medulla will most likely result in coma and death due to compression of surrounding critical brainstem structures. Smaller, more contained lesions in the medulla generally do not result in coma (Plum and Posner, 1982). Instead, they can present as primary sensory loss (proprioception and vibratory sense) from the body and face; loss of motor control (spastic paralysis) in the limbs; loss of pain and temperature sensations (analgesia) from the body and face; loss of hearing or balance; speech (dysarthria) and swallowing (dysphagia) disorders; or paralysis of tongue movement (Brazis, 1996). Since the medulla also contains respiratory and cardiovascular control circuits, their damage can result in cardiac arrhythmias and dyspnea, eventually leading to death. The unfortunate patient can remain conscious throughout much of this process (Plum and Posner, 1982). Descending fiber tracts from the hypothalamus involved with the

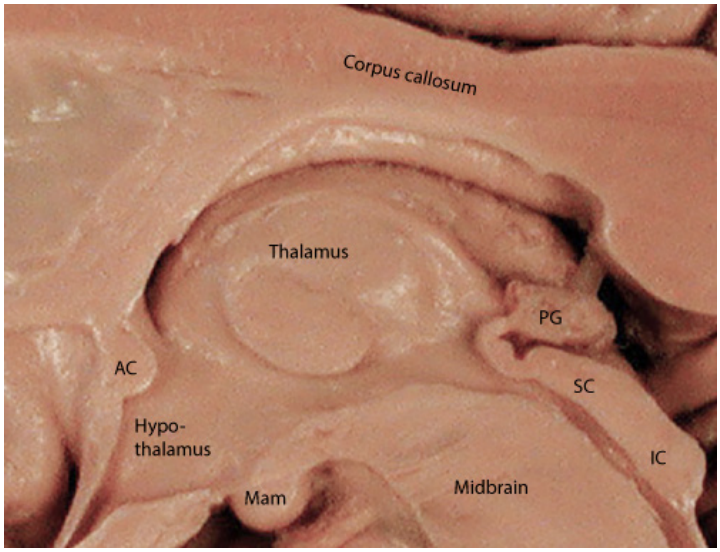


Figure 1-16 A sagittal view of the thalamus illustrating the major regions located at the rostral end of the brainstem.

autonomic nervous system pass through the medulla; hence medullary lesions can also result in dysautonomic symptoms.

Apneic breathing (Cheyne-Stokes respiration) is characteristic of medullary destruction. This form of breathing was seen during the terminal minutes of life in the patient presented in Case 1-1.

Pons

The pons is located ventral to the cerebellum in the infratentorial compartment (Figure 1-11, Figure 1-13, Figure 1-14 and Figure 1-15). Its external features are dominated by three large cerebellar peduncles – inferior, middle and superior. The pons contains major ascending sensory and descending motor fiber tracts interconnecting spinal cord, cerebral cortex, and cerebellum. In addition, it contains the central nuclei related to the fifth, sixth, seventh, and portions of the eighth cranial nerves. The reticular formation of the pons contains the caudal portion of a major cerebral activating system. This system functions to arouse and maintain the level of activity in the supratentorial structures, such as the thalamus and cerebral cortex.

The dorsal surface of the pons forms the floor of the fourth ventricle (Figure 1-13). It is marked by the median eminence and sulcus limitans. The roof covering the fourth ventral is the cerebellum.

On the ventral surface of the brainstem, the large middle cerebellar peduncle is seen prominently wrapping around the pons (Figure 1-14). The vestibulocochlear and facial cranial nerves leave the pons laterally along the pontomedullary border while the abducens nerve exits medially. The trigeminal nerve exits the pons by penetrating the middle cerebellar peduncle laterally. The neuronal circuitry in the reticular formation, surrounding the cranial nerve structures of the pons, is involved in controlling postural musculature and in directing horizontal (lateral) eye movements (see Chapter 4).

The architecture of the pons is dominated by numerous large fiber

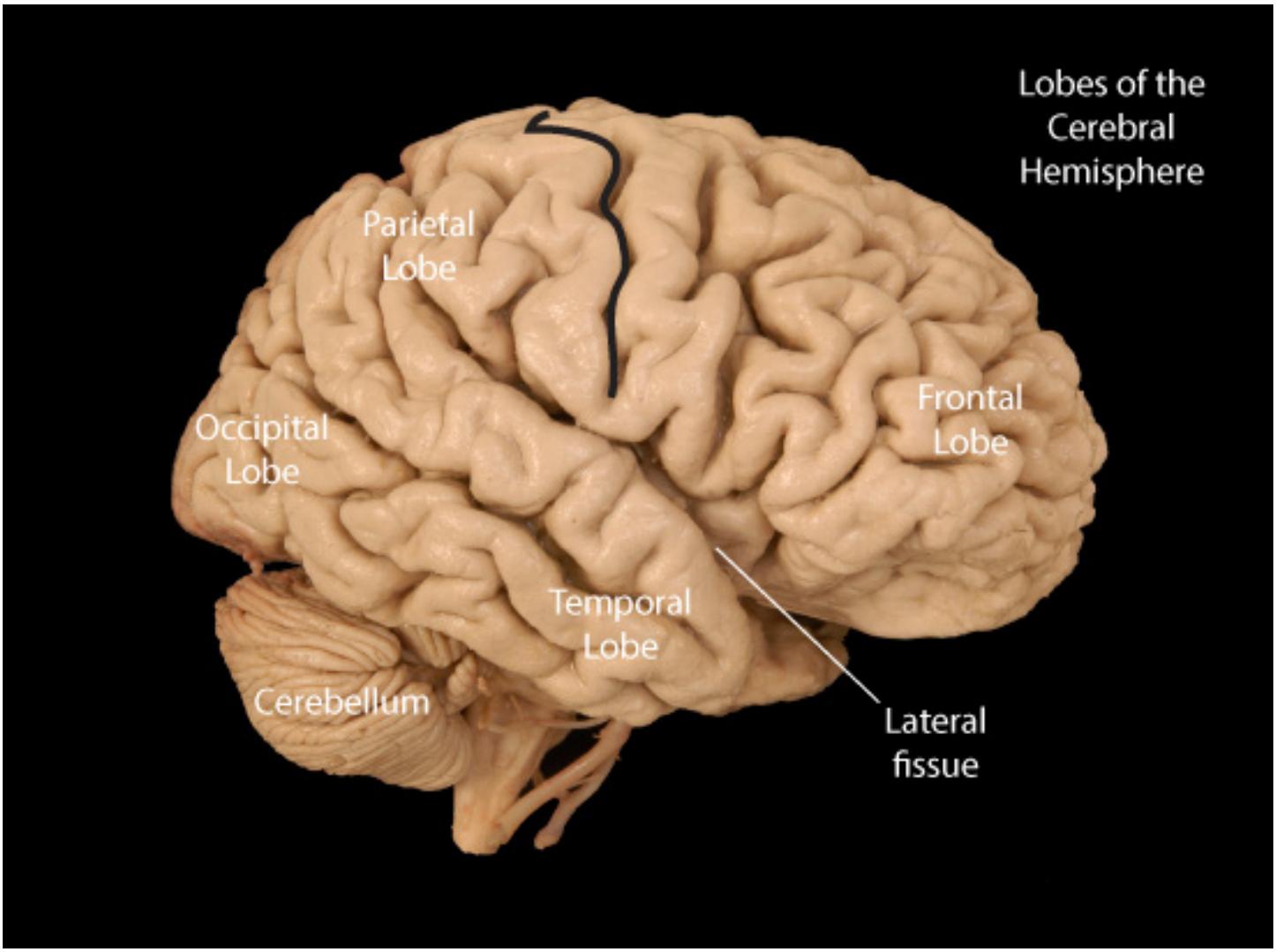


Figure 1-17 A lateral view of the brain illustrating the major lobes of the cerebrum. The black line marks the central sulcus, the border between the frontal lobe and the parietal lobe. The boundary between parietal, occipital and temporal lobes is very arbitrary.

tracts connecting the spinal cord, thalamus, cerebral cortex and cerebellum. Some of its intrinsic functions involve cardiovascular and respiratory control.

CLINICAL DISCUSSION: Large, bilateral lesions of the pons that damage the reticular activating system most likely will result in coma and death. Smaller, more confined lesions, especially if they are unilateral, can have several different presentations, such as: loss of primary, sensory modalities (vibratory sense, discriminative touch, and proprioception) as well as pain and temperature sensations from the body and face, aberrant motor control (ataxia or paralysis) of the limbs, facial paralysis, paralysis of the jaw, lateral gaze palsies, or internal strabismus (esotropia) of the eye. Finally, if the brain above the pons is severely damaged, the anti-gravity structures in the pons (vestibular nuclei) will generate a strong output, forcing the patient into extreme extensor posturing also known as decerebrate posturing. Such posturing can be seen in the late stages of the patient in Case 1-1.

Cerebellum

The cerebellum is located in the dorsal portion of the infratentorial compartment, lying in the angle between the brainstem and tentorium cerebelli (Figure 1-11, Figure 1-12). It is divided into two large hemispheres by a narrow vermis positioned on the midline. The cerebellum is connected to the brainstem through three major fiber tracts termed the superior, middle, and inferior cerebellar peduncles (Figure 1-13 and Figure 1-14). Through these peduncles, the cerebellum receives proprioceptive information from muscles and joints via the spinal cord as well as programming instructions from the cerebral cortex. Its function in motor control – computing the timing of muscle contractions for coordinated movements – has been known for a long time, and more recently its role in the cognitive processes of the brain have become apparent (Schmahmann and Sherman, 1998) (also see Chapter 5).

CLINICAL DISCUSSION: Lesions involving the hemispheres of the cerebellum result in defects in the timing of muscle con-

tractions, a condition terme termed ataxia. Cerebellar damage can present as a breakdown of rapid hand or finger movement, dysmetria, loss of balance, swaying, staggering, and intention tremor. Lesions in the midline of the cerebellum can affect the postural (truncal) musculature and eye movements (Biller and Brazis, 1996). It has also been reported that lesions of the posterior aspects and vermis can result in changes in executive functions, spatial cognition and personality changes (Schmahmann and Sherman, 1998); also see Chapter 5. The patient in Case 1-1 did not demonstrate any obvious signs or symptoms of cerebellar dysfunction during his demise.

Midbrain

The midbrain is located at the rostral end of the brainstem (Figure 1-13, Figure 1-14 and Figure 1-15). It passes through the incisura cerebelli (the large opening in the tentorium), thereby straddling the border between the supratentorial and infratentorial compartments (Table 1-1). The midbrain contains major ascending sensory and descending motor tracts similar to other portions of the brainstem. In addition, it contains structures related to the third (oculomotor) and fourth (trochlear) cranial nerves. Control of eye movements is a characteristic feature of the midbrain. The midbrain reticular formation has neural circuits involved in controlling vertical eye movements. The midbrain reticular activating system regulates the level of neural activity in the thalamus and cerebral cortex; this structure is involved in controlling sleep and arousal.

The ventral surface of the midbrain is characterized by two large cerebral peduncles (Figure 1-14). Between the peduncles is the interpeduncular fossa; the oculomotor nerve emerges from the midbrain along the walls of this fossa. Dorsally, the two pairs of colliculi (little hills) – inferior and superior – identify IV of the midbrain (Figure 1-13). The trochlear nerve, cranial nerve IV, emerges from the dorsal surface at the base of the inferior colliculus (also see Chap. 6).

CLINICAL DISCUSSION: Both large and small paramedian lesions in the midbrain reticular formation or its ascending projections can result in coma and sleep dysfunctions (Plum and Posner, 1982), ultimately leading to death. Smaller lesions, especially those occurring more laterally, can present as loss of primary sensory modalities (vibratory sense, discriminative touch and proprioception), as well as pain and temperature sensations from the body and face (analgesia), abnormal motor control (ataxia and paralysis), and eye movement dysfunction (third and fourth nerve palsies and vertical gaze palsies). Lesions at the midbrain level can separate the cerebral and midbrain controls of the motor system from the motor regions of the lower brainstem and spinal cord. In such cases the patient can experience decerebrate posturing, with the upper and lower limbs going into extreme, extensor-dominated positions.

Loss of reflex control of eye movements can be indicative of midbrain damage especially if it presents with loss of consciousness. This combination was seen in the patient presented in Case 1-1.

Thalamus

The thalamus is an egg-shaped mass of cells and fibers located deep in the supratentorial compartment, rostral to the midbrain and nestled under the cerebral cortex (Figure 1-11 and Figure 1-16). The medial wall of the thalamus can be seen on a mid-sagittal preparation of the brain. Laterally, the thalamus is bordered by the white matter of the internal capsule. The ventral surface of the thalamus is exposed externally and presents the optic chiasm and optic tracts rostrally, the mammillary bodies caudally, and in between, the infundibulum (stalk) of the pituitary.

The dorsal surface of the thalamus is covered by the massive corpus callosum (Figure 1-16). Sectioning this fiber bundle at the base of the longitudinal fissure can expose the third ventricle lying between the two hemispheres of the thalamus. The roof of the third ventricle is formed by the fornix, a fiber bundle connecting the hippocampal formation in the temporal lobe to the hypothalamus.

The rostral boundary of the thalamus extends to a thick, round fiber bundle termed the anterior commissure; the caudal boundary of the thalamus lies at the pineal gland and midbrain. The thalamus is divided into two symmetric hemispheres by the third ventricle; its medial or ventricular surface contains the massa intermedia or thalamic adhesion (Figure 1-16; also see Chap. 7).

The thalamus is reciprocally connected by axons to most areas of cerebral cortex. Through these connections it relays ascending sensory information to the primary sensory areas of the cortex. It also contains pathways involved in cortical motor control systems. Thus, through the thalamocortical and corticothalamic connections, the thalamus is intimately involved in the functioning of the overlying cortical mantle. In addition, several pathways from the brainstem to the thalamus influence memory processing, consciousness, and arousal. These pathways typically contain monoamine transmitters such as norepinephrine and serotonin.

The ventral portion of thalamus, called the hypothalamus, is separated from the (proper or dorsal) thalamus by the hypothalamic sulcus. The hypothalamus controls the autonomic nervous system and, through the infundibulum and pituitary gland, modulates the endocrine system. The integration of the autonomic nervous system and the endocrine system in the hypothalamus can also influence the operation of the immune system (Freier, 1990);(Goetzl and Spector, 1989).

CLINICAL DISCUSSION: Damage to the thalamus can present in a manner very similar to a lesion of the cerebral cortex. This can include loss of primary sensory modalities as well as pain and temperature sensation, abnormal motor control (ataxia, hyperkinesia, hypokinesia, or paralysis), intractable intense pain, memory loss, confusion and altered behavioral and cognitive patterns, sleep disorders, and coma (see Chap. 7). Damage to the hypothalamus can present altered homeostasis involving endocrine and autonomic dysregulation (Masdeu, 1996). In addition, a Horner's syndrome can be present on the ipsilateral side. The change in pupil size seen in the patient described in Case 1-1 is most likely due to increasing pressure placed on the hypothalamus.

Cerebrum

The cerebral hemispheres are contained in the supratentorial compartment. They are separated by a dense connective tissue septum termed the falx cerebri lying in the longitudinal fissure (Figure

1-17). The hemispheres are interconnected at the base of this fissure by a large fiber tract, the corpus callosum (Figure 1-11). The rostral-most portion of each hemisphere is the frontal lobe; its caudal boundary is the central sulcus and is separated from the temporal lobe laterally by the lateral fissure (Figure 1-17). Nestled deep within the lateral fissure is the insula lobe. The parietal lobe extends from the central sulcus to the parieto-occipital sulcus. The caudal-most portion of the hemisphere is the occipital lobe (also see Chap. 8).

The ventral surface of the cerebrum presents a long, curved, medially placed ridge termed the parahippocampal gyrus, which wraps around the lateral aspect of the brainstem. Rostrally, this gyrus ends in an enlarged mass, the uncus. The medial surface of the hemisphere displays the profile of the corpus callosum arched over the thalamus (see Fig. 1-3). Dorsally, the cingulate gyrus borders the corpus callosum. The parahippocampal and cingulate gyri are continuous around the caudal end of the corpus callosum and form the limbic lobe.

CLINICAL DISCUSSION: When the cerebral cortex is damaged, clinical deficits range from specific sensory and motor losses to alterations of cognitive functions – language, speech, writing, and reading as well as changes in awareness, social mores, memory, or consciousness. Damage to the subcortical structures can result in memory loss, aberrant emotional behavior, and personality changes. Movement disorders, such as hyperkinesia or hypokinesia, can also occur consequent to lesions involving the corpus striatum (see Chapters 8-10).

When the cerebral cortex comes under increased pressure, for example, from a space-occupying lesion or a bleeding intracranial vascular accident, its function can diminish. The patient becomes obtunded or unconscious. Cerebral control of the brainstem motor regions is diminished and the patient displays varying degrees of decorticate posturing, with the upper extremity dominated by the flexor muscles and the lower extremity dominated by the extensor muscles.

The patient in Case 1-1 initially demonstrated the acute onset of focal neurologic signs and symptoms characteristic of a cerebral lesion. These included left-sided weakness, greater in the arm, and visual loss. These are focal signs, suggesting an acute focal lesion in the cerebrum such as a vascular accident. These events can be either infarctive or hemorrhagic in nature. The patient then goes on to display an obtundation and eventual loss of consciousness – more generalized signs of global cerebral damage, most likely due to rapidly increasing intracranial pressure and strongly suggestive of an ongoing intracerebral hemorrhage.

▶ Cerebral Vasculature

Cerebral arteries, derived from the internal carotid or vertebral arteries, supply blood to the central nervous system. Occlusion or rupture of a cerebral vessel (artery or vein) can compromise the blood flow to a specific region of the central neuraxis, resulting in infarction or hemorrhage and, ultimately, damage to neural tissue. Based on the signs and symptoms displayed by the patient, it may be possible to localize the vascular accident on the neuraxis and to determine its nature: infarctive or hemorrhagic. This information is important when considering where to look with sophisticated and expensive imaging techniques and when designing rehabilitative therapy. An understanding of cerebral vascular distribution is critical for the localization process in neurology.

Cerebral circulation can be divided into anterior and posterior sources. The anterior circulation derives from the internal carotid arteries and typically forms the anterior and middle cerebral arteries; the posterior circulation comes from the vertebral arteries and comprises the posterior cerebral artery. These two sources anastomose at the base of the brain in the circle of Willis. Although this seems fairly straightforward, be aware that there is much variation in the organization of the cerebral vessels and only the most common form will be described in this text.

Anterior Circulation

The anterior circulation is generally confined to the supratentorial compartment. It arises from the bifurcation of the internal carotid arteries to form the anterior cerebral artery and middle cerebral artery (Figure 1-19). The short anterior communicating artery connects the two anterior cerebral arteries. The anterior cerebral artery is distributed across the cingulate gyrus, portions of the medial frontal lobe, and the corpus callosum (Figure 1-20); the middle cerebral artery divides into two divisions – upper and lower (MCA UD and MCA LD respectively on Figure 1-19) – whose combined territory perfuses the lateral aspect of the frontal lobe and portions of the temporal lobe. Penetrating branches of both anterior and middle cerebral arteries reach the corpus striatum and anterior thalamus.

Posterior Circulation

The anterior and posterior spinal arteries join with the vertebral artery to form the source of the posterior circulation (Figure 1-18). Subsequently, both vertebral arteries unite on the midline to form the basilar artery, which, after giving off vessels to the cerebellum, divides to form the posterior cerebral arteries. The posterior circulation supplies the spinal cord in the vertebral compartment, most of the brainstem and cerebellum in the infratentorial compartment, and the medial and caudal aspect of the temporal and occipital lobes in the supratentorial compartment (Figure 1-19 and Figure 1-20). Penetrating branches of the posterior cerebral artery reach the hippocampal formation and posterior thalamus.

Intracranial Hemorrhages

Epidural Hemorrhage

The dura is closely adhered to the inner table of the cranium; wedged snugly in a groove in the inner cranium and bordered by the dura is the middle meningeal artery. A traumatic blow to the lateral convexity of the head, resulting in a fracture of the temporal or parietal bone, can rupture the middle meningeal artery or its branches. The middle meningeal artery is derived from the external carotid artery. The result is an epidural hematoma (Figure 1-21). During this process extravasated blood accumulates between the dura and inner table of the cranium (Dacey and Jane, 1984; Morris, 1989). In addition to laterally located hematomas

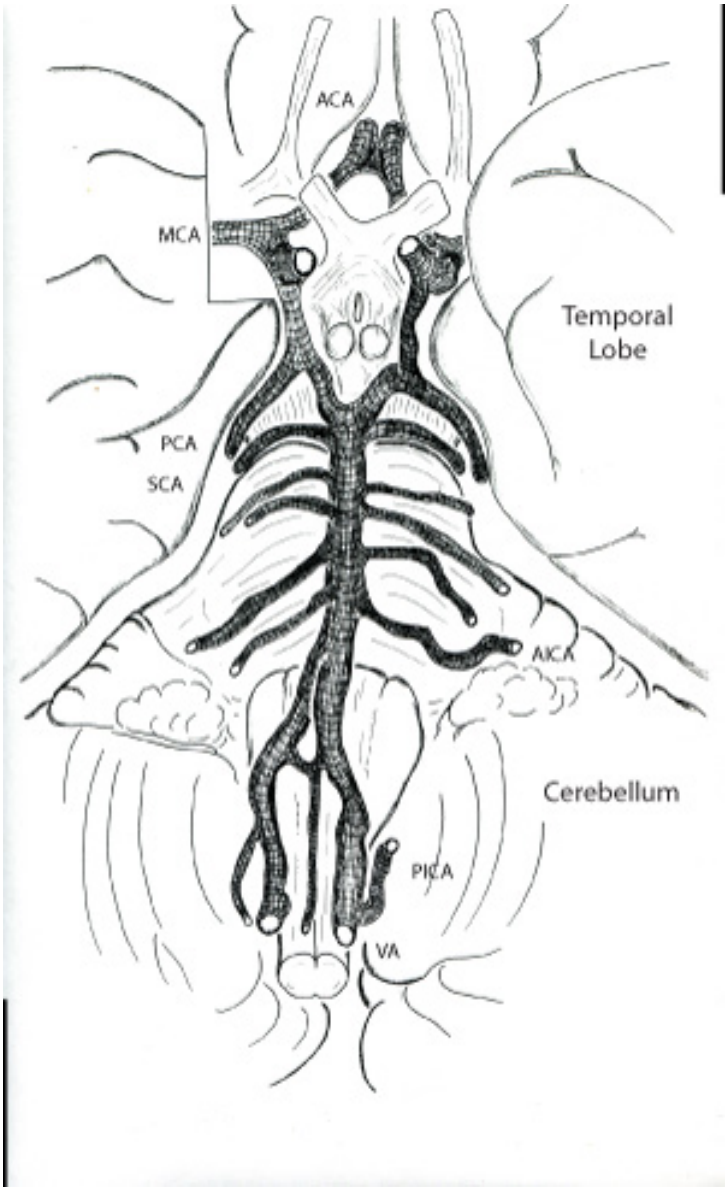


Figure 1-18 The posterior circulation of the brain. The two vertebral arteries (VA) are seen joining to form the basilar artery. The basilar then divides to form the two posterior cerebral arteries (PCA), which communicate with the two internal carotid arteries. The internal carotid arteries divide to form the middle cerebral arteries (MCA) and the anterior cerebral arteries (ACA). The vertebrobasilar system gives off numerous arteries to the brainstem and cerebellum including the posterior inferior cerebellar artery (PICA) and the anterior inferior cerebellar artery (ANICA).

resulting from the middle meningeal artery, frontal and posterior epidural hematomas have also been reported.

A "lucid interval" without neurologic symptoms can occur following traumatic injury as the nascent hematoma grows in size. Bear in mind that the characteristically described "lucid interval" in not seen in most cases of epidural hematoma. Generally, after the hematoma reaches 50 ml in volume, drowsiness, confusion, and headache appear in the patient's presentation; these symptoms can rapidly progress to obtundation and coma in a patient with a supratentorial epidural hematoma (Ritchie, 1990).

The increased intracranial pressure accompanying the epidural hematoma can cause herniation of the uncus towards the midbrain. Medial displacement of the uncus compromises the closely positioned third cranial nerve. Thus pupillary responses can be sensitive indicators of the progress of the herniation in an unconscious patient. The side of the dilated pupil is an indicator of the hematoma's laterality. Continued progression of the hematoma can lead to tonsillar herniation (downward displacement of the tonsils of the cerebellum through the foramen magnum), compression of the medulla, and respiratory arrest resulting in death (Morris, 1989).

Herniation of the uncus occurred in the patient presented in Case 1-1. Marking this occurrence was his loss of movement of the right pupil and its accompanying dilation, unresponsive to light.

Subdural Hemorrhage

The dura mater adheres to the calvarium and the arachnoid adheres to the cerebral hemispheres. The dura and arachnoid are adjacent, but not tightly adherent to one another; numerous cerebral (bridging) veins pass between these two layers. Trauma to either the frontal or posterior aspect of the skull can result in rebound shearing of the cerebral veins, with extravasated blood accumulating in the potential space between dura and arachnoid and forming a subdural hematoma.

When the head strikes a stationary object with force, a subdural hematoma frequently results. If the force is applied across the long axis of the cranium (e.g., the forehead striking a windshield), the resulting hematoma can be bilateral, as bridging veins tear along both sides of the brain. If the arachnoid layer preserves its integrity, the blood initially compartmentalizes without contact with the cerebrospinal fluid (CSF; Figure 1-21). Since the hemorrhage is from low-pressure venous blood, it can discontinue after 25 to 30 ml have accumulated (Vogel and Bouldin, 1988).

Subdural hematomas are divided in the two categories based on their temporal profile: acute and chronic. Acute subdural hematomas have a latency period between the traumatic event and the onset of neurologic sequelae of up to 3 days. These types of of hematomas are often associated with trauma and can occur in young individuals. Chronic subdural hematoma, which has an age-related and alcohol-associated predisposition, can have a longer latency period to the onset of neurologic sequelae (Hardman, 1997).

Subarachnoid Hemorrhage

Subarachnoid hemorrhages are usually due to trauma, rupture of an intracranial aneurysm, or leakage from an arteriovenous malformation (Morris, 1989; Hardman, 1997). Extreme hemorrhage may cause shock, coma, and death within a few hours; limited bleeding, on the other hand, may present as only a slight headache. The patient may appear confused, irritable, and semicomatose. Neck rigidity and signs of meningeal irritation can be present. On lumbar puncture, blood will be seen to discolor the cerebrospinal fluid (CSF).

The discoloring of the CSF by the breakdown products of blood is called xanthochromia. This process is characterized by a colored

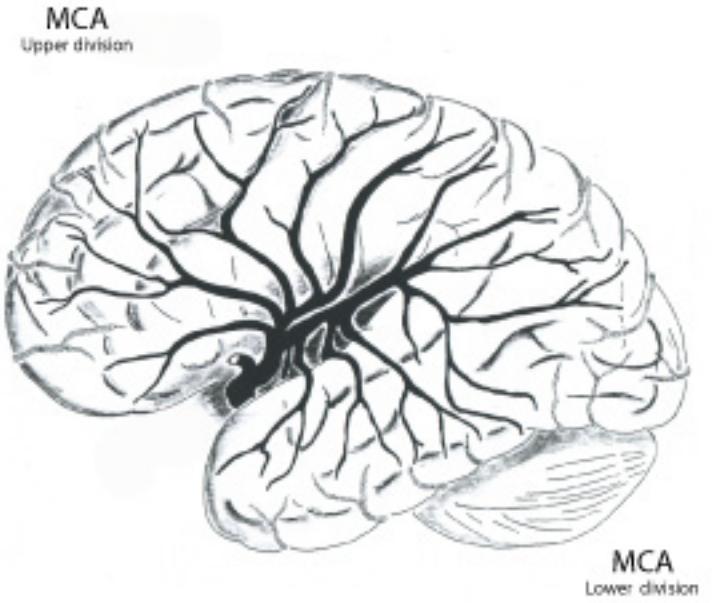


Figure 1-19 The distribution of the middle cerebral artery. In the lateral fissue, the MCA separates into upper and lower divisions.

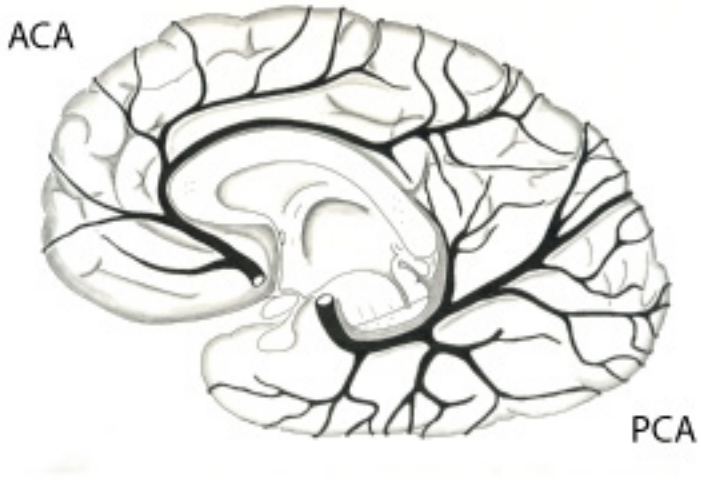


Figure 1-20 The distribution of the anterior cerebral artery (ACA) and the posterior cerebral artery (PCA) as seen in a sagittal view of the cerebrum.

pigment, a product of the breakdown of oxyhemoglobin and bilirubin, appearing in the CSF. Within 2 hours of entry into the CSF, red blood cells release hemoglobin. The hemoglobin breaks down to oxyhemoglobin, thus initiating xanthochromia in the CSF. Oxyhemoglobin is broken down into bilirubin within 10 hours (Adams, Victor, and Ropper, 1997). Following a subarachnoid bleed, red blood cells can be seen in the CSF. Conversely, subdural bleeding generally will not show red blood cells in the CSF, although the degradation products may traverse the arachnoid membrane and result in xanthochromia. This process may be detected up to 3 weeks after the initiating incidence.

Intracerebral Hemorrhage

Rupture of blood vessels within the central nervous system can result in intracerebral hemorrhage, that is, a bleeding event within the central nervous system tissue. The concomitant loss of circulation in the surrounding area of the bleed can initiate a period of local hypoxia and ischemia. The irritating effects of extravasated blood also compound tissue damage in the brain.

The ischemic event and the extravasated blood in an intracranial hemorrhage can produce immediate focal neurologic sequelae, usually of rapid onset. Subsequent to the initial presentation, the hemorrhaging vessel may continue to release blood, resulting in gradually increasing intracranial pressure. A progression of diffuse neurologic signs and symptoms can compound the initial focal presentation as the central nervous system tissue attempts to herniate out of the cranial compartment affected by the bleeding vessel.

Increased intracranial pressure is said to occur when the CSF pressure exceeds 200 mm water (15 mmHg) with the patient lying in the lateral decubitus position (Morris, 1989). The pressure inside the cranium increases for several reasons, such as the presence of an expanding tumor, an active hemorrhage, a ventricular occlusion, or an infectious, inflammatory and edematous process. The consequence of prolonged increase in intracranial pressure can be devastating. Brain tissue, being soft and pliable, usually herniates out of the more rigid cranial spaces as the surrounding pres-

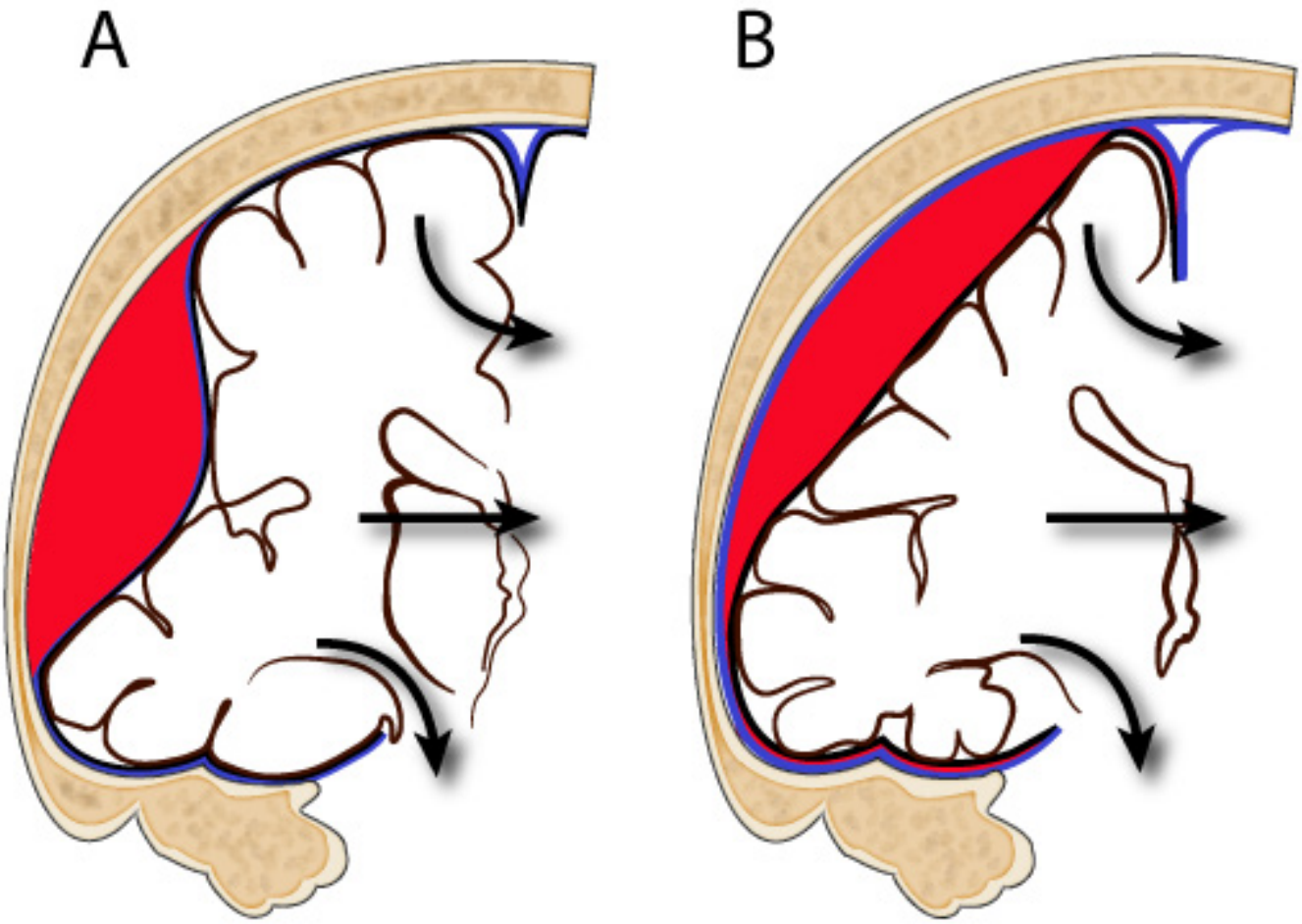


Figure 1-21 Coronal views of a section through the cerebrum illustrating the formation of an epidural hematoma (left) and a subdural hematoma (right). The red area represents the hematoma. In the figure on the left (A) the hematoma is located between the bone and the dural sac (blue) whereas in the figure on the right (B) the hematoma is located between the dural lining (blue) and the arachnoid membrane (black).

sure increases. Various types of herniations have been described (McComb and Davis, 1985). Performing a lumbar puncture on a patient with increased intracranial pressure can have extremely serious consequences. The medulla and cerebellum attempt to herniate through the foramen magnum in response to the rapidly diminished pressure in the vertebral compartment.

The effects of a hernia on cerebral function depend on its location. Supratentorial expanding lesions can produce a shift of the falx cerebri toward the contralateral side, a process that can be monitored with computerized imaging. An index of this shift is seen in the lateral displacement of the pineal, which is in close juxtaposition with the falx; its calcium deposits are usually easily detectable in CT scans. A displacement of up to 3 mm of the pineal and midline can be present in an alert patient. Displacement of 3 to 4 mm is associated with drowsiness; one of 6 to 8.5 mm, with stupor; and one of 8 to 13 mm, with coma (Ropper, 1986).

Unlike intracranial bleeding, where hypoxia and ischemia occur, the expression of neurologic signs and symptoms in epidural and subdural hematomas is due primarily to the effect of an expanding mass as well as compression. Consequently, there is usually a time delay between the injury and the onset of neurologic sequelae as the volume of blood accumulates in the hematoma (Adams, Victor, and Ropper, 1997). This lag time in the onset of neurologic signs can help to distinguish patients with epidural and subdural hematomas from those with intracranial hemorrhage.

▶ Summary

This chapter has examined the meningeal compartments that house the brain and spinal cord. It has also explored the functions of each major regional component of the central nervous system and related these structures to their associated neurologic signs and symptoms when lesioned. Finally the blood supply to the brain has been presented and the various regional vascular accidents discussed.

The chapter has also presented a method for structuring a neurological exam such as to facilitate your ablity to determine the location of a lesion on the central neuraxis.

Reference List

Adams,R.D., Victor,M., and Ropper,A.H. (1997) Principles of Neurology. New York: McGraw-Hill Health Professions Division.

Andresen,M.C. and Kunze,D.L. (1994) Nucleus tractus solitarius - gateway to neural circulatory control. Ann.Rev.Physiol. 56:93-116.

Batson,O.V. (1940) The function of the vertebral veins and their role in the spread of metastases. Arch.Surg. 112:138-149.

Batson,O.V. (1957) The vertebral vein system. American Journal of Roentgenology, Radium Therapy and Nuclear Medicine 78:195-212.

Biller,J. and Brazis,P.W. (1996) The localization of lesions affecting the cerebellum. In P.W.Brazis, J.C.Masdeu, and J.Biller (eds): Localization in Clinical Neurology. Boston: Little, Brown and Company, pp. 365-380.

Blessing,W.W. (1997) The lower brainstem and bodily homeostasis. New York: Oxford University Press.

Brazis,P.W. (1996) The localization of lesions affecting the brainstem. In P.W.Brazis, J.C.Masdeu, and J.Biller (eds): Localization in Clinical Neurology. Boston: Little, Brown and Company, pp. 343-364.

Brazis,P.W., Masdeu,J.C., and Biller,J. (1996b) Localization in Clinical Neurology. Boston: Little, Brown, and Company.

Brazis,P.W., Masdeu,J.C., and Biller,J. (1996a) Localization in Clinical Neurology. Boston: Little, Brown and Company.

Dacey,R.G. and Jane,J.J. (1984) Craniocerebral trauma. In R.J.Joynt (ed): Clinical Neurology. Philadelphia: J.B. Lippincott Co., pp. 1-61.

Damasio,H. and Damasio,A.R. (1989) Lesion Analysis in Neuropsychology. New York: Oxford University Press.

DeMyer,W. (1979) Anatomy and clinical neurology of the spinal cord. In R.J.Joynt (ed): Clinical Neurology. Philadelphia: J.B. Lippincott, pp. 1-32.

Freier,S. (1990) The Neuroendocrine-Immune Network. Boca Raton, Florida: CRC Press, Inc..

Goetzl,E.J. and Spector,N.H. (1989) Neuroimmune Networks: Physiology and Diseases. New York: Alan R. Liss.

Goldman-Rakic,P.S. (1988) Topography of cognition: Parallel distributed networks in primate association cortex. Ann.Rev.Neurosci. 11:137-156.

Haines,D.E., Harkey, and Al-Mefty,O. (1993) The "subdural" space: a new look at an outdated concept. Neurosurgery 32:111-120.

Hardman,J.M. (1997) Cerebrospinal trauma. In R.L.Davis and D.M.Robertson (eds): Textbook of Neuropathology. Baltimore: Williams and Wilkins, pp. 1179-1232.

Masdeu,J.C. (1996) The localization of lesions of the hypothalamus and pituitary gland. In P.W.Brazis, J.C.Masdeu, and J.Biller (eds): Localization in Clinical Neurology. Boston: Little, Brown and Company, pp. 381-401.

McComb,J.G. and Davis,R.L. (1985) Choroid plexus, cerebrospinal fluid, hydrocephalus, cerebral edema, and herniation phenomena. In R.L.Davis and D.M.Robertson (eds): Textbook of Neuropathology. Baltimore: Williams & Wilkins, pp. 147-175.

Mesulam,M.-M. (1990) Large scale neurocognitive networks and distributed processing for attention, language, and memory. Ann.Neurol. 28:597-613.

Moore,K.L. and Persaud,T.V.N. (1998) The Developing Human. Philadelphia: W.B. Saunders Company.

Morris,J.H. (1989) The Nervous system. In R.S.Cotran, V.Kumar, and S.L.Robbins (eds): Robbin's Pathologic Basis of Disease. Philadelphia: W.B. Saunders Co., pp. 1385-1449.

Nauta,W.J.H. and Feirtag,M. (1979) The organization of the brain. Sci.Am. 241(3):88-111.

Parke,W.W. and Watanabe,R. (1990) Adhesions of the ventral lumbar dura: an adjunct source of discogenic pain? Spine 15:300-303.

Plum,F. and Posner,J.B. (1982) The Diagnosis of Stupor and Coma. Philadelphia: F.A. Davis Company.

Quagliarello,V. and Scheld,W.M. (1992) Bacterial meningitis: pathogenesis, pathophysiology, and progress. N.Engl.J.Med. 327:864-872.

Ritchie,A.C. (1990) Boyd's Textbook of Pathology. Philadelphia: Lea & Febiger.

Ropper,A.H. (1986) Lateral displacement of the brain and level of consciousness in patients with acute hemisperal mass. N.Engl.J.Med. 314:953-958.

Sarnat,H.B. and Netsky,M.G. (1981) Evolution of the Nervous System. New York: Oxford University Press.

Schmahmann,J.D. and Sherman,J.C. (1998) The cerebellar cognitive affective syn-

drome. Brain 121 (Pt 4):561-579.

Schuchat,A., Robinson,K., Wenger,J.D., Harrison,L.H., Farley,M., Reingold,A.L., Lefkowitz,L., and Perkins,B.A. (1997) Bacterial meningitis in the United States in 1995. N.Engl.J.Med. 337:970-976.

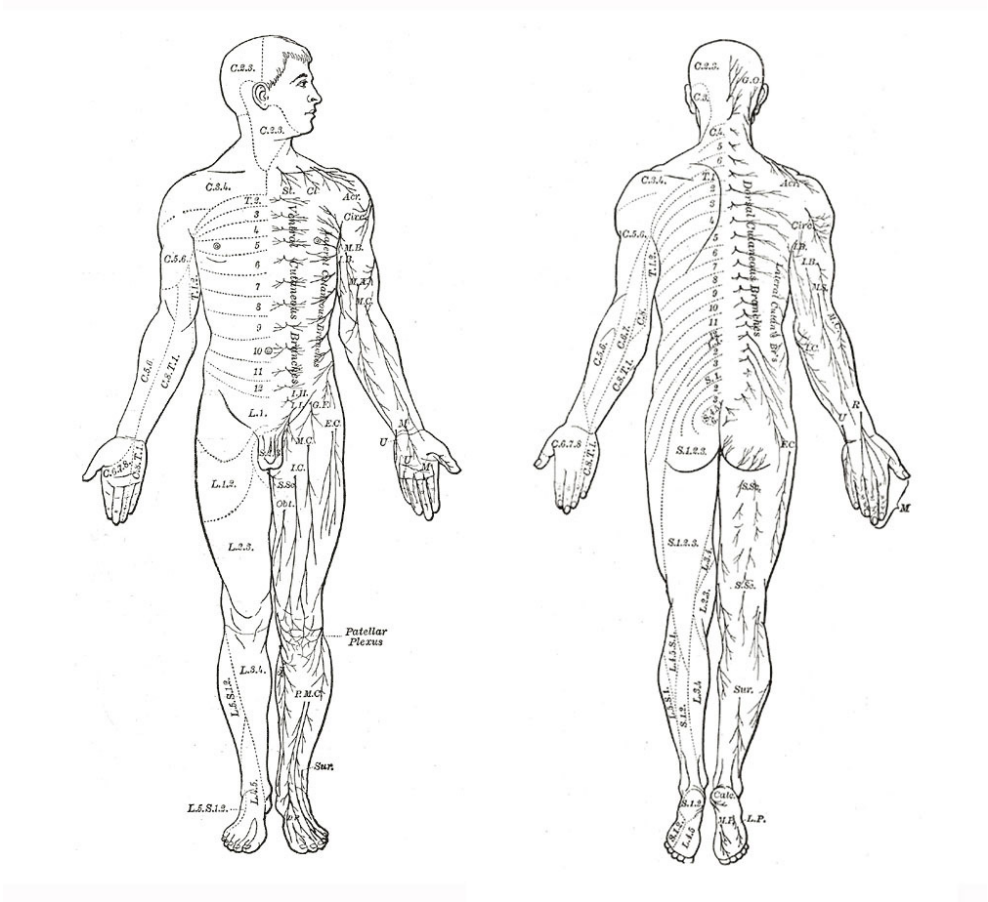
Spence,A.M. (1984) Pain and sensory disturbances in the extremities: radiculopaties, plexopathies, and mononeuropathies. In P.D.Swanson (ed): Signs and Symptoms in Neurology. Philadelphia: J.B. Lippincott Comp., pp. 245-281.

Spencer,D.L., Irwin,G.S., and Miller,J.A.A. (1983) Anatomy and significance of fixation of the lumbosacral nerve roots in sciatica. Spine 8:672-679.

Vogel,F.S. and Bouldin,T.W. (1988) The nervous system. In E.Rubin and J.L.Faber (eds): Pathology. Philadelphis: J.B. Lippincott Co., pp. 1416-1499.

Von Euler,C. (1986) Brain stem mechanisms for generation and control of breathing

Chapter 2
Peripheral Nerves



▶ INTRODUCTION

The nervous system can be divided anatomically into peripheral and central components. The peripheral nervous systems consist of the spinal roots, dorsal root ganglia and the spinal and cranial nerves. These later structures extend throughout the somatic and visceral tissue of the body. The peripheral nervous system is critical in bidirectional passage of information between the tissues of the body and the spinal cord and brain, the two components of the central nervous system.

An important step in the differential diagnosis of any neurological complaint is an initial determination as to whether it is localized to the peripheral nervous system, to the central nervous system or possibly involves both of these compartments. This decision can significantly alter the direction into which one goes for treatment, therefore it is very important to recognize the distinctive features of peripheral nervous system disease. In this chapter we will examine the organization of the peripheral nervous system and consider the defining clinical characteristics of peripheral nervous system disorders.

GENERAL OBJECTIVES

1. To identify to the major components of the peripheral nervous system including the spinal roots, dorsal root ganglion, spinal nerves, plexuses, and peripheral nerves.

2. To understand the neural circuitry involved in peripheral reflexes.

3. To identify the clinical signs and symptoms related to damage involving each component of the peripheral

nervous system.

4. To use the above information to locate accurately the position of a lesion occurring in the peripheral nervous system

INSTRUCTIONS

In this chapter you will be presented with two clinical case studies. Each study is followed by a list of questions that can be best answered by using knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions is a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer the questions, compile a list of the patient's neurologic signs and symptoms. Then examine the structures and their functions and study their known deficits presented in the section marked CLINICAL DISCUSSIONS. After becoming comfortable with the material, reexamine the list of neurologic signs and symptoms and answer the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human spinal cord and its dural covering
2. Photographs and drawings of illustrating the peripheral nervous system
3. A medical dictionary

Chapter Two Topics:

CASE STUDY 2-1

Chief Complaint

This is a 17-year-old male high school student presenting with progressively worsening weakness and muscle atrophy in the lower extremities.

History of Chief Complaint

He is the product of a normal pregnancy and an uneventful delivery. He achieved his developmental milestone on time. His mother notes that he always seemed clumsy and did not do well in sports activity although he loves sports and tries very hard. He has suffered three sprained ankles while playing soccer. His legs always appeared very thin and recently the high school physical education instructor became concerned and asked for a physician's evaluation. The patient notes that over the past three years he thinks he has experienced a gradual increase in weakness in his lower extremities and states that he now finds it difficult to run the length of the soccer field. He complains the even walking can be difficult on occasion and that he frequently trips especially at night or in dimly lit areas. His mother notes that over the past year he has developed a very loud sounding gait.

Family History

The patient's mother and father are alive and in good health. He has a 10-year-old brother who also has reduced muscle mass in his legs. His mother's uncle has very thin legs and complains of feeling tired and weak when having to walk any distance.

Medical History

Positive for a tonsillectomy at 10 years of age; all vaccinations are up to date.

Allergies

NKA

Review of Systems

GENERAL: Patient denies any recent weight change but admits to progressive loss of strength in his legs. SKIN: He denies any rashes or sores on his skin. HEENT: denies headache, head injury, or dizziness. Denies changes in vision or eye pain. He denies changes in hearing, tinnitus or ear pain. He admits to an occasional cold with runny nose but denies nosebleeds, sore throat or dental pain. NECK: denies swelling or stiffness. RESPIRATORY: Denies cough or dyspnea. CARDIOVASCULAR: Denies chest pain or palpitations. ABDOMINAL: Denies dysphagia or odynophagia, admits to normal colored stools once a day. Denies any abdominal pain. URINARY: Denies any hematurea, frequency or urgency. Denies any flank pain. GENITAL: Denies discharge or pain. Admits to sexual activity, denies any rashes or sores. MUSCULOSKELETAL: admits to muscle cramping and muscle pain in the lower extremity especially the calves, admits to pain in the arch of both feet while walking. NEUROLOGIC: Denies any changes in mood or any depression. Denies blackouts and dizziness, denies any loss of sensation or strength in the upper extremity. Admits to loss of strength in the lower extremity and a blunting of feeling in his legs but mainly in his feet. Admits to feeling unsteady when walking and to frequently tripping on small objects especially at night.

General Physical Examination

The patient is awake, oriented and cooperative with pleasant affect. His blood pressure is 121/79, heart rate is 61, respirations are 16 and temperature is 98.6° F. HEAD & NECK: Head is normocephalic, pupils are equal and reactive to light. Auditory canals are patent and non-reddened. Nose, mouth and pharynx are clear without tenderness. Neck has normal range of motion and without lymphadenopathy. CARDIOVASCULAR: regular rate and rhythm, normal apex beat, no jugular-venous distention. There is an audible carotid pulse with no bruits. ABDOMINAL: mild abdominal obesity with no masses or tenderness palpable. MUSCULOSKELETAL: Extremities are four in number without tenderness except in the feet. No pretibial edema. No joint swelling. Notable atrophy is present in the calf region of the lower extremity bilaterally. His arches are markedly elevated and his toes are blunt and square in shape. SKIN: No rashes, echymosis, petichiae.

Neurologic Examination

Mental Status. Patient is awake and oriented to person, place and time. His mood is appropriate and memory and speech are intact.

Cranial Nerves. Cranial nerves 1-12 were intact.

Motor Systems. Strength and reflexes were intact everywhere in the upper extremities. Muscle bulk was intact in the upper extremities. Strength was 4/5 for flexion and extension at the hip and knee bilaterally and 3/5 for dorsi and plantar flexion at the right ankle and 2/5 for dorsi- and plantar flexion at the left ankle. Deep tendon reflexes were 1/4 at the knee and trace at the ankle bilaterally. Gait was slightly wide-based with occasional audible foot slapping. Heel-to-shin testing was normal with eyes open but abnormal with eyes closed.

Sensory Exam. Sensory was intact in the upper extremities. In the lower extremities, vibration sense and position sense were diminished about the knee and absent about the ankle and foot. Two-point discrimination was absent on the sole of the foot but present about the ankle and knee. Response to pinprick was intact throughout the upper and lower extremities.

Follow-up Examination

Six months later the weakness in the lower extremity worsened slightly, with strength being 2/5 for dorsi- and plantar flexion bilaterally. Diminution of 2-point discrimination was now observable about the knee bilaterally. He is beginning to complain of a perceived weakness in his hands.

Questions:

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. How could the diagnosis be best established in this patient?

10. What is the prognosis for this patient if the disease is left untreated?

11. What types of assistance can be of help for this patient?

▶ DISCUSSION I

Organization of the Peripheral Nervous System

The peripheral nervous system represents the communication pathway between the tissues of the body and the spinal cord and brain. Sensory information from both the body and the external world is conducted into the spinal cord for processing over the peripheral nerves. Simultaneously, somatic motor information is carried peripherally to the skeletal muscles of the body while autonomic information is conducted outward to all remaining tissues of the body through the peripheral nervous system. Significantly, diseases may strike individual parts of the peripheral nervous system or the entire peripheral system at once. In this section we will examine the anatomy of each portion of the peripheral nervous system and consider its function. From this information we can begin to understand its presenting signs or symptoms when diseased.

Dorsal and Ventral Roots

The dorsal roots lie in the dural sac dorsal to the denticulate ligament of the spinal cord. In total there are typically 31 dorsal roots, however, each dorsal root is composed of numerous (5-8) rootlets. The rootlets exit the spinal cord along the dorsolateral sulcus and

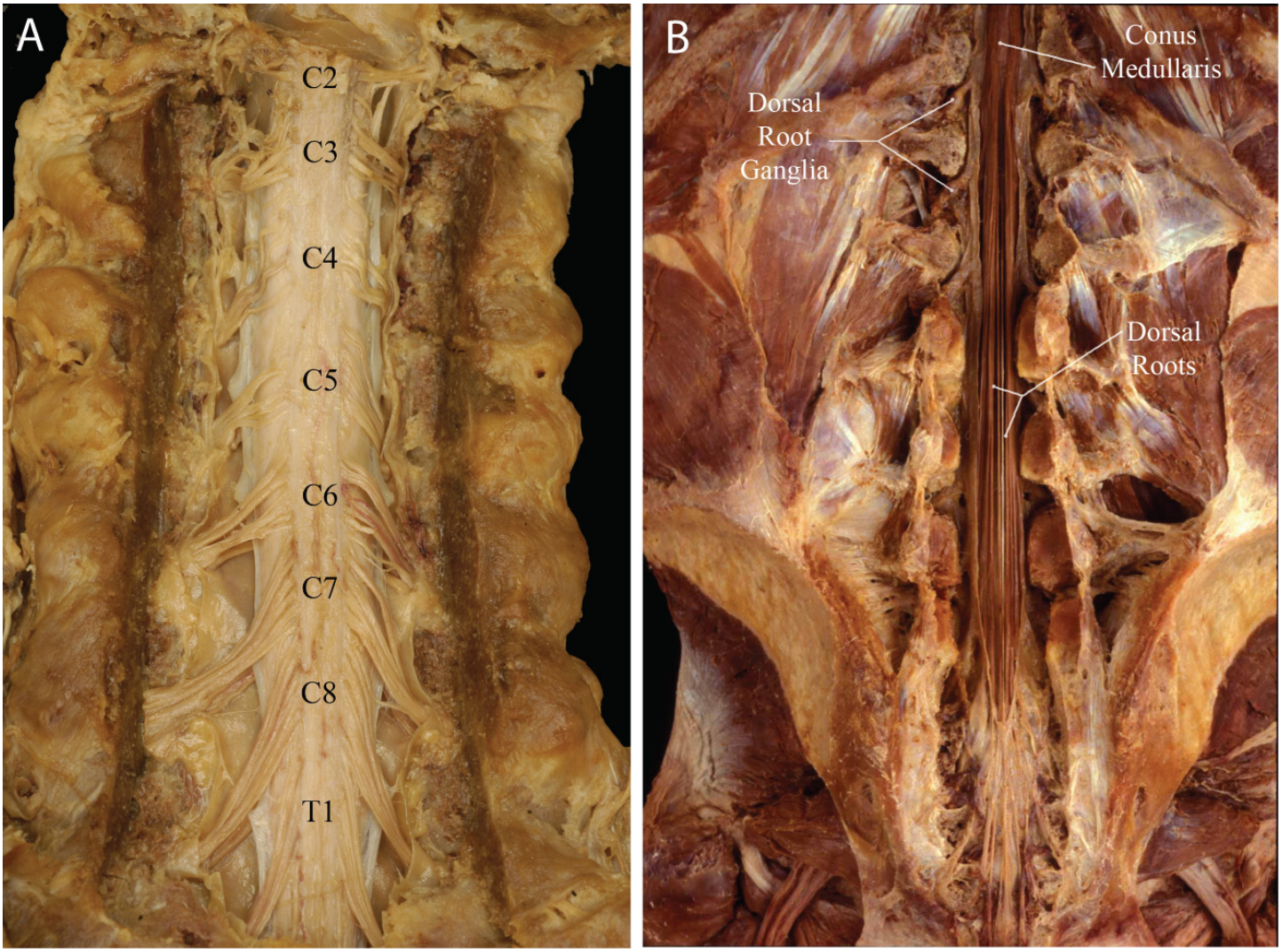


Figure 2-1 Dorsal Roots. A. A dorsal view of a laminectomized cervical spinal cord demonstrating the thin delicate dorsal rootlets sweeping laterally from the spinal cord to form dorsal roots. B. Dorsal view of a laminectomized lumbar spine illustrating the elongated dorsal roots forming the cauda equina.

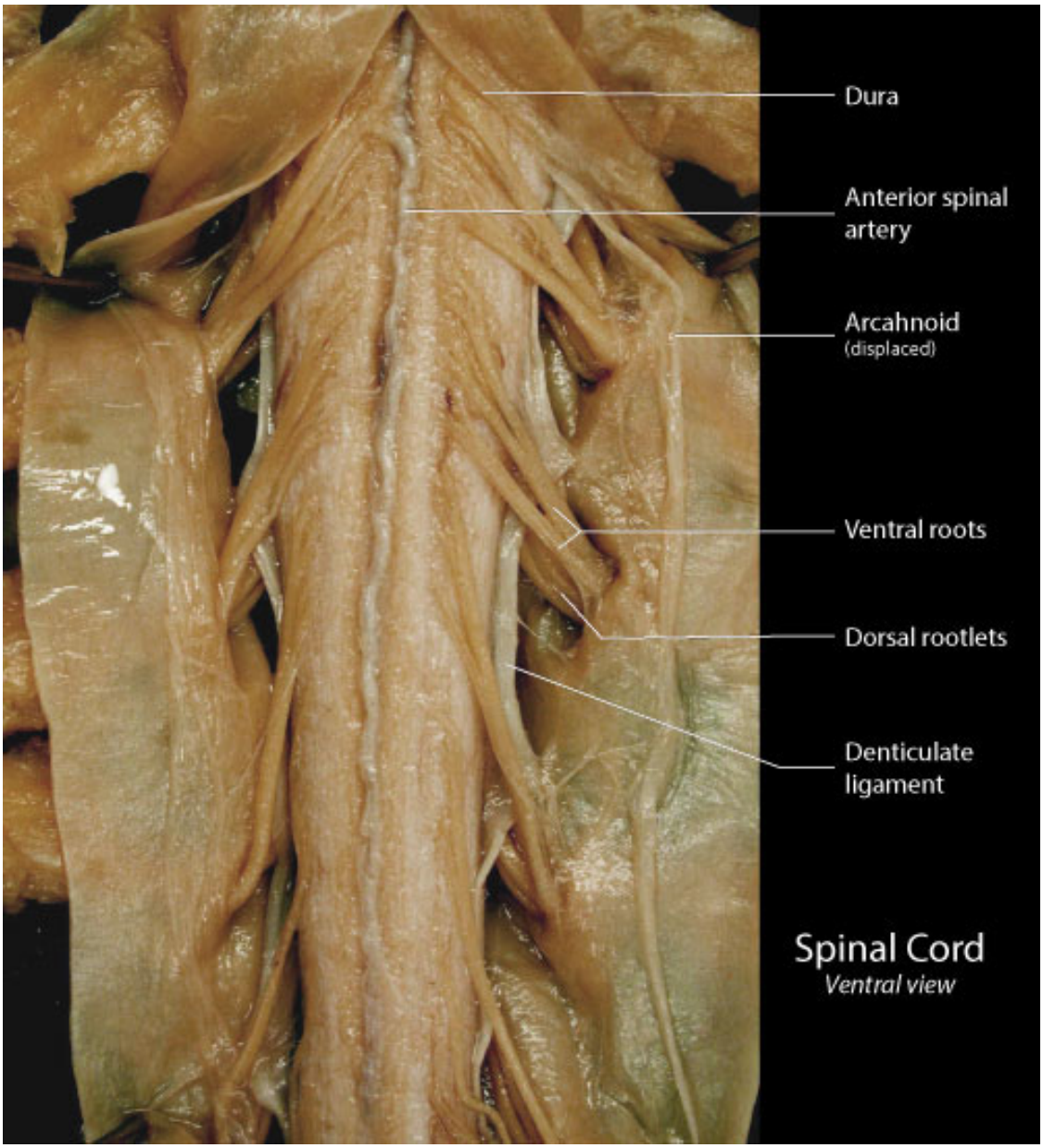


Figure 2-2: A ventral view of the spinal cord following the opening of the dura and arachnoid. The ventral rootlets pass over the free border of the denticulate ligament to join with the dorsal rootlets. The combined bundle of rootlets enters the lateral recess, an evagination of spinal dura that extends into the intervertebral canal.

are surrounded by a loose plexus of small arteries that, in total, form what is termed the posterior spinal artery. As the rootlets sweep laterally off of the spinal cord, they begin to unite with each other to form the dorsal root. These roots may be relatively short and horizontally oriented, as seen in the cervical region, or extremely long (<12 inches) and vertically oriented as seen in the lumbar and sacral regions.

Contained within the dorsal roots are the processes of primary afferent or sensory neurons. The primary afferent neurons have a cell body located in the dorsal root ganglion and a central process that extends over the dorsal root and rootlet to enter the spinal cord. The peripheral process of the neuron passes distally in the dorsal root to enter the spinal nerve at the point where the dorsal and ventral roots fuse. The peripheral process extend into the somatic or visceral tissues where they end either as naked nerve endings or embed into an elaborate encapsulated ending.

The ventral roots contain axons that arise from motoneurons located in the ventral horn of the spinal cord. Unlike the dorsal rootlets, the ventral rootlets arise irregularly from the ventromedial aspect of the spinal cord. Once the ventral rootlet leaves the spinal cord it turns laterally to approach the lateral recess of the spinal dura. As the ventral roots enter the lateral recess they approximate the dorsal root but no interchange occurs at this point. The ventral root contains the axons of the large alpha and gamma motoneurons from the ventral horn of the spinal cord and the axons of the preganglionic autonomic neurons whose cell bodies are located the in

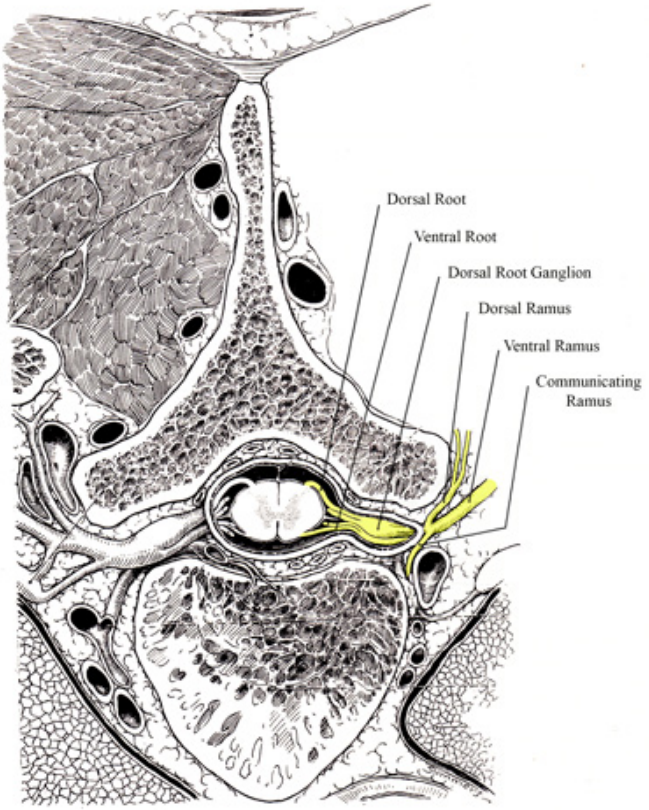


Figure 2-3: A drawing of an axial plane section of the vertebral canal illustrating the joining of the dorsal and ventral roots and the extension of the roots into the lateral recess. Note that the lateral recess extends into the intervertebral canal. (Figure modified from: Mettler, F.A., Neuroanatomy, C.V. Mosby Company, 1942).

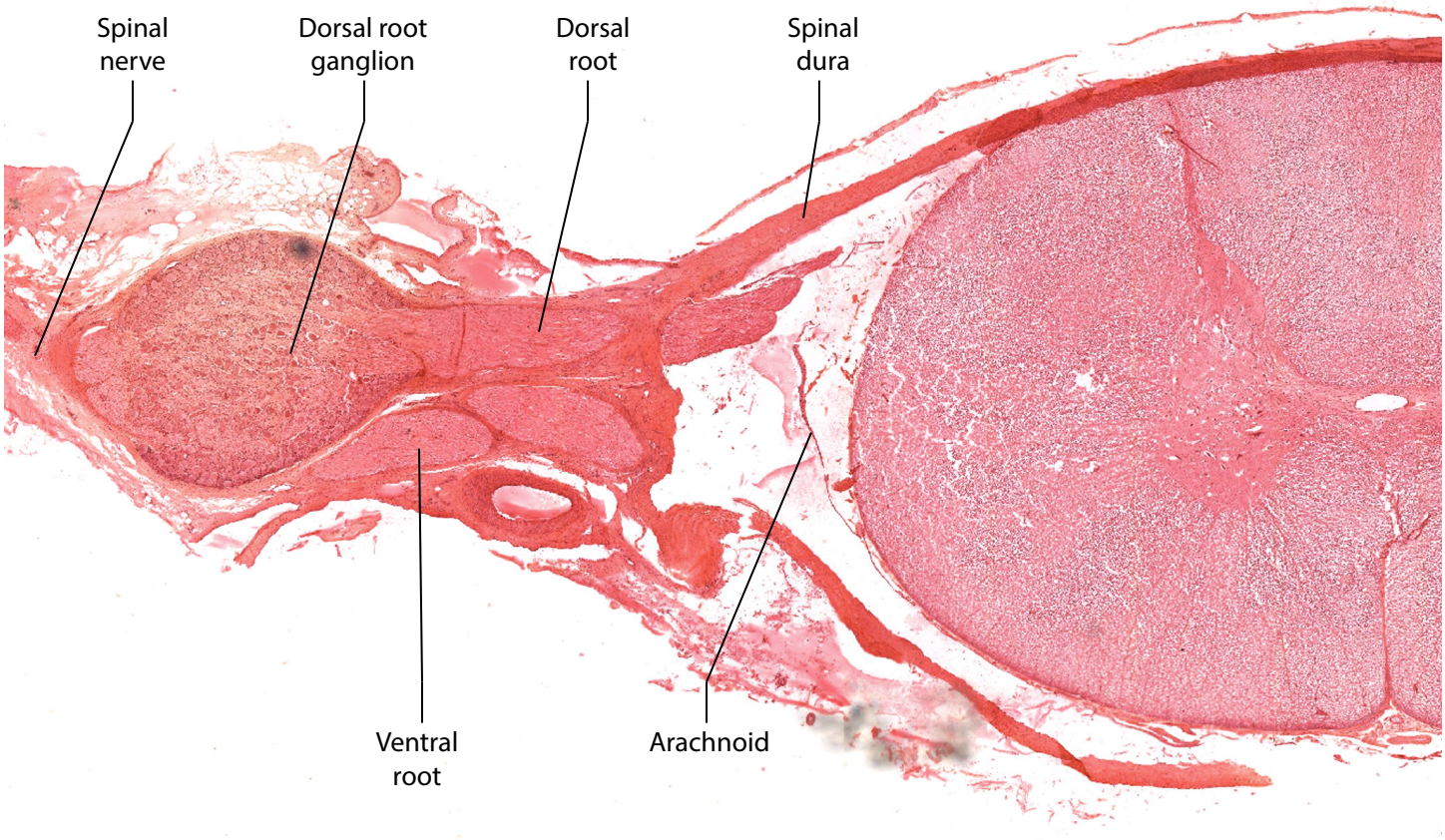
the lateral horn.

The dorsal and ventral roots pass through the lateral recess of the spinal canal to enter the intervertebral canal. The dorsal root ganglion is located inside the canal and at the distal end of the canal, the roots merge together to form the spinal nerve. Generally throughout the canal, the roots are in close proximity to the intervertebral disc.

Formation of the Spinal Nerve

The rootlets cluster together to form roots that will enter an evagination of dura termed the lateral recess. This pocket represents the entrance to the root sleave, a dural lined canal that passes through the intervertebral foramen. The dorsal root ganglion is located in the root sleave. Proximal to the dorsal root ganglion, the dorsal and ventral roots approximate each other as they pass through the lateral recess to enter the root sleave. However at this point there is no intermingling of fibers between these two functionally distinct roots. The union of the roots does not occur until they are distal to the dorsal root ganglion. It is at this point that the true spinal nerve is formed. All of this is occurring in the intervertebral canal. As the nerve exits the intervertebral foramen there has been

Figure 2-4: An axial plane section of the spinal cord and dorsal root ganglion. Note how the dorsal and ventral roots are separate as they pass through the root sleeve. The lateral recess of the dura forms the opening to the root sleeve. The sleeve fuses with the roots distal to the dorsal root ganglion to form the spina nerve



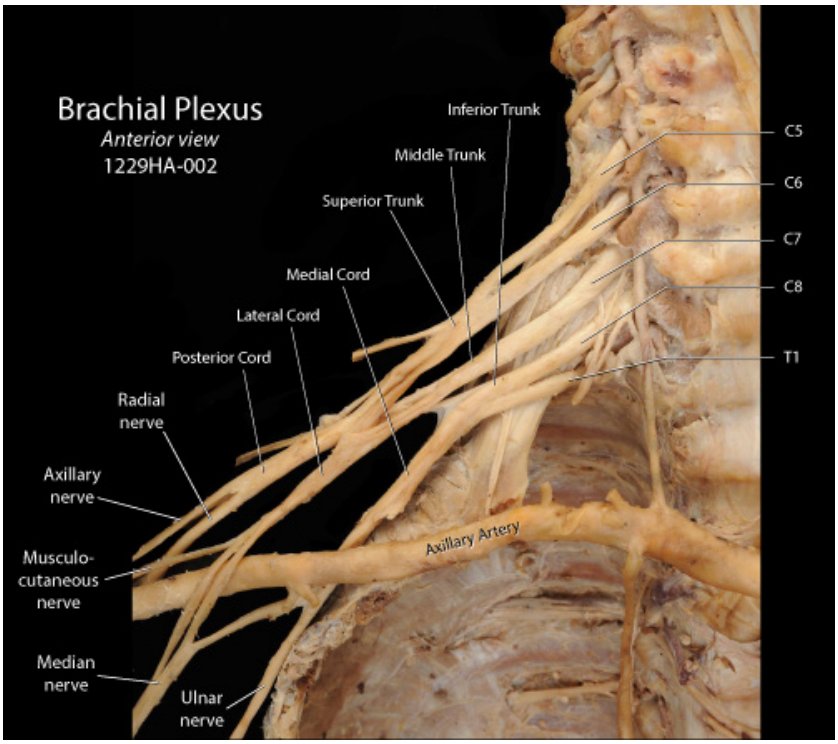


Figure 2-5: The brachial plexus. The roots of the brachial plexus actually represent ventral rami. Multiple exchanges occur between the nerve bundles involved in the plexus; thus when the peripheral nerves are ultimately formed they contain nerve fibers from multiple ventral rami.

complete intermingling of sensory and motor axons from the dorsal and ventral roots respectively.

Formation of a Peripheral Nerve

Shortly after the spinal nerve forms, it divides into small dorsal and large ventral rami. Collectively, the dorsal rami innervate all somatic tissue developing dorsal (posterior) to the transverse process of the vertebrae. This includes the paraspinal muscle and the skin on the back. The ventral rami innervate all the somatic tissue forming anterior to the transverse processes and the extremities, which form from the limb buds composed of lateral mesoderm. For body segments C1-C4, T2-T12, S4-S5 and Co1-Co3, each ventral ramus essentually forms a peripheral nerve, however ventral rami C5-T1 and L1-S3 contribute to the brachial and lumbosacral plexi respectively. Each plexus represents a complex intermingling of nerve fibers from the involved ventral rami. Thus when the peripheral nerves emerge from the distal region of the plexus they contain numerous fiber contributions from multiple ventral rami, thus they are said to be **pleurisegmental** in nature.

Spinal Reflexes

Within the gray matter of the spinal cord the information from the primary afferent fibers is transfered to the large alpha motor neurons of the ventral horn. This transfer may be by direct synaptic relationship between primary afferent endings and the motoneurons or it can pass through one or more interneurons before reaching the motoneuron.

Reflexes of a proprioceptive nature involve the stretch of a muscle or tendon, a high-speed volley of discharges sent into the spinal cord, priamry afferent synapses on motoneurons, and subsequent contraction of the muscle to relieve the stretch. Conversely, reflexes of nociceptive origin involve peripheral tissue damage or threatened damage, a volley relayed onto neurons in the dorsal horn from which connections are established through interneurons to the motoneurons in the ventral horn. The motoneurons involved typically produce a withdrawal reflex that is protective in nature.

Distruction of any component of these reflexes will abort the reflex. Thus if the peripheral nerve or its associated roots are severed, stretching related muscles will not elicit a reflex. This hyporeflexia on tendon stretch (tap) is a characteristic of a root or peripheral nerve lesion. It has also been termed a “lower motor neuron” lesion because the connection between the motoneurons of the spinal cord and the muscle has been severed. Upper moto neurons are cells in the brainstem and cerebrum that control the lower motoneurons of the spinal cord. Upper motor neuron lesions will be discussed in the next chapter.

CLINICAL DISCUSSION In the diagnosis of peripheral nerve lesions several featues should be considered. First should be the distinction between peripheral vs. central nervous system injury. The presence of ***long tract*** signs in a patient should steer you towards the involvement of the central nervous system. Long tract signs include such findings as spasticity in the extremities and level-down sensory loss. Barring the presence of either of these findings, an anatomical differential of the peripheral nervous system can be approached. Here are some general observations that may prove helpful:

Primary muscle disease - no sensory loss, weakness may not involve any changes in tendon reflexes and is regionally distributed, not in the pattern of a peripheral nerve or spinal root. Fasciculations would not be expected in this situation.

Neuromuscular junction disorders - no sensory loss, weakness may not involve any changes in tendon reflexes and is regionally distributed, not in the pattern of a peripheral nerve or spinal root. Weakness may involve fatigue. Fasciculations would not be expected.

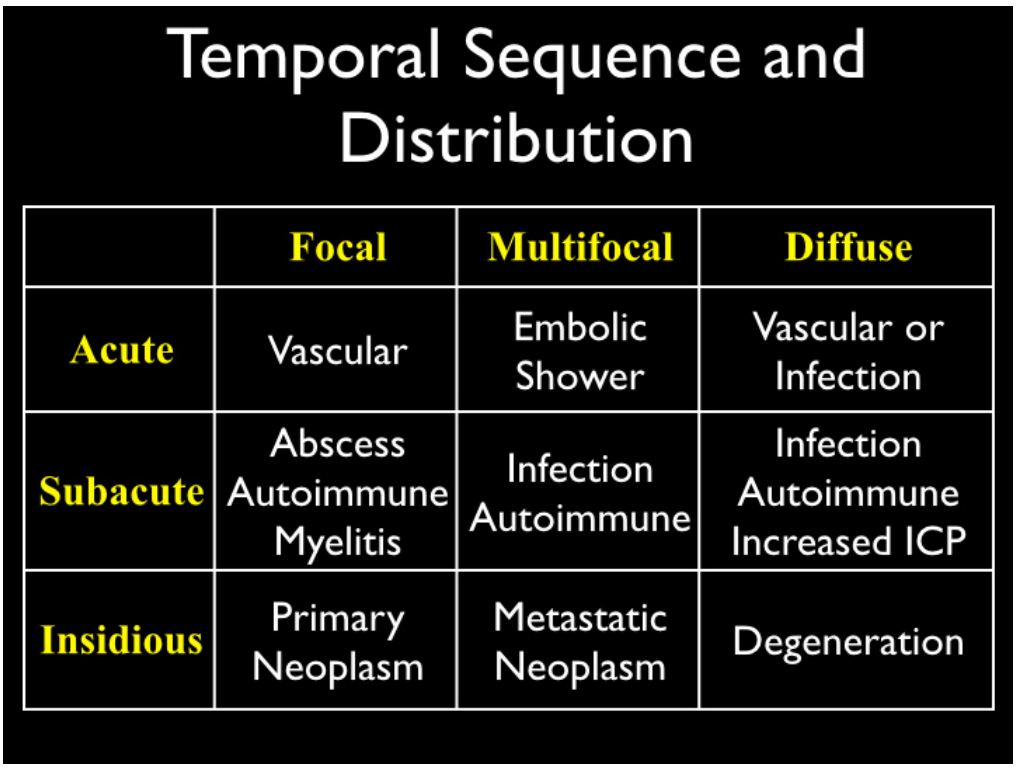
Peripheral nerve - Both weakness and sensory loss may be present. The weakness is invarably of a flaccid nature featuring hypotonicity and hyporeflexia. One or several related muscles in a peripheral nerve territory may be mildly paretic or completely paralyzed. Fasciculations may be present depending on the temporal profile. Sensory loss may be acompanied by paresthesias and pain.

Plexus - Both weakness and sensory loss may be present. The weakness is invarably of a flaccid nature featuring hypotonicity and hyporeflexia. A functional group of muscles, innervated by closely related spinal segments, are typically involved. Fasciculations may be present. For example upper brachial plexus lesions involving C5-C7 (Erb-Duechenne type or "waiter's tip hand") or lower brachial plexus lesions involving C8-T1 (Klumpke-Dejerine type or "claw-hand").

Spinal root - Flaccid paraylsis and complete ansethesia develop over the myotome and dermatomes of the involved spinal roots. Fasciculations may be present dependent on the temporal profile. If only one root is involved there may only be paresis of selected muscles since most muscles, with the exception of the rhomboids and levator scapulae, are innervated by multiple spinal segments. With only one root involvment, the anesthesia may not be detectable due to the overlap of peripheral dematomes. Radicular pain may be the dominant feature of the presentation.

Along with the anatomical considerations presented above, the clinicotemporal profile is also critical in arriving at a diagnosis. This process should take into consideration the temporal profile of the signs and symptoms as well as their distribution about the body. For example, acute onset of focal neurologic signs and symptoms often is indicative of a vascular or traumatic event. While subacute onset with multifocal distribution can suggest an infection or and inflammation, the latter especially if the time course is waxing and waning. Finally insidious onset of a focal event is suggestive of a mass expanding lesion such as a neoplasm while insidious onset with diffuse distribution is pointing toward a degenerative process. The following chart is meant to provide guidance, however bear in mind that the rules are very flexible.

Figure 2-6: A chart demonstrating the integration of temporal profile and distribution of neurologic signs and symptoms to arrive at an approximation of the pathophysiology involved in the lesion.



Case Study 2-2

Chief Complaint

This is a 26-year-old student who is complaining of sharp, burning pain in his right leg with weakness and difficulty walking

History of Chief Complaint

The young man had enjoyed his usual good health until last Sunday afternoon when he was playing intramural football. During a vigorous play he experienced the sharp burning pain down the inside of his right leg. He describes the pain as feeling like burning gasoline being poured down the inside of his leg and foot. He denies hearing or feeling any popping or cracking associated with the onset of the pain. He stopped playing football and noticed a mild weakness in the leg as well. Although he reports that the burning pain has subsided somewhat since then, the weakness has persisted and he feels that it may even be getting worse.

Family History

Both mother and father are alive and well. He has a sister who is 23 and is well also.

Allergies

NKA

Review of Systems

Due to previous good health and the specificity of the Chief Complaint, the ROS will be focused on the back and extremities. He denies tics or adventitious movements but admits to weakness in his right lower extremity. He denies painful or swollen joints but admits to a dull pain in the center of his lower lumbar spine. He admits that it is painful to stand on the right leg and attempts to unweight the extremity when ever possible. He complains that the pain is made worse by sitting, walking or standing for long periods of time and by coughing or sneezing.

Physical Examination

This is an alert and cooperative 26-year-old well nourished male. He is standing and leaning to the left and elevating the right leg. He admits to feeling uncomfortable at this time. Blood pressure is 140/95, heart rate is 75 b/m, respirations are 17 and temperature is 98.6°F. The remainder of the exam will focus on his back and extremities. Extremities are four in number and without clubbing or cyanosis. Full range of motion is intact in the left lower extremity but the patient has restricted movement of the right especially in the sagittal plane. There is no tenderness to percussion on the spinous processes of L1 through L5. Straight leg raising on the right leg is painful at 20 degrees, and right sided pain is reproduced with left leg rising at 45 degrees. He walks with an antalgic gait, favoring the right leg.

Neurologic Exam

Mental Status. He is awake and oriented to person, place and time. Fund of knowledge and memory appears intact. Speech is clear.

Cranial Nerves. All cranial nerves 1-12 are intact

Motor Exam. Strength, tendon reflexes and range of motion in the upper extremities and the left lower extremity were intact. In the right lower extremity, strength in flexion and extension was 5/5 at the knee with a patellar reflex of 2/4. Strength in plantar flexion and eversion was 2/5 in the right foot, normal in the left. The Achilles tendon reflex was 1/4 to trace in the right. Dorsiflexion of the great toe was 2/5. Minor's sign was present upon rising from a seated position and the patient complained of pain in the right leg at this time.

Sensory Exam. All systems were intact throughout the head and body with the exception of the lower extremity on the right. Reduced sensation to touch and pin-prick was present on the lateral aspect of the calf, lateral aspect of the ankle and lateral aspect of the foot including the fifth digit. Patient complained of an achy feeling in the lateral calf muscle extending to the ankle. His gait was markedly antalgic, favoring the right side and he could not walk on his toes due to his right weakness.

QUESTIONS:

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious ?, Is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. How could the diagnosis be best established in this patient?

10. What is the prognosis for this patient if the disease is left untreated?

11. What types of assistance can be of help for this patient?

▶ Discussion II

Peripheral nervous system lesions: Position along a nerve

Radiculopathy Damage to the dorsal and/or ventral roots as they enter the intervertebral canal, damage that occurs in the intervertebral canal or that occurs at the exit of the intervertebral canal is termed a radiculopathy or root lesion. Radiculopathies characteristically produce pain that refers the peripheral territory of that segment of the spinal cord. Thus a C5 radiculopathy refers typically refers pain in the region of the C5 dermatome, myotome and scleratome. The pain is described as sharp and burning, like lightening or fire and can be positional. Sensory abnormalities, such as sensory loss (anesthesia), may occur in dermatomal bands on the body or extremities. However, due to significant overlap between successive root territories, it may be difficult to find well demarcated bands of sensory loss. A weakness of a flaccid nature can also occur in these patients. The weakness is a paresis and not a paralysis and involves a variety of muscles, not just one muscle. Fasciculations may be present, however their abscence does not rule out radiculopathy.

Plexopathy Damage that occurs to the cervical, brachial or lumbosacral plexus is termed a plexopathy. Penetrating wounds, trauma and inflammation are significant contributors to plexopathies. The sensation of pain is wide spread and not confined to a specific dermatome. The sensory loss is patchy and distributed over a wider territory than that seen in a radiculopathy; this territory also does not match the distribution of any given peripheral nerve. Motor loss can involve a paralysis of a functional group of muscles such as is seen in Erb's and Klumpke's paralysis resulting from upper or lower brachial plexus lesions respectively.

Peripheral Neuropathy Damage that occurs distal to the plexus affects the peripheral nerves. In this setting, isolated muscle paralysis can occur since a given muscle may be innervated by only one nerve. Sensory loss is in a peripheral nerve territory and is often detectable.

Peripheral nervous system lesions: Distribution amongst nerves

Mononeuropathy Mononeuropathy involve isolated or focal damage to one peripheral nerve anywhere in the body. As such, mononeuropathies are most often caused by traumatic injury such as a blow or penetrating wound, expansion of a focal mass occupying lesion such as a tumor, or abscess or compression from a surrounding structure such as a tunnel syndrome (carpal tunnel syndrome or tarsal tunnel syndrome). Damage to a specific root could also be termed a monoradiculopathy.

Acute onset of a mononeuropathy is most suggestive of a compressive lesion such as blunt trauma or a herniated intervertebral disc. Subacute onset of a mononeuropathy can reflect an underlying inflammation or an infection. Finally the insidious onset of a mononeuropathy may result from progressive spinal canal stenosis.

Mononeuropathy multiplex The presence of multiple, isolated mononeuropathies is termed mononeuropathy multiplex. All of the neuropathies may be caused by a common disorder however they are distributed in a multifocal nature about the body and/or head. Typically mononeuropathy multiplex is related to a vasculopathy such as those that occur in the setting of diabetes mellitis or polyartieritis nodosa, however it can also be caused by an infection such as Lyme disease.

Polyneuropathy In general, polyneuropathies occur in the presence of a diffuse disease process that effect all nerves in a region or in regions of the body such as the upper or lower extremities or both. Examples of such processes include autoimmune diseases such as Guillain-Barre disease, toxic processes such as alcoholic neuropathy, chemotherapy-induced neuropathy or lead intoxication neuropathy, metabolic processes porphryia or infectious processes such as leprosy. Symmetric polyneuropathies of insidious onset are suggestive of a degenerative process such as is seen in Charcot-Marie-Tooth syndrome, a congenital, degenerative polyneuropathy. Typically, polyneuropathies affect axons by size class, therefore large, long fiber polyneuropathies present initally with a distal pattern (stocking-glove pattern); only very rarely will the small or short fibers be effected first leading to a proximal initial presentation.

CLINICAL DISCUSSION A example of damage to the peripheral nerveous system involves the entrapment of the spinal roots in an intervertebral foramen generating a monoradiculopathy. Generally there are three different causes of this type of lesion:

1. herniated intervertebral disc
2. hypertrophied facet joint capsule
3. osteophyte encroachment on the canal.

Although the herniated disc is the least common form of monoradiculopathy, it is the most treatable. The nerve root involved depends on the specific disc herniated and the direction in which the disc fragment is herniated. For example, a lateral herniation (rare) of the L4/L5 disc will place the fragment in the intervertebral canal where it can damage the L4 nerve roots (Figure 2-7); a herniation passing backward (also very rare) could damage roots will still in the center of the canal (S1 and below); finally the most common

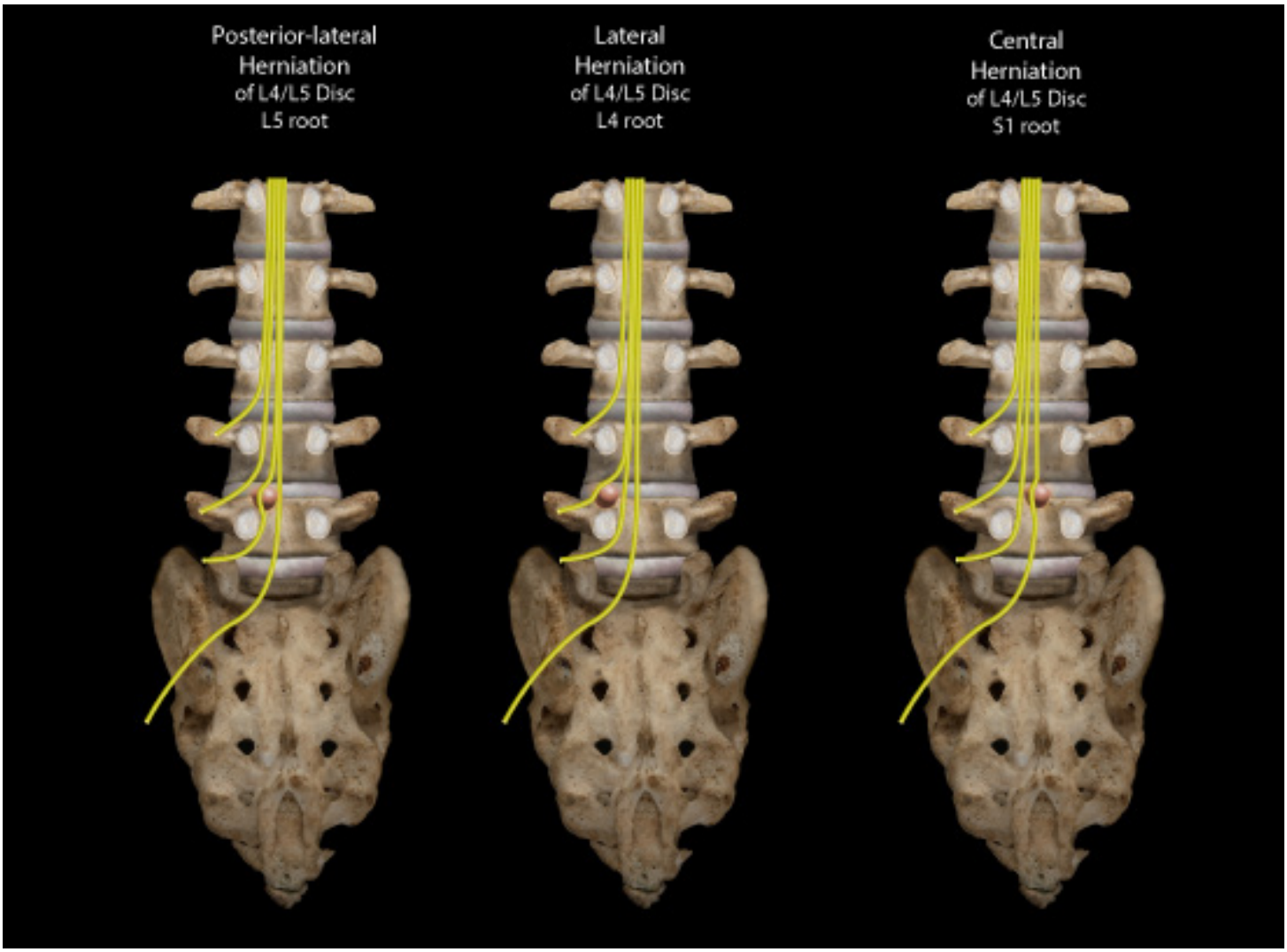


Figure 2-7: These are posterior views of the laminectomized lumbar spine to illustrate the affects of disc herniation. The first view (left) shows the most common form of L4/L5 herniation - posterolateral - leading to compression of the L5 nerve noots. The middle diagram demonstrates a lateral herniation (rare) of the L4/L5 disc leading to an occlusion of the L4 canal and compression of the L4 roots. Finally the diagram on the right represents a centrally positioned hernia (rare) that can compromise S1 or below.

herniation, posterolateral, will place the L4/L5 fragment on the L5 nerve roots.

▶ Summary

The peripheral nervous system begins with the spinal rootlets and progresses distally including the roots, dorsal root ganglia, spinal nerve, and associated plexi and peripheral nerves. Damage to the peripheral system can happen anywhere along this route. Careful examination of the neurologic signs and symptoms can lead to an exact anatomical and neurological diagnosis.

References

Alberstone, C. D. , E. C. Benzel, I. M. Najm, and M. P. Steinmetz. Anatomic basis of neurologic diagnosis, New York:Thieme, 2009.

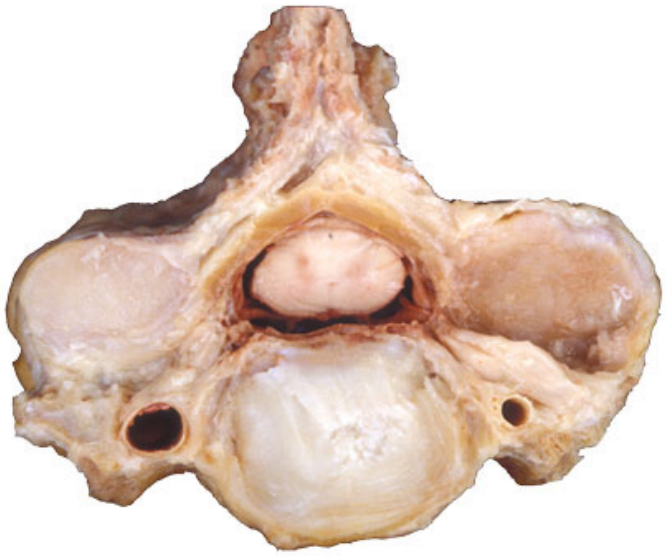
Benarroch, E. E., J. R. Daube, K. D. Flemming, and B. F. Westmoreland. Mayo Clinic Medical Neurosciences, Rochester, MN:Mayo Clinical Scientific Press, 2008.

Brazis, P.W., J. C. Masdeu, and J. Biller. Localization in Clinical Neurology, Boston:Little, Brown and Company, 2007.

Chad, D. A., Disorders of nerve roots and plexuses. In: *Bradley's* Neurology in Clincial Practice, edited by R. B. Daroff, G. M. Fenichel, J. Jankovic, and J. C. Mazziotta, Philadelphia:Elsevier Saunders, 2012, p. 1890-1914.

Katirji, B. and D. Koontz. Disorders of peripheral nerve. In: *Bradley's* Neurology in Clincial Practice, edited by R. B. Daroff, G. M. Fenichel, J. Jankovic, and J. C. Mazziotta, Philadelphia:Elsevier Saunders, 2012, p. 1915-2015.

Chapter 3
The Spinal Cord



▶ INTRODUCTION

The spinal cord represents a caudal extension of the brain stem and lies within the vertebral canal reaching from the foramen magnum at the base of the skull to the L1-2 vertebral level. This elongated portion of the central nervous system functions as a major conduction pathway for motor and sensory information and links the activity of the brain to that of the body. Two different but interconnected levels of neural activity occur in the spinal cord. At each nerve entry/exit zone, or segmental level, neuronal circuitry exists that can mediate spinal reflexes. These reflexes function to withdraw a limb from pain or alter muscle tone in response to shifting gravitational or inertial forces. Yet daily living requires more than simple reflexes; consequently, suprasegmental systems arising in the brainstem and cerebral cortex and extending into the spinal cord control these more complex activities.

The suprasegmental systems involve ascending connections from each of the spinal segments to the brain stem and thalamus and are relayed ultimately to the cerebral cortex. These ascending connections carry information about activity and position of the body and its surrounding environment. Conversely, descending connections from each of these brainstem and cortical areas return to the spinal cord segments, influencing their output and controlling their intake of sensory information. These reciprocal connections mediate suprasegmental control of the spinal cord and strongly influence the complex activity patterns that characterize our lives.

The division between segmental and suprasegmental levels in spinal cord organization is both a functional and a clinical distinction. Damage to the spinal cord can present as intense pain, sensory loss and weakness. The weakness is characterized by either hypotonia (segmental damage) or hypertonia (suprasegmental damage). Making the distinction between these two clinical presentations can provide important information that can help to identify the locus of damage in a patient.

GENERAL OBJECTIVES

1. To identify cross section profiles of spinal cord taken through the four major vertebral levels
2. To locate, within a given spinal segment, the circuitry of the gray matter
3. To examine and understand the neuronal circuitry under-

lying spinal reflexes (segmental level activity)

4. To learn the major spinal tracts and describe their origin, laterality, termination, and function (supra-segmental activity) and to describe any deficit associated with their lesion (supra-segmental activity)

5. To use the clinical manifestations of a lesion to locate accurately the position, level, and extent of any spinal cord pathology

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study is followed by a list of questions that can be best answered by using knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions is a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer the questions, compile a list of the patient's neurologic signs and symptoms. Then examine the structures and their functions and study their known deficits as presented in the sections entitled CLINICAL DISCUSSIONS. After becoming comfortable with the material, reexamine the list of neurologic signs and symptoms and answer the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human spinal cord and its dural covering

2. Spinal cord histology sections

Chapter Three Topics:

CASE STUDY 3-1

Chief Complaint

This 68-year-old, left-handed, retired businessman is complaining of progressive weakness and atrophy of his extremity musculature.

History of Chief Complaint

He has enjoyed good health up until 9 months prior to the current presentation. At that time the patient had noticed an abnormal weakness in his arms; over the 9-month period since, the weakness has become progressively worse, spreading to his legs. He also commented that his hands had become much thinner than before. Three months prior to his current evaluation, his wife noted a change in his speech; in addition, he began to have difficulty swallowing. Recently, he has experienced difficulty dressing and eating. At present, he no longer feels capable of safely driving the family car.

Family History

He is married, his wife is alive and they have two children, both of whom are no longer residing in the house.

Medical History

Tonsillectomy at age 12 and a hernia repair operation at age 45.

General Physical Examination

He is an awake, oriented, well-hydrated man who appears slightly older than his stated age and of lean habitus. Pharynx was non-reddened and no cervical lymphadenopathy was present. His heart rate was 78 and blood pressure was 125/83; respirations were 18. Peripheral pulses were intact at the wrists and ankles. Abdomen was soft with no masses; normal bowel sounds were present. Extremities were four in number. Significant loss of muscle mass was noticeable in the shoulders, arms, and less so in the legs. Muscle loss was most prominent in the thenar eminence of both hands.

Neurologic Examination

Mental Status. He was awake and oriented for time and place. His fund of knowledge and memory were appropriate for his age. He could recite a list of the last five presidents and accurately follow four-step commands. His speech was slow and his pronunciation of words was slurred; however, speech patterns and content were meaningful. He gave an accurate history.

Cranial Nerves. His visual fields were full and he had a complete range of eye movements. Pupillary reflexes were intact to both direct and consensual light. Facial expressions were intact and bilaterally symmetrical; the corneal, jaw-jerk, and gag reflexes were trace. He reported that touching the corneal surface hurt. His tongue protruded on the midline, but was weak; fasciculations were present on the surface of the tongue. Response to pinprick was intact throughout his face.

Motor Systems. Strength was 3/5 at the shoulder and elbow and 2/5 at the wrist bilaterally; grip strength was 2/5. Strength was 3/5 at the hip, knee and ankle bilaterally. Deep tendon reflexes were elevated at 3/4 around the knees and 4/4 around the ankles. Deep tendon reflexes were depressed at the elbows and wrists (1/4). Significant atrophy was present bilaterally in the forearms and arms and most prominent in the thenar eminences. Widespread fasciculations were noted at rest in all four extremities. The patient was able to rise from a chair and walk only a short distance unassisted. A fine tremor was present in the upper extremities when they were held in the extended and pronated position. The tremor diminished when his arms were lowered into a resting position. He noted that the tremor becomes worse when he is feeling stressed and when he drinks 2-3 cups of coffee. Finger-to-nose and heel-to-shin testing was normal in all extremities. No pronator drift was observed. His bowel and bladder functions were intact.

Sensory Exam. Discriminative touch, vibratory sense, proprioception, and pain and temperature sensation were intact throughout his body.

Follow-Up

Re-examination in six months revealed strength at the shoulder and elbow to be 2/5 and at the wrist 1/5. Grip strength was also 1/5. Strength at the hip was 3/5 and at the knee and ankle 2/5. Deep tendon reflexes remained trace to 1/4 in the upper extremity, 2/4 at the knee and 1/4 at the ankle. He lacked any gag response and complained of frequent episodes of choking when swallowing.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious ?, Is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

▶ DISCUSSION I

Spinal Cord Segmental Organization

Primary Afferent Fibers

The spinal cord receives approximately 32 pairs of spinal nerves. Each spinal nerve innervates the tissue derived from a specific embryological somite. The entry of each nerve root into the cord defines the spinal segment. The area of skin (cutaneous distribution) of each spinal nerve is referred to as a dermatome, the muscles innervated by that nerve constitute a myotome, and the connective tissue structures so innervated belong to the corresponding scleratome. Dermatomes, myotomes, and scleratomes do not necessarily lie in register in the body even though they innervate tissue derived from a common somite. Often, because of migration events in the embryo, considerable distances can separate these three components of a given spinal nerve from one another.

As a spinal nerve approaches the spinal cord, it passes through an intervertebral foramen. Within the foramen, the nerve divides into dorsal (sensory) and ventral (motor) roots (Figure 3-1). At the point of this division, the dorsal root contains the dorsal root ganglion. This ganglion contains the cell bodies of the sensory neurons or primary afferent neurons. The peripheral process of the sensory neuron courses in the spinal nerve to reach skin, muscle, bone, joint, or viscera, while the central process of the sensory neuron runs in the dorsal root to enter the spinal cord. Once inside the spinal cord, the central process of the sensory neuron can either form synaptic endings in the gray matter or enter the white matter and ascend to higher spinal levels.

Primary afferent (sensory) fibers are classified based on their size, degree of myelination, and the type of ending present in the periphery. Each nerve in the body contains many different primary afferent fibers. The features used in classification of the sensory neuron are related to its function (Table 2-1). An easy-to-remember classification of primary afferent fibers simply divides them into two groups: the big fibers – groups I and II, with heavy myelination and fast conduction velocities, and the small fibers – groups III and IV, with little to no myelination and slow conduction velocities. This latter classification scheme is the most useful in clinical situations since the tests done in the neurologic exam can usually distinguish between functional losses in the big versus small fiber systems, but do not easily distinguish fiber types (e.g., group I from group II or group III from group IV).

Central Spinal Cord Organization

Within each spinal segment, the cord is composed of an inner column of gray matter containing nerve cell bodies, surrounded by an outer sheath of white matter composed of neuronal processes. A cross section (taken transverse to its long axis) of a fresh spinal cord preparation reveals a gray, H-shaped area at the center (Plates 1 to 4), which extends the entire length of the cord. The dorsal portion of the "H" or dorsal horn is involved with processing the sensations of pain, temperature, and light touch, as well as visceral sensory information. The ventral portion of the "H" or ventral horn is involved in the motor system, containing the neurons that innervate skeletal muscle. Between the dorsal and ventral horns is an intermediate zone composed of interneurons linking the sensory, suprasegmental, and motor systems together. In between spinal cord segments T1 and L2-3, a lateral horn of the gray matter can

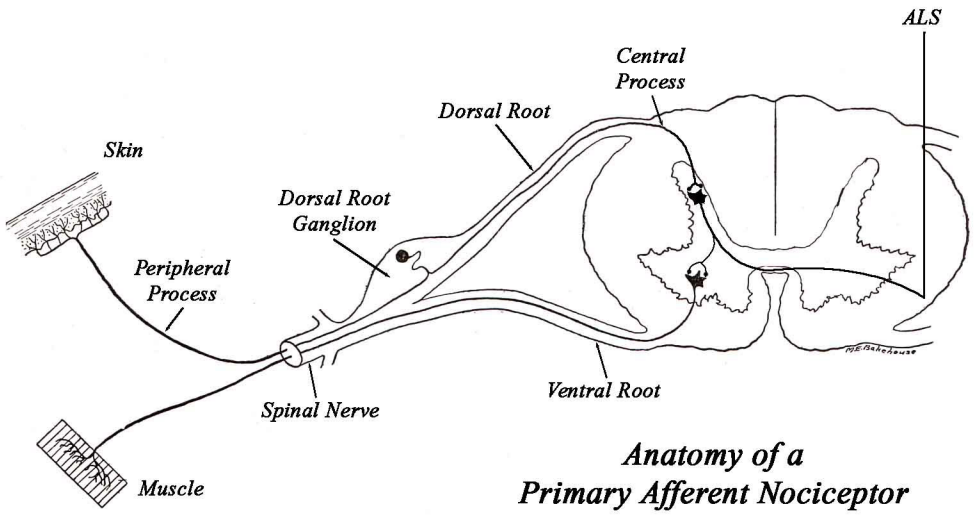


Figure 3-1. Segmental level of the spinal cord. The sensory neuron has its cell body in the dorsal root ganglion and its central process terminates on a neuron in the dorsal horn of the spinal cord. The dorsal horn neuron has an axon that contributes to the anterolateral tract and has collateral fbers to the ventral horn. The ventral horn neuron provides an axon to the peripheral nerve, eventualluy innervating a skeletal muscle.

be seen; it is involved with the sympathetic outflow from the autonomic nervous system.

In the older literature, the spinal gray matter was described as containing discrete clusters of neurons called nuclei; however, in the midcentury this structure was divided into several distinct layers or laminae (Rexed, 1952). Each lamina represents a slab of neurons and fibers that, in most cases, extends the full length of the spinal cord (Figure 3-2 through Figure 3-4). In general, the individual laminae of spinal gray matter have a unique cellular and chemical composition, establish differential connections, and serve differing functions (Schoenen, 1991;Schoenen and Faull, 1990a;-Schoenen and Faull, 1990b).

Table 3-1 The characteristics of axons (fibers) found in a peripheral nerve

Fiber Type	Fiber Size	Conduction Velocity	Myelination
Aα or Group I	12-20 μ	70-120 m/sec	Very heavily
Aβ or Group II	6-12 μ	35-75 m/sec	Heavily
Aδ or Group III	1-5 μ	5-30 m/sec	Lighly
C or Group IV	0.2-1.5 μ	0.5-2 m/sec	No

LAMINA I

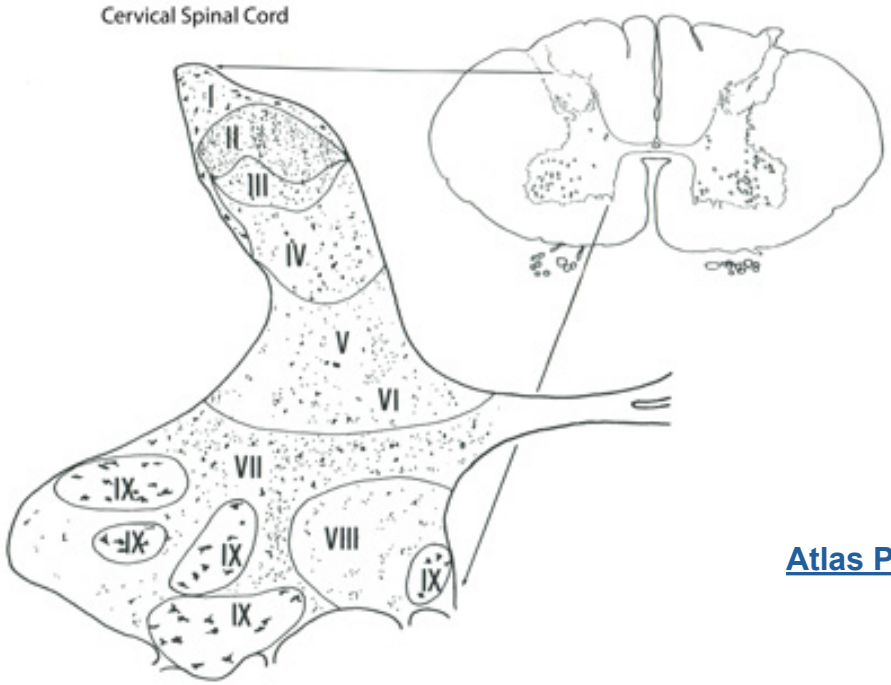
The first lamina forms a thin cap perched on the apex of the dorsal horn. It was referred to previously as the posterior marginal nucleus (Figure 3-2 through Figure 3-4). Cells in lamina I receive synapses from small, unmyelinated cutaneous primary afferent fibers carrying the sensations of prickling pain, tickling, and coolness. Axons from some lamina I neurons cross to the contralateral side of the spinal cord and ascend to the brain stem and thalamus. These crossed fibers contribute to the perception of painful stimuli, particularly the fast pain of an acute injury.

LAMINAE II AND III

The second lamina contains a dense population of small neurons (Figure 3-2 through Figure 3-4); while lamina III contains larger neurons. Small, unmyelinated, primary afferent fibers carrying sensations of burning pain, itch, and warming from cutaneous receptors terminate in laminae II and III. (Lamina II corresponds to the substantia gelatinosa of older terminology.) This type of afferent information is called nociception. Axons from neurons in these two laminae innervate surrounding neurons or exit the dorsal horn and travel up or down the spinal cord for several segments in a thin band of fibers, the propriospinal tract, which surrounds the spinal gray matter (Plates 1 to 4). In general, the neurons of laminae II and III do not project axons out of the spinal cord, contributing instead to the integration of multiple segments.

LAMINA IV

Laminae III and IV correspond to the nucleus proprius of older terminology (Figure 3-2 through Figure 3-4). The afferent fibers to this region are mostly of the large-caliber type, carrying low-threshold stimuli referred to as light touch. Axons from some



Atlas Plate 4

Figure 3-2. Gray matter of the cervical spinal cord. The dots indicate the relative size and distribution of neurons within the laminae.

of these neurons cross to the contralateral side of the spinal cord and ascend to the brain stem and thalamus.

LAMINAE V AND VI

Laminae V and VI are positioned at the ventral portion of the dorsal horn (Figure 3-2 through Figure 3-4). Afferent fibers to these laminae arise from peripheral cutaneous and visceral sources as well as from descending fiber systems, such as the corticospinal and rubrospinal tracts. Some of the large-caliber primary afferent fibers from muscles, entering the cord in the dorsal roots, end by projecting into lamina VI; thus, this region receives a mixture of sensory information. Of note, convergence of somatic and visceral input onto individual lamina V cells has been documented. Cells in this lamina contribute to the phenomenon of referred pain. Axons from cells in laminae V and VI cross to the contralateral side of the spinal cord and ascend in the anterolateral system to reach the brain stem and thalamus. Lamina VI is present only in the enlargements of the spinal cord. Therefore, it is absent from segments T4 to L2.

LAMINA VII

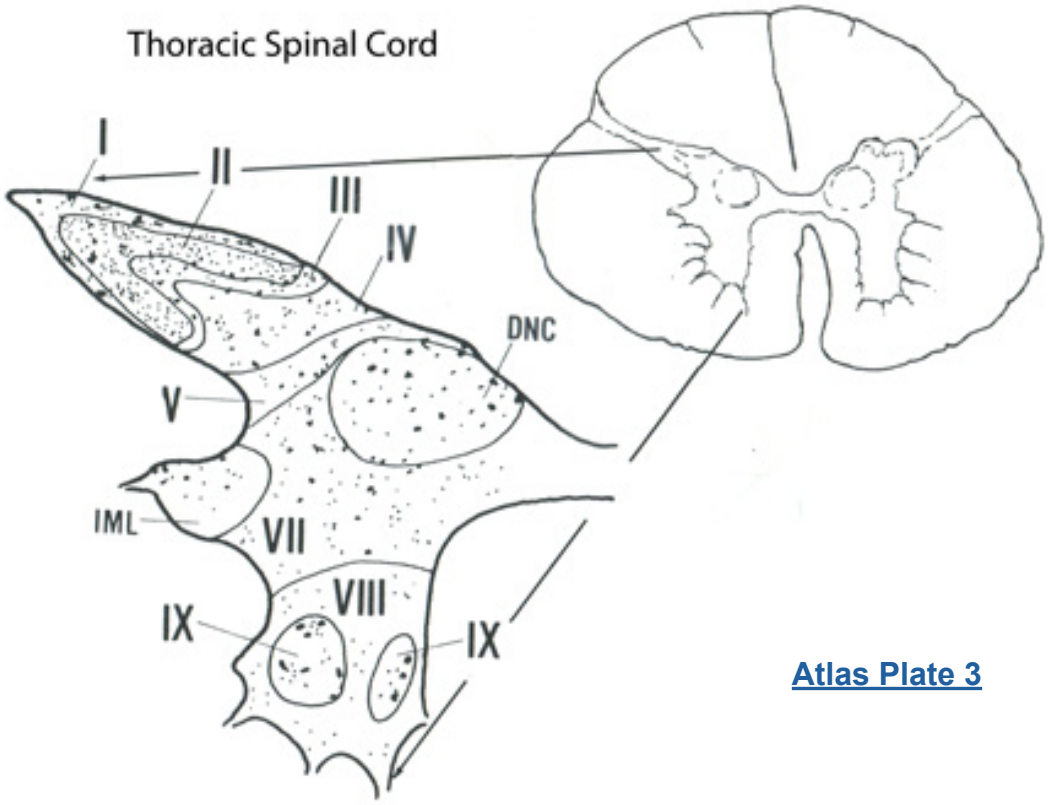
The seventh lamina receives large-caliber, myelinated primary afferent fibers that originate in the encapsulated receptors of skeletal muscle and tendon. Its neurons have axons that innervate motoneuron cell columns of lamina IX. In addition, several regions of lamina VII are differentiated into specific cell clusters: the dorsal nucleus of Clarke (Figure 3-3) and the intermediolateral nucleus.

The dorsal nucleus of Clarke is located in the medial aspect of lamina VII, at the ventromedial base of the dorsal horn of spinal segments C8-L3 (Plate 3 and Figure 3-3). It receives large caliber, myelinated, primary afferent fibers from muscle spindle receptors. The large neurons in Clarke's nucleus give rise to axons that ascend in the dorsal spinocerebellar tract (Plates 3 and 4) to reach the ipsilateral cerebellum. These fibers carry information concerning the positioning of limb muscles (proprioception).

The nucleus intermediolateralis is found in a lateral protuberance off of lamina VII, called the lateral horn (Figure 3-3). This region is present in spinal segments T1 to L2-3 and S2 to S4. These lateral areas receive information both from visceral and somatic primary afferent fibers and from descending fibers from the hypothalamus and brain stem. Preganglionic neurons of the sympathetic nervous system (T1 to L2-3) and parasympathetic nervous system (S2 to S4) are contained within the lateral horn.

LAMINA VIII

Lamina VIII surrounds the ventromedial motoneuron column of lamina IX (Figure 3-2 through Figure 3-4). Its afferent fibers are derived from descending systems originating in the cerebral cortex, vestibular nuclei, and reticular formation of the brain stem. Lamina VIII interneurons function to integrate activity in the me-



Atlas Plate 3

Figure 3-3. Gray matter of the thoracic spinal cord segments. Note the presence of a laterally positioned intermediolateral lamina (IML) containing components of the autonomic nervous system and the medially positioned large dorsal nucleus of Clarke (DNC) .

dial columns of motoneurons, controlling the axial musculature.

LAMINA IX

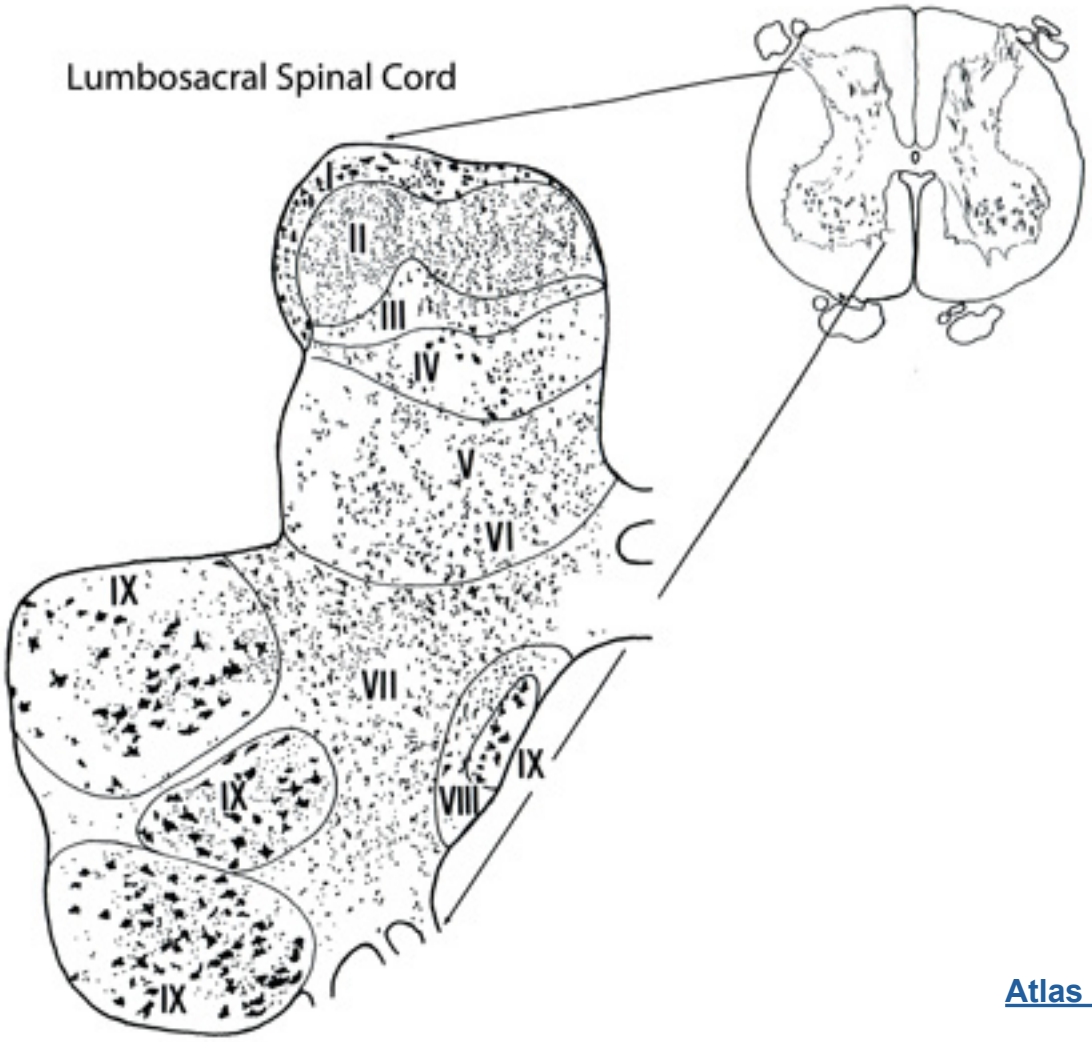
The columns of motoneurons in the ventral horn constitute lamina IX (Figure 3-2 through Figure 3-4). Several prominent cell columns are identified by their position in the ventral horn.

Dorsolateral Motor Columns

The dorsolateral motor columns occupy the dorsal and lateral portions of the ventral horn and contain alpha and gamma motoneurons. These cells have axons that travel in peripheral nerves to innervate appendicular muscles. Large, myelinated, primary afferent fibers from muscle spindles form synaptic endings on the motoneurons. The monosynaptic connections that are established between the primary afferent fibers and the ventral horn motoneurons mediate the myotactic reflex. Other inputs to the dorsolateral column of motoneurons include the corticospinal tract and the medullary reticulospinal tract. The motoneuron columns are arranged in a topographic fashion with those neurons innervating proximal limb musculature located medially, and those innervating distal limb musculature situated laterally. Columns innervating flexor muscles are found dorsally; those innervating extensor muscles are located more ventrally in the ventral horn.

Ventromedial Motor Columns

The ventromedial motor column occupies the ventral and medial portion of the ventral horn. It contains alpha and gamma motoneurons whose axons innervate axial (truncal) musculature. Inputs to this column of motoneurons are complex; it receives descending projections from the corticospinal, vestibulo-spinal, and pontine reticulospinal tracts. Coordination with other regions of the spinal cord is accomplished through its connections with the propriospinal tract. Feedback from the muscles (proprioception) is obtained



Atlas Plate 2

Figure 3-4. Gray matter of the lumbosacral spinal cord segments. The lateral aspect of the ventral horn has exapnded, similar to that seen in the cervical spinal cord, to accomodate the motoneurons innervation the lower extremity.

through large-caliber primary afferent fibers (Table 3-1). Much of this input does not reach lamina IX directly, but is filtered instead through the interneurons of lamina VIII.

CLINICAL DISCUSSION: Damage to the dorsal horn or its efferent projections, which can occur with occlusion of the central branch of the anterior spinal artery (see section on spinal vasculature), will result in the loss of pinprick and temperature sensation over the affected body dermatomes, a condition termed analgesia. Damage to the ventral horn, which occurs in occlusion of the anterior spinal artery or in motoneuron disease, can result in the loss of the ventral horn motoneurons. Death of the motoneurons denervates the skeletal muscle related to that spinal segment. Since the nerve terminal normally provides a trophic substance(s) to the muscle, denervated skeletal muscle becomes flaccid and atrophies. Clinically, flaccid weakness presents as weakness, muscle wasting, and fasciculations. Affected muscles do not resist passive stretch and have diminished deep tendon reflexes, or hyporeflexia.

Dorsal Root Entry Zone

Located between the end of the dorsal root and the apex of the dorsal horn is a complex area termed the dorsal root entry zone. It can be partitioned into lateral and medial divisions based on a segregation of primary afferent fiber sizes in the dorsal roots (Figure 3-9). The medial division contains large, myelinated fibers (groups I and II; see Table 3-1) carrying precise sensory information concerning body (muscle and joint) position and discriminatory touch from the dermis. The lateral division contains small myelinated (group III) and unmyelinated (group IV) fibers that carry information concerning light touch, thermal sense, pain (nociception), and visceral sensations. Due to this segregation of primary afferent fibers in the dorsal root entry zone, nociception, light touch, and thermal senses are conducted into the dorsal horn, whereas proprioception and the discriminative senses are diverted medially around the apex of the dorsal horn. These large fibers can (1) enter the dorsal columns to ascend the length of the spinal cord, (2) enter the base of the dorsal horn where they can innervate the dorsal horn neurons, or (3) continue into the ventral horn where they participate in segmental reflex arcs.

CLINICAL DISCUSSION: The presentation of pain is common when pathology affects the spinal cord or its roots and spinal nerves. Often the quality of the pain and its distribution can reveal its origin. Several different pain presentations have been defined (Biller and Brazis, 1996). Radicular pain is described as usually unilateral and dermatomal in its distribution; its quality is lancinating or shooting, sharp pain. This type of pain, typical of extradural (outside the spinal cord) lesions, can be caused by pressure on the nerve root or spinal nerve in and around the intervertebral foramen. Surgical lesions of the dorsal root entry zone have been used to treat intractable pain of peripheral origin (Friedman and Nashold, 1986). As such, the lesion interrupts the small-caliber primary afferent fibers as they enter the dorsal horn, thus preventing the transmission of nociceptive information to the spinal cord from that specific spinal nerve. Funicular (central) pain is described as a deep, poorly defined painful experience, not related directly to the distribution of any spinal nerves; it is more characteristic of intramedullary (inside the spinal cord) lesions. Surgical lesions of the spinal cord, termed cordotomies, have been used in the past to treat intractable pain of central and peripheral origin (Gybels and Tasker, 1999). Both types of pain – radicular and funicular – involve damage to the nervous system and, as such, are termed collectively as neuropathic pain. This form of pain is the most difficult to treat clinically since it is often refractory to most pharmaceuticals.

Neuropathic pain is to be distinguished from pain that arises due to damage focused on non-neural structures. For example, straining ligaments or muscles of the vertebral column or damaging the vertebral facet joints also presents with pain, however this can occur without necessarily damaging a spinal nerve or root or the spinal cord itself. In this case the pain typically is non-radiating in nature. This type of pain is referred to as axial pain and is the most common source of back pain.

Highlight Point

The clinical signs of ventral horn or ventral root damage include:

Weakness

Hypotonicity

Hyporeflexia

Muscle wasting

Fasciculations

Loss of resistance of passive range of motion

Regional Variation in Spinal Cord Architecture

The spinal cord represents an elongated column of nuclear masses surrounded by thick fiber tracts. Based on the changing size of the nuclear masses and the addition and subtraction of fibers, there is significant regional variation along the entire length of the spinal cord. In this section we will consider the general features of that variation.

Lumbosacral segments

TThe lower lumbar segments (L4 and L5) of the spinal cord combine with the upper sacral segments (S1-S3) to form the lumbosacral enlargement. Plate 01 is taken through the sacral spinal cord in the upper segments. These segments are characterized by the thin columns of surrounding white matter and the expanded lateral portion of the ventral horn (representing the lower extremity) and the enlargement of the substantial gelatinosa in the dorsal horn. The gray commissure is thick and very short compared to the higher segments of the spinal cord. The lower

lumbar segments appear much the same as those in the upper sacral cord except that both the nuclear masses (gray matter) and the white matter columns are significantly thicker. Lacking the spinocerebellar tracts at this level, the corticospinal tract lies on the lateral surface of the cord. The higher lumbar segments feature a reduction in the size of the nuclear masses with an increase in the thickness of the surrounding white matter. Both L1 and L2 will also contain a small lateral horn containing preganglionic sympathetic neurons and located between the dorsal and ventral horns.

Thoracic segments

Ascending from T12 to T1 the white matter surrounding the spinal cord continues to enlarge in size. Against this background, the gray matter diminishes significantly in thickness in the thoracic region reflecting the diminished sensitivity of the torso to somatic stimuli and the reduced amount of muscle in the torso compared to that of an extremity. The lateral enlargements of the ventral horn disappear leaving only the medial portion of the horn, an area that represents the axial muscles of the body. The ventral horn of the lower thoracic segments is slightly thicker, on average, than that of the upper segments, this accounts of the increased number of motoneurons needed to innervated the thick abdominal muscles compared to the much thinner intercostal muscles. In the dorsal horn the substantia gelatinosa becomes thin and elongated. At the base of the dorsal, the dorsal nucleus of Clarke forms a large, rounded nuclear mass throughout most of the thoracic segments. Small but prominent lateral horns are typically seen at all thoracic levels.

Cervical segments

Cervical spinal cord segments are large and oval in profile with massive amounts of white matter tracts surrounding the enlarged dorsal and ventral horns. The ventral horn features a lateral enlargement to house the motoneurons for the upper extremity muscles. Although the dorsal horns are not as broad as those seen in the lumbar region, that as substantially enlarge and feature an irregular lateral border, termed the reticular process, that extends into the surrounding white matter. A notable feature of the massively enlarged dorsal column system is the presence of a posterior median septum dividing the columns into two fascicli, gracilis and cuneatus.

Case Study 3-2

Chief Complaint

A 27-year-old right-handed machinist was brought by ambulance to the emergency room after suffering a knife wound in the back. He was conscious but somewhat intoxicated. A penetrating wound was present on his back, slightly off the midline and opposite the superior border of the right scapula.

History of Chief Complaint

He had been involved in an altercation in a local tavern. The knife wound was received at 1:35am, after an evening spent watching a national sports event and consuming alcoholic beverages.

Family History

He is single and lives in an apartment. He has two brothers and a sister. His mother and father are divorced.

Physical Examination

This is a stable male patient with a penetrating wound on his right back that entered the spinal column. It is located on the right and approximately one inch above and medial to the spine of the scapula. The patient is an awake, intoxicated male. He is large, muscular, well nourished, well hydrated, and appears his stated age. Blood pressure, heart rate, and respirations were slightly elevated; peripheral pulses were intact at the wrists and ankles.

Neurologic Examination

Mental Status. He was awake but somewhat intoxicated. Affect is agitated and bellicose; problems with cooperation occured. Speech was slurred and rambling; however, no word substitution or word confusion was present. Memory and knowledge could not be tested adequately because of his level of intoxication.

Cranial Nerves. A full range of eye movements was present. Visual fields were full to confrontation. Hearing was normal bilaterally. Pupillary, gag, and corneal reflexes were intact; facial movements were full; uvula and tongue were midline.

Motor Systems. There is a proximal-to-distal, graded diminution of strength in the upper extremity on the right. Power was 4/5 for shoulder elevation, 3/5 for the forearm flexors and extensors, 1/5 for the flexors and extensors of the wrist and in the fingers. Grip strength was abolished completely. All strength was absent in the right lower extremity. Deep tendon reflexes were depressed about the elbow (1/4) and absent about the wrist and in the digits as well as throughout the lower extremity (0/4).

Sensory Systems. Complete loss of sensation for pinprick and temperature was found over the left trunk below C8 and in the left lower extremity. Loss of discriminative touch and vibratory sense was found over the right half of the body below and including C8.

Follow-up

Two weeks later a neurologic examination revealed no change in the distribution of sensory loss. Strength remained diminished in the forearm, hand, and complete lower extremity on the right, and deep tendon reflexes around the right elbow remained diminished at 1/4. However, the following changes had occurred: deep tendon reflexes were elevated at the wrist, finger, knee, and ankle on the right side (approximately 3/4). A positive Babinski sign could be elicited from the right foot.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, and is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

Case Study 3-3

Chief Complaint
A 36-year-old man is referred for evaluation by his family physician. He is presenting with progressing weakness and sensory loss in the upper and lower extremities and with recent onset of dyspnea.

History of the Chief Complaint
He first noticed a mild weakness and loss of sensation to temperature in the upper extremities 12 months previously; the onset of weakness in the lower extremities has occurred in the past 4 months. He states that both the weakness and the sensory loss have progressively worsened. He has noticed the onset of shortness of breath in the last month.

Medical History
He had enjoyed good health until 18 months ago when he suffered a road traffic accident. While stopped at an intersection he was struck from behind by a driver who was talking on a cell phone. He received a whiplash cervical injury. Following the accident, a neurological exam was within normal limits, however he complained of persistent headache as well as neck and arm pain. He wore a cervical collar for two months following the accident and still experiences neck pain and paraspinal muscle spasms for which he is taking medication. He has no history of blood transfusions, denies IV drug abuse, and has not been out of the country except for an occasional trip to Canada. He denies any recent history of noticeable viral or bacterial infections. He denies any history of respiratory tract illnesses. He denies any change in weight or appetite.

Medications
Voltarin to relieve the neck pain and Flexeril for the paraspinal muscle spasms.

Social History
He is a faculty member at a small liberal arts college, has never married, and lives alone. He does not smoke or consume alcohol and denies any sexual activity.

Family History
His mother and father are still alive and in good health. He has no siblings.

General Physical Examination
This is an awake, oriented male, appearing older than his stated age and with noticeable muscle wasting in the upper extremities. His heart rate is 90, blood pressure is 127/85, temperature is 98.7°F, and respirations are 19. His weight is 181 lbs. During respiratory movements his sternum moves anteriorly, but little lateral motion occurs along the sub-

costal margins. On inhalation, his sternocleidomastoid muscle becomes prominent. Respiratory movements are rapid but of short duration. His skin is moist and supple. His chest is clear to auscultation and abdomen is soft to palpation with no tenderness. No lymphadenopathy is detected in the axilla or groin area.

Neurologic Examination

Mental Status. He is awake, oriented for person, place and time, and has an appropriate memory and knowledge base. Speech is clear and meaningful. He can follow three- and four-step commands, but is hampered by his weakness.

Cranial Nerves. A full range of eye movements is present; visual acuity is 30/20 in the right eye and 40/20 in the left eye without glasses. Pupillary reflexes are present to direct and consensual light. Hearing is intact to finger rub at both ears. Gag and corneal reflexes are intact and facial movements are full. The uvula is symmetric and the tongue protrudes on the midline.

Motor Systems. Strength in the upper right extremity is 4/5 at the deltoid, 3/5 at the triceps, 3/5 at the biceps, and 2/5 at the brachioradialis; grip strength is 3/5. In the left upper extremity strength is 4/5 at the deltoid, 3/5 at the triceps, 2/5 at the biceps, and 2/5 at the brachioradialis; grip strength is 4/5. The lower extremity strength exam finds the quadriceps at 3/5, the gastroc at 3/5 and anterior tibialis at 4/5 on the right. On the left, the quadriceps is 2/5, the gastroc is 3/5 and anterior tibialis is 4/5. Both upper extremities have diminished deep tendon reflexes at the elbow and wrist; muscular fasciculations and atrophy are present bilaterally. Both lower extremities have elevated deep tendon reflexes, and the plantar reflex is extensor bilaterally.

Sensory Exam. Patient lacks sensation to temperature and pinprick in a cape-like distribution over the chest and shoulders, extending throughout the upper extremities to the fingertips. Vibratory sense, discriminative touch, and proprioception were intact throughout his chest and upper extremities. Normal sensation was found elsewhere over the body.

Follow-up

Examination in three months finds analgesia spreading onto his chest wall as low as T3; the weakness in his extremities has increased, with notable loss of deep tendon reflexes in the upper extremity and increased deep tendon reflexes in the lower extremity. No change in mental status is noted.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious; is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likeley involved with the lesion in this patient

▶ DISCUSSION II

Spinal Cord Suprasegmental Organization

The white matter of the spinal cord is partitioned into three large divisions called dorsal, lateral, and ventral funiculi. Each funiculus is further divided into several smaller bundles, called fasciculi. Individual fasciculi are composed of fiber tracts containing ascending or descending axons. Ascending fiber tracts have their cell bodies of origin in the spinal gray or dorsal root ganglia and project their axons up the spinal cord toward the brain stem and thalamus. Conversely, descending fiber tracts have cell bodies in the cerebral cortex or brainstem and project their axons down the spinal cord. Somatic and visceral sensory information passes from the segmental level of the spinal cord to the brain through the ascending fiber tracts. Conversely, motor and sensory control information from the cerebral cortex and brain stem is carried downward in the descending fiber tracts. Within a given fiber tract, the axons tend to share a common function, such as conducting sensory information of a similar modality or specific aspect of the motor control signals.

Axons within a tract are often arranged in an orderly fashion, such that those carrying information from the distal end of the extremities are found on one border of the tract, and those involved with the proximal end of the extremity course along the opposite border. This general organization is called topography or, when referring specifically to the somatic sensory system, somatotopy. Arranging axons in an orderly topographic fashion helps the nervous system maintain fidelity in its sensory and motor pathways. Interruption of portions of either sensory or motor tracts within the spinal cord results in neurologic signs and symptoms localized to a specific region of the body; understanding the somatotopic maps can help predict the extent to which the central nervous system has been damaged by a lesion.

DORSAL FUNICULUS

Fasciculus Gracilis and Cuneatus (Ascending)

The axons in the fasciculus gracilis are said to carry proprioception, two-point discrimination, and vibratory sensation from the lower extremity to the brain stem for relay into the somatic sensory portions of the thalamus and cerebral cortex. The cell bodies for axons in the fasciculus gracilis are located in the dorsal root ganglia of vertebral levels T6 and below (Figure 3-5). The tract begins in the sacral cord (PLATE 1) and ascends to the caudal medulla (PLATES 2 to 4), where it terminates in the ipsilateral nucleus gracilis. In a similar organization, axons of the fasciculus cuneatus carry information concerning two-point discrimination, vibratory sense, and proprioception from the upper extremity. The cell bodies of these fibers are found in dorsal root ganglia above T6 (Figure 2-5). The tract first appears as a thin band in the spinal cord at, or slightly above T6, expanding in thickness as it extends rostrally to reach the nucleus cuneatus in the caudal medulla (PLATES 3 to 8).

The two tracts, gracilis and cuneatus, are referred to collectively as the dorsal column system. The cell bodies of neurons giving rise to the axons in the dorsal column system are located in the dorsal root ganglia. Their peripheral processes are composed of Aβ-fibers (Group II fibers) that arise in encapsulated nerve endings in skin, fascia, bone, and muscle.

The axons in fasciculus gracilis and cuneatus are organized in a topographic fashion. The sacral dermatomes, starting with S5, are represented most medially in the fasciculus gracilis. Successive ascending dermatomes are added laterally, such that at the cervicomedullary junction, the C2 dermatome is located at the lateral extreme of the fasciculus cuneatus. The division between gracilis and cuneatus is found at approximately T6. In summary, the somatotopic map of the human dorsal column system is arranged so that the person's feet are presented toward the midline and the arms lie laterally (Smith and Deacon, 1984).

CLINICAL DISCUSSION: Pure lesions of either of the dorsal column tracts will reduce, but not completely eliminate vibratory or position sense in the human. It appears that these modalities are also carried by some of the axons in the adjacent dorsolateral fasciculus and in the anterolateral system (Wall and Noordenbos, 1977;Davidoff, 1989) as well as in the dorsal spinocerebellar tracts (Ross et al., 1978). The clinically demonstrable deficit resulting solely from isolated lesions of the dorsal columns appears to be astereognosis. Thus, tests for stereognosis and graph-esthesia have been proposed as the only appropriate clinical tests of dorsal column system integrity (Wall and Noordenbos, 1977;Bender et al., 1982).

Dorsolateral Fasciculus

The thin band of fibers forming a cap over lamina I represents the zone of Lissauer, or dorsolateral fasciculus (labeled DLatF in PLATES 1 to 4). It contains small and large caliber ascending axons as well as the axons of dorsal horn neurons traveling between segments. These latter fibers are part of the propriospinal system for integrating segmental-level activities. The fasciculus contains a mixture of sensory modalities. The smallest caliber fibers are

Highlight Point

Knowledge of the topography anatomy of a fiber tract can be of assistance in localizing a partial lesion within the spinal cord or brain.

involved in nociception, whereas some of the larger-caliber fibers carry modalities similar to those present in the dorsal columns. It has been proposed, on the basis of lesion studies, that the dorsolateral fasciculus can at least blunt, if not mask, the effects of lesions restricted to the dorsal column system (Wall and Noordenbos, 1977;Davidoff, 1989). At the level of the medulla, the dorsolateral fasciculus becomes the tract of the spinal trigeminal nucleus which is involved in processing nociception from the face (labeled SpTT in PLATE 5).

LATERAL FUNICULUS—SUPERFICIAL

Dorsal and Cuneate Spinocerebellar Tracts (Ascending)

The cerebellum utilizes proprioceptive information from muscles and joints to coordinate sequences of muscle contractions during limb movement. It receives this information from a complex series of tracts called the spinocerebellar system. The sensory information carried in the dorsal spinocerebellar tract informs the cerebellum of the position in space of individual muscles in the lower extremity. This proprioceptive information is gathered from large-caliber, primary afferent fibers that innervate muscle spindles and Golgi tendon organs located in the lower extremity muscles. The cell bodies of origin for this tract are located in the dorsal nucleus of Clarke, which extends from spinal segments L3 to C8 (Figure 3-6 and PLATE 3). Primary afferent fibers entering the spinal cord below L3 ascend to this level in the fasciculus gracilis to reach the caudal border of Clarke's nucleus. Axons from Clarke's neurons gather into the dorsal spinocerebellar tract located in the lateral fasciculus (DSCT in PLATES 3 to 7). In the medulla, these axons join the inferior cerebellar peduncle and ascend into the ipsilateral cerebellum (see PLATES 8 to 14).

Since the nucleus of Clarke does not extend rostral to C8, it cannot receive primary afferent fibers from the upper extremity. Instead, the large caliber, primary afferent axons from these upper spinal levels join the fasciculus cuneatus, where they form the cuneospinocerebellar tract, and course upward to terminate in the lateral cuneate nucleus of the medulla (PLATES 8 and 9) in the caudal brainstem. Axons from the lateral cuneate nucleus enter the inferior cerebellar peduncle, delivering proprioceptive information from the upper extremity to the ipsilateral cerebellum.

Many of the axons in the dorsal spinocerebellar tract send collateral branches to the nucleus Z located in the lower medulla close to the cuneate nucleus. Neurons in this nucleus project their axons to the contralateral thalamus through the medial lemniscus along with those from the cuneate and gracile nuclei. From the thalamus, this proprioceptive information is relayed to the cerebral cortex. Thus, the spinocerebellar projections to the cerebellum provide this structure with proprioceptive information, but because we are not aware of any ongoing neural activity in the cerebellum, this activity is termed unconscious proprioception. Conversely, the collateral branches of the spinocerebellar fibers that innervate nucleus Z and that structure's subsequent projections to thalamus and its relay to the cerebral cortex provide the cerebral cortex with similar proprioceptive information, but since we are aware of this information, it is termed conscious proprioception.

CLINICAL DISCUSSION: Lesions of the spinocerebellar tracts have received little attention in the clinical literature; however, the few that have been reported demonstrate ataxia (Gudesblatt et al., 1987) and loss of vibratory and position sense (Ross et al., 1978) as presenting symptoms. Lesions of the spinocerebellar fibers in the brain stem also contribute to dysmetria, ataxia, and a loss of position sense of the extremities. Based on these and other studies (Wall and Noordenbos, 1977;Ross et al., 1978), it has been speculated that vibratory and position senses are also carried in the spinocerebellar system rather than being completely contained in the dorsal column system. The conduction of vibratory and position sense in both the dorsal column system and the spinocerebellar tracts represents a form of redundancy. Profound ataxia and intense loss of position and vibratory senses are the salient symptoms of combined spinocerebellar and dorsal column degeneration. Such sensory losses are present in syphillis and other degenerative diseases that affect the large-caliber fibers of peripheral nerve and spinal cord. The patient is effectively stripped of somatic proprioceptive information. Although visual cues can combine with vestibular information to mask the deficit created by the loss of these fibers during the day, affected individuals will become unstable and ataxic at night or when asked to close their eyes (Schoene, 1985). This phenomenon is called sensory ataxia and forms the basis of the Rhomberg Test.

Ventral (Anterior) and Rostral Spinocerebellar Tracts (Ascending)

A second component of the spinocerebellar system carries information concerning the activity of local circuit neurons in the gray matter of the spinal cord to the cerebellum. This information reflects the spinal pattern of motor activity and is referred to as the "efference copy" of the spinal motor instructions. The ventral spinocerebellar tract carries this information from the lower extremities, and the rostral spinocerebellar tract carries it from the upper extremities. Thus, the cerebellum receives data concerning where the limb muscles are in space (dorsal and cuneo-spinocerebellar tract) as well as information concerning what these muscles are

Highlight Point:

Cardinal manifestations of dorsal column system injury:

Diminution of vibratory and discriminative touch

Astereognosis

Agraphesthesia

Topography of the dorsal column system:

Feet medially; arms laterally

being told to do (ventral and rostral spinocerebellar tracts). All of these data are used to coordinate muscle activity during limb movement (See Chapter 5).

The cell bodies of origin for the ventral spinocerebellar tract are located in the deeper laminae of the dorsal horn in the lumbar and sacral spinal cord. Their axons cross the midline to form a fasciculus in the ventral and lateral aspect of the spinal cord, medulla, and pons (VSCT on PLATES 3 to 14). In the cervical region this tract is joined by axons from cervical interneurons forming the rostral spinocerebellar tract. In the rostral pons, both spino-cerebellar tracts join the superior cerebellar peduncle to enter the cerebellum (PLATE 15). Upon entering the cerebellum, some of the spinocerebellar fibers cross back to the opposite side; others do not. Thus, the termination of these spino-cerebellar tracts is considered to be bilateral in the cerebellum.

LATERAL FUNICULUS—DEEP

Raphe-Spinal Tract (Descending)

The raphe-spinal system plays a role in the modulation of nociception transmission through the dorsal horn as well as in controlling motor activity in the ventral horn. It also influences the activity of preganglionic neurons in the lateral horn. The cell bodies of origin for the raphe-spinal tract are located along the midline in the caudal portion of the medulla (PLATES 11 to 14). Some of their axons descend into the spinal cord coursing in the dorsolateral fasciculus. In the spinal cord, axons from the raphe nuclei innervate cells in the dorsal, ventral, and lateral horns.

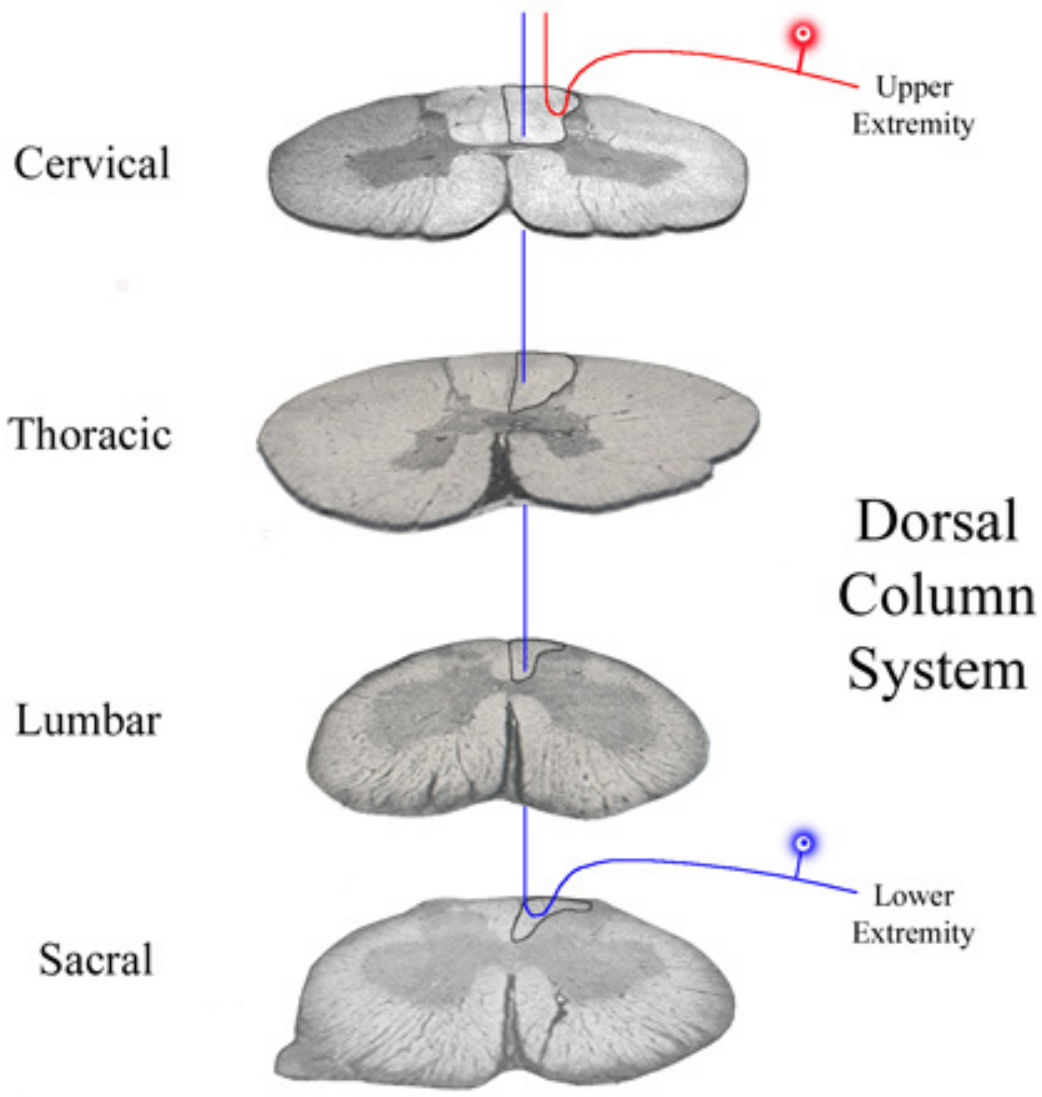


Figure 3-5 Diagram of the dorsal column pathway. (Source: large, primary afferent, group II fibers; Function: discriminative touch, vibratory sense and position sense; Laterality: crosses the midline in the internal arcuate fibers of the caudal medulla.)

CLINICAL DISCUSSION: Information on isolated lesions of the raphe-spinal system in humans is unavailable; however, chemically blocking this system with naloxone in human subjects can decrease their threshold of pain (Basbaum and Fields, 1978).

Lateral Corticospinal Tract (Descending)

The lateral corticospinal tract controls mastery of fine motor movements in the distal extremities (Kennedy, 1990). This descending system contains the axons of pyramidal neurons located in the precentral gyrus of the cerebral cortex and to a lesser extent, the postcentral gyrus. Upon reaching the caudal medulla in the pyramidal tract, these axons cross the midline in the pyramidal decussation and shift laterally in the brainstem to form the lateral corticospinal tract (Figure 3-7 and PLATES 4 to 6). Since it has crossed the midline at the cervicomedullary junction, axons of corticospinal tract terminate in the ventral horn, contralateral to their cell bodies located in the cerebral cortex.

The corticospinal neurons are part of a complex array of descending projections controlling the ventral horn motoneurons of the spinal cord. Collectively cells in these descending systems are referred to as upper motoneurons, thus distinguishing them from the lower motoneurons located in the ventral horn. Upper motoneurons represent the suprasegmental level of control and, by definition, innervate lower motoneurons (or their surrounding interneurons). Lower motoneurons represent the segmental level of control. They directly innervate skeletal muscle through the neuromuscular junction. The distinction between upper and lower motoneuron is of clinical significance in localizing damage on the neuraxis and requires careful study (See Chapter 2).

CLINICAL DISCUSSION: The clinical results of damaged corticospinal fibers in the human spinal cord have been the subject of controversy. Lesions restricted to the primary motor cortex, the origin of the corticospinal system, in nonhuman primates have resulted in a flaccid paresis of the affected limbs with no accompanying spasticity (Lawrence and Kuypers, 1968a) and the corticospinal role, if any, in the genesis of spasticity has been questioned (Da-

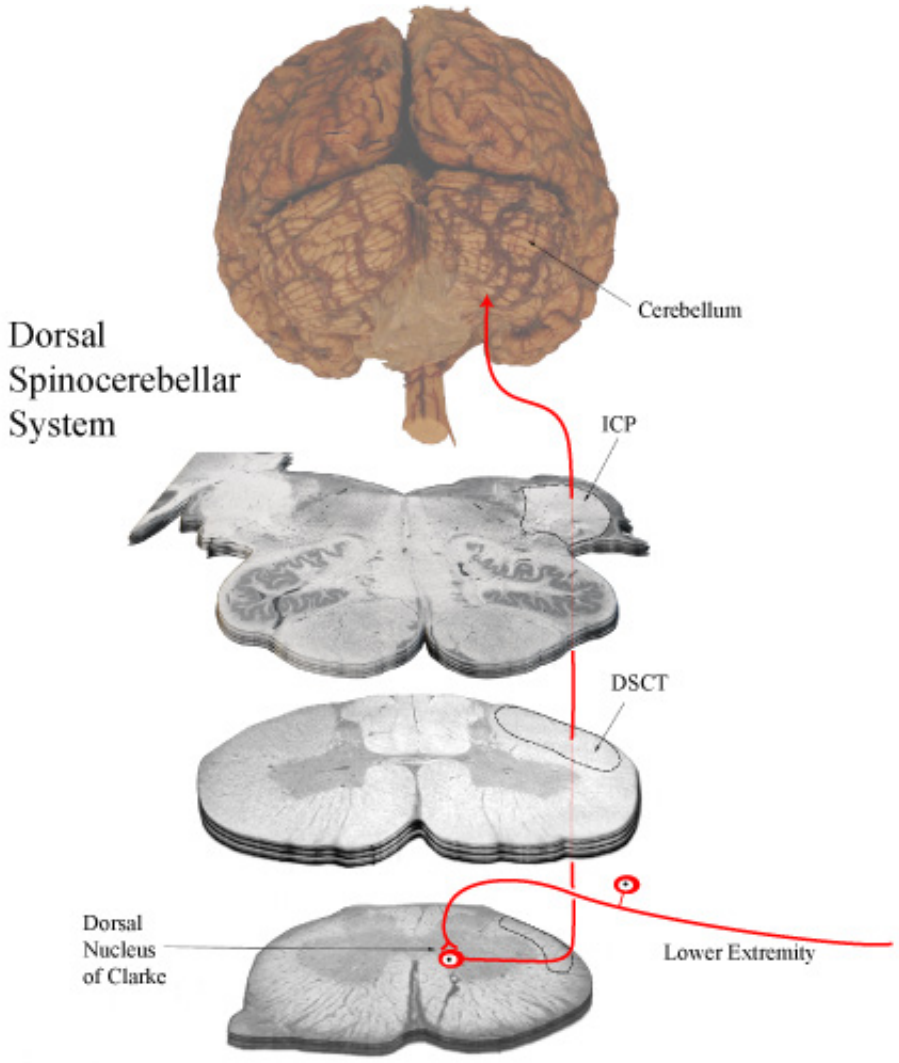


Figure 3-6. Diagram of the dorsal spinocerebellar tract. (Source: large, primary afferent, group I fibers; Function: proprioception; Laterality: uncrossed.)

vidoff, 1990). However, recent reports of seemingly isolated lesions of the human pyramidal tract in the medulla, involving destruction of axons in the lateral corticospinal tract, have demonstrated ipsilateral spastic paresis (Paulson et al., 1986;Jagiella and Sung, 1989); suggesting that the corticospinal tract in humans has more control over the spinal cord than that seen in non-human primates.

Clinically, spasticity is defined as decreased dexterity, loss of strength, increased deep tendon reflexes, increased resistance to slow passive muscle stretch, and hyperactive flexor spasms (Landau, 1980). The intense spastic paralysis that follows severe brain stem or high spinal cord transection involves destruction of not only the corticospinal fibers, but the other descending motor systems as well.

A complex pattern of suprasegmental and segmental-level motoneuron degeneration can occur in diseases such as amyotrophic lateral sclerosis (see Case Study 3-1). Typically, the loss of ventral horn cells initially strikes heaviest in the cervical enlargement, with only mild loss occurring in the lumbosacral region during the early stages of the disease. Meanwhile, a broader spectrum of corticospinal fiber loss occurs that involves those fibers to both upper and lower extremities. Consequently, the lower extremities initially present with signs of spacticity: elevated tendon reflexes and a feel of stiffness; however, these signs of suprasegmental level involvement are masked in the upper extremities, where ventral horn cell loss results in decreased tendon reflexes and flaccid paralysis. Since motoneurons are dying throughout the ventral horns at all levels, there are fasciculations present throughout all the skeletal musculature of the body. This disease process does not affect sensory neurons or autonomic neurons, thus the sensory modalities are intact throughout the body. In summary, flaccidity in the upper extremities, spasticity in the lower extremities with fasciculations present throughout the body and no sensory changes is considered pathognomonic for motor neuron disease or amyotrophic lateral sclerosis.

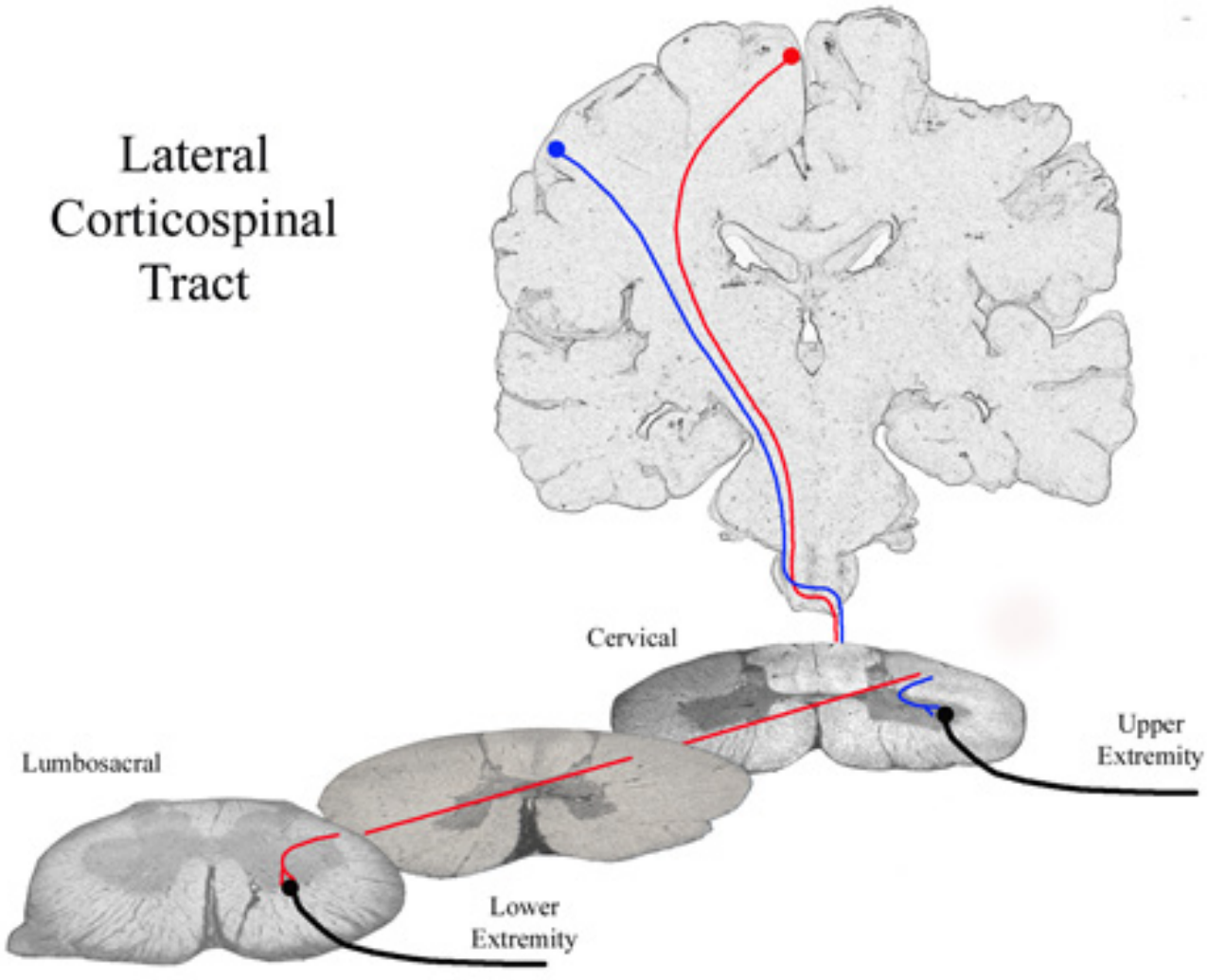


Figure 3-7. Diagram of the lateral corticospinal tract. (Source: cerebral cortex; Function: volitional movements of the extremities and fine movements of the distal extremities; Laterality: crosses the midline in the spinomedullary junction in the decussation of the pyramidal tract)

Rubrospinal Tract (Descending)

The rubrospinal tract regulates ventral horn motoneuron activity, especially that of neurons innervating proximal flexor musculature of the upper extremity. In the spinal cord, this tract courses in close association with the lateral corticospinal tract (PLATES 3 to 5). It has been proposed that the rubrospinal tract is primarily involved in automated movements, whereas the lateral corticospinal tract is involved in the learning and mastering of new movements (Kennedy, 1990).

The rubrospinal tract arises from neurons in the red nucleus of the midbrain (PLATE 20). Axons from these neurons cross the midline while still in the midbrain and then de-scend toward the spinal cord in the rubrospinal tract. Most of the axons in the rubrospinal tract terminate in the caudal portions of the brain stem; however, a few of them descend into the cervical spinal cord, where they end in the contralateral gray matter between the dorsal and ventral horn (Nathan and Smith, 1982). Thus, the human rubrospinal tract can directly influence control of musculature in the upper extremity; however, any influence it has over the lower extremity has to be indirect or multisynaptic at best.

CLINICAL DISCUSSION: In terms of clinical signs and symptoms, the loss of the rubrospinal tract in humans is masked in large part by the function of the corticospinal tract. In non-human primates, isolated destruction of the rubrospinal tract results in some proximal limb weakness that eventually resolves (Lawrence and Kuypers, 1968b). Combined lesions of both tracts in non-human primates can result in a more severe weakness and spastic paralysis.

Medullary Reticulospinal Tract (Descending)

The medullary reticulospinal tract is involved in regulating somatic motor activity in the spinal cord. Its cell bodies of origin are located in the reticular formation of the medulla (PLATES 8 to 11), and their axons form a tract that descends along the ventrolateral aspect of the ipsilateral ventral horn (PLATES 1 to 4). At each segment, axons from the medullary reticulospinal tract enter the gray matter and terminate in the lateral aspect of the ventral horn. These axons can have either excitatory or inhibitory influences on motoneurons controlling limb muscles, depending on the particular phase of the locomotion cycle (Martin et al., 1990).

CLINICAL DISCUSSION: Isolated lesions of the medullary reticulospinal tract have not been reported for humans; however, lesions of the spinal cord involving this tract present with increased spasticity. Most likely, the loss of this tract enhances the expression of spasticity by lessening the brain stem control over motoneurons involved in the myotactic reflex.

Anterolateral Tract or System (Ascending)

The anterolateral system (a portion of which is termed the spinothalamic tract) extends from the segmental level of the spinal cord to the brainstem and thalamus. It carries the modalities of crude touch in the anterior portion of the tract and nociception (pain) in the more lateral portions of the tract. The distinction between light and crude touch is poorly made in the neurologic literature and often texts use the two terms synonymously. These modalities of touch sensation are carried in both anterolateral and dorsal column systems. Pain and temperature are carried in the lateral portion of the anterolateral tract. In addition, it most likely carries some fibers with discriminative touch, vibratory sense, and proprioception (Wall and Noordenbos, 1977;Davidoff, 1989). The cell bodies of origin for the anterolateral system are found in laminae I, IV and V of the dorsal horn (Figure 3-8). These tract cells receive information from small caliber, unmyelinated or lightly myelinated primary afferent fibers (Aδ-fibers or Group III fibers and C-fibers or Group IV fibers) carrying the sensory modalities of pain, crude touch, and temperature. Their axons cross the midline in the anterior white commissure at or near the segmental level of origin and join the contralateral anterolateral system to ascend the spinal cord (PLATE 1 to 4). Termination of these axons occurs in the medullary and mesencephalic reticular formation as well as in the thalamus (PLATES 5 to 20).

CLINICAL DISCUSSION: Lesions of the anterolateral system result in diminished sensation to pinprick, touch, and temperature below the segmental level of lesion, a condition termed analgesia. The dermatome where the patient reports sensory diminution is referred to as a sensory level. Because of the overlap in dermatome distribution of primary afferent fibers for this system, the lesion can be one or two segmental levels above the presentation of the sensory level. Surgical lesions of the anterolateral system have been used to relieve intractable pain. Although initially successful, the pain often returns to these unfortunate patients in a matter of weeks or months. The return of pain may be related to the presence of small caliber, primary afferent fibers coursing in other ascending fiber tracts (Briner et al., 1988) such as the dorsal columns and propriospinal system.

Highlight Point:

Cardinal manifestations of **lateral corticospinal tract** damage are:

Weakness with spasticity

Hypertonicity

Hyperreflexia

Velocity-dependent resistance
to passive range of motion

Topography of the Lateral Corticospinal Tract:

Feet laterally; arms medially

An expanding lesion of the central canal of the spinal cord, termed a syrinx, can compromise the anterior white commissure. When this happens in the cervical spinal cord, it is called cervical syringomyelia. Initially, the patient can experience the loss of pain and temperature sensation over the shoulders and upper extremities in a cape-like distribution. This is a progressive disease, often related to cervical whiplash or other traumatic injuries (Krammer and Levine, 1997), and with time further expansion of the syrinx infringes upon the ventral horns, thus adding flaccid paralysis to the presenting signs of the patient. Finally, in extreme cases, the expanding syrinx, which often grows laterally more than anteriorly or posteriorly, reaches the anterolateral tract. At this point a sensory level develops; below this segmental level the patient loses pain and thermal sensation, but retains discriminative and proprioceptive senses. Typically, the dorsal column system and dorsolateral fasciculus are not affected in this disease. Because the syrinx first impinges on the medial aspect of the anterolateral system and then pushes laterally across the tract, the sensory level clinically presents cervically in the patient and marches sacrally. This effect is due to the medial (cervical) to lateral (sacral) topography of the anterolateral system (Biller and Brazis, 1996).

VENTRAL FUNICULUS—SUPERFICIAL

Lateral Vestibulospinal Tract (Descending)

The lateral vestibulospinal system functions to maintain posture against gravity. Stimulation of this tract results in facilitation of motoneurons to extensor muscles and inhibition of motoneurons to flexor muscles. The cell bodies of origin for the lateral vestibulospinal tract are located in the ipsilateral lateral vestibular nucleus of the medulla (PLATES 11 to 14). These cells receive input from primary afferent fibers that arise in the utricle of the vestibular apparatus and carry information on head position with respect to gravity. Axons of the lateral vestibulospinal tract extend into the spinal cord to terminate in the medial portion of the ipsilateral ventral horn (PLATES 1 to 10).

CLINICAL DISCUSSION: Isolated lesions of the vestibulospinal tract in humans have not been reported. However, lesions of the spinal cord involving the lateral vestibulospinal tract present with the signs of damage to the suprasegmental control systems: weakness and spasticity. Conversely, loss of suprasegmental control of the lateral vestibulospinal nucleus, such as occurs when the cerebral cortex and upper brainstem are damaged (see Case Study 1-1 in Chapter 1), contributes to decerebrate posturing in humans and is an ominous sign in an unconscious patient.

Highlight Point:

Clinical manifestations pathognemonic for amyotrophic lateral sclerosis include:

Flaccidity in the upper extremities

Spasticity in the lower extremities

Fasciculations present throughout the body

All sensory systems intact

Tectospinal Tract (Descending)

The tectospinal tract mediates neck reflexes, especially those related to visual and acoustic stimuli. The cell bodies of origin for the tectospinal tract are located in the midbrain (also termed the tectum or superior colliculus; PLATES 18 and 19). The midbrain receives afferent fibers carrying visual, auditory, and somatic sensory information. These sensory modalities are combined into a neuronal map of external space used to guide the tectospinal neurons in mediating appropriate reflex responses. Tectospinal axons cross to the contralateral side in the brain stem and descend into the cervical and thoracic spinal cord where they terminate in the medial aspect of the ventral horn (PLATES 4 to 16).

VENTRAL FUNICULUS—DEEP

Pontine Reticulospinal Tract (Descending)

The pontine reticulospinal tract mediates facilitation of the gamma motoneurons controlling muscle spindles involved in the myotactic reflex. It is particularly excitatory to moto-neurons influencing spindle organs in extensor muscles. The cell bodies of origin for the pontine reticulospinal tract are in the pontine reticular formation (PLATES 12 to 16). Their axons form a tract descending along the ventromedial aspect of the medulla and spinal cord (PLATES 1 to 10). Most of these axons terminate in the medial aspect of the ipsilateral ventral horn.

CLINICAL DISCUSSION: Isolated lesions of this tract in humans have not been reported, however, lesions of the spinal cord involving the pontine reticulospinal tract result in increased spasticity. This tract, as with the other descending tracts from the brain stem reticular formation, red nucleus, and cerebral cortex, contributes to control of segmental (lower) motoneurons. Damage to these tracts deregulates the spinal segment, resulting in muscles with tone, but diminished power (termed spasticity). Conversely, loss of suprasegmental control of the pontine reticulospinal tract, such as occurs when the cerebral cortex and upper brainstem are damaged (see Case Study 1-1 in Chapter 1), contributes to decerebrate posturing in humans and is an ominous sign in an unconscious patient.

Anterior (or Ventral) Corticospinal Tract (Descending)

The anterior corticospinal tract influences the medial motor columns of the ventral horn, thereby controlling the axial musculature. Its cell bodies of origin are located in the motor area of the cerebral cortex; their axons travel with the corticospinal tract to the pyramidal decussation (PLATE 6). The majority of corticospinal axons cross the midline and shift laterality; however, a small number (approximately 8%) remain ventrally positioned to enter the cervical spinal cord in the ventral funiculus near the midline.

These axons form the anterior corticospinal tract; they terminate bilaterally in the medial portion of the ventral horn of the cervical to lumbar cord (PLATES 2 to 5).

Medial Vestibulospinal Tract (Descending)

The medial vestibulospinal tract is involved in coordinating neck and head movement with eye position. The cell bodies of origin for this tract are in the medial vestibular nucleus of the brain stem (PLATE 9 to 13). These nuclei receive input from primary afferent fibers that arise in the semicircular canals and carry information concerning the angular velocity of head movement. Axons from the medial vestibular nucleus join other fibers to form a tract along the midline of the brain stem, termed the medial longitudinal fasciculus. As this tract enters the spinal cord, it is referred to as the medial vestibulospinal tract; its fibers terminate bilaterally in the ventral horn of the cervical cord. The caudal extent of this tract in humans is not known.

▶ SUMMARY

This section has presented the details of a number of fiber tracts in the spinal cord from a regional perspective. Each tract has been described within the context of the three large funiculi of the spinal cord: dorsal, lateral, and ventral. Table 3-2 represents a summary of those tracts significant in clinical diagnosis. It is important that each tract, its origin, termination, topography, function, and deficit be thoroughly understood. It is also instructive to consider certain aspects of the spinal cord suprasegmental organization from a systematic perspective. This summary section reviews the general organization of sensory and motor systems.

▶ SPECIAL TOPICS

Sensory Systems

Three major ascending systems for somatic sensory information have been presented: the dorsal columns (FG&C), the spinocerebellar tracts (DSCT & CSCT), and the anterolateral system (ALS; Figure 3-9). Although each of these systems has been assigned distinct functions in the tertiary literature (Table 3-2), there is little in the primary literature to support this concept. Rather, it appears that vibration and position (both conscious and unconscious) sense are carried in all three systems, but primarily in the spinocerebellar tracts (Ross et al., 1978). Nociception is primarily carried in the anterolateral system, but is also represented in the dorsal column system (Wall and Noordenbos, 1977) and the only unique function of the dorsal column system may be stereognosis along with its action as a high-speed feedback pathway for fine movements (Davidoff, 1989).

Motor Systems

Two fundamentally different types of movements are possible in humans. The discrete and delicate movements of the distal extremities give us the ability to write, play musical instruments, or operate complex machinery. Conversely, postural and balance movements involve the axial and proximal limb musculature and serve to maintain our station, thus building a platform for the discrete movements of the distal limb musculature. To manage these two categories of movements, two motor systems, termed lateral and medial, are contained in the brain and spinal cord (Kuypers, 1981). The lateral motor system consists of the lateral corticospinal and rubrospinal tracts and the lateral reticulospinal tract. Their axons terminate in the lateral portion of the ventral horn, influencing the motoneurons that innervate the distal musculature of the limbs. Although both descending systems influence musculature in the arm and hand, only the corticospinal tract controls the fine movements of the digits.

The medial motor system involves the anterior corticospinal tract, the medial reticulospinal tracts, and both vestibulo-spinal tracts. Axons from these tracts terminate on the medial portion of the ventral horn, influencing primarily the motoneurons that innervate the axial and proximal limb musculature. These tracts function in balance and postural movements.

Flaccid And Spastic Paralysis

The descending somatic motor system can be divided into two operational and anatomic levels: segmental and suprasegmental (Figure 3-10). The segmental level contains the neuronal circuits between muscle spindle apparatus, ventral horn motoneurons, and

Highlight Point:

Cardinal manifestations of **Anterolateral Tract** injury are:

Analgesia located contralateral to and below the level of the lesion

Pain and paresthesias at the level of the lesion

Tract	Modality	Function
LCST	Motor	Fine volitional motor control
DCs	Sensory	Discriminative touch, vibratory and position sense
ALS	Sensory	Pain and temprature
SCTs	Sensory	Vibratory and position sense

Table 3-2. A summary of fiber tracts in the spinal cord and their ascribed functions (Abbreviations: ALS, anterolateral system; DCs, dorsal columns including the fasciculus gracilis and cuneatus; LCST, lateral corticospinal tract; SCTs, spinocerebellar tracts including the dorsal and cuneospinocerebellar tracts)

extrafusal muscle fibers, whereas the suprasegmental level includes the cortico-, rubro-, vestibulo-, and reticulospinal tracts that control the segmental-level circuits. These two levels reflect not only operation distinctions, but also differences in their clinical presentation subsequent to damage.

Damage to portions of the somatic motor system will present clinically as diminished strength or power and altered reflex tone in the affected muscles. The altered tone in affected muscles can be either hypotonic (flaccidity) or hypertonic (spasticity); the specific type is contingent on the location of damage in the motor system.

Interruption of a spinal segment interferes with the circuits containing ventral horn motoneurons (segmental level or lower motoneurons), thus denervating the musculature. Damage to the segmental level results in a loss of power or strength. Denervated muscles lack tone and control and are said to be in flaccid paralysis (lesion "B" in Figure 3-10). In addition, the nerve terminal (neu-

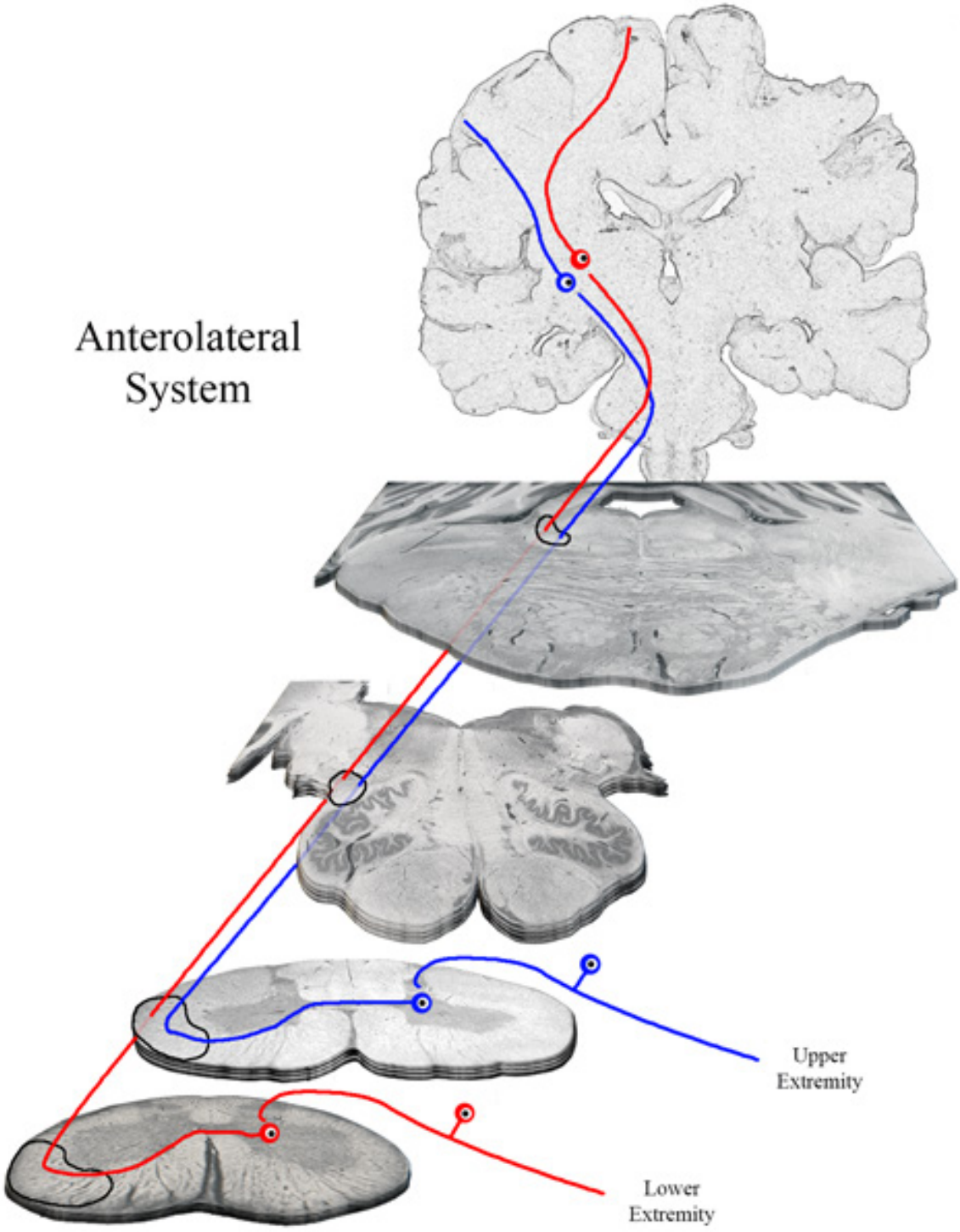


Figure 3-8. Diagram of the anterolateral tract (Source: small, primary afferent, group III or group IV fibers; Function: pain, temperature and crude touch; Laterality: crosses the midline at the segmental level)

romuscular synapse) normally supplies a trophic substance to the muscle, in the absence of which the muscle atrophies.

Interruption of suprasegmental control pathways (upper motoneuron) will also result in a loss of strength or power. However, in this case there is diminished control over the segmental circuit, but the lower motoneurons are still intact. The muscle is still connected to its ventral horn motoneurons, and these cells are still receiving information from the muscle spindle apparatus. Although the patient cannot control the muscle, it still has an intrinsic tone and is said to be in spastic paralysis (lesion 'A" in Figure 3-10). Since the circuit connecting spindle apparatus, motoneurons and extrafusal muscle fiber is intact, tendon reflexes can still be elicited; however, the lack of control from suprasegmental sources renders the reflex hyperactive. The uncontrolled neural circuit is resistive to change; hence, the patient's limbs resist passive stretch.

Suprasegmental level lesions can also unmask primitive reflexes that have been suppressed by the descending control systems. An example of this is the extensor reflex or Babinski response of the great toe following strong stimulus to the sole of the foot. This reflex is normally expressed in neonatal children and suppressed as the corticospinal tract develops its myelin sheaths. Damage to the corticospinal system can unmask the reflex.

The signs of suprasegmental, or upper motoneuron lesions are pathognomonic for damage to the central nervous system, however, those of the segmental, or lower motoneuron lesions can result from either central or peripheral nervous system damage. Although the presence of segmental- and suprasegmental-level signs in a patient strongly suggests a central nervous system lesion, it cannot rule out the possibility of an extradural process (e.g., a herniated disk) that has progressed into a central lesion (Biller and Brazis, 1996).

Flaccid and spastic paralysis are important concepts in clinical medicine. The anatomic principles behind each of these clinical presentations need to be fully understood. Reread Case Study 3-3 and determine which portions of the patient's body are showing signs of suprasegmental-level injury and which are showing signs of segmental-level injury.

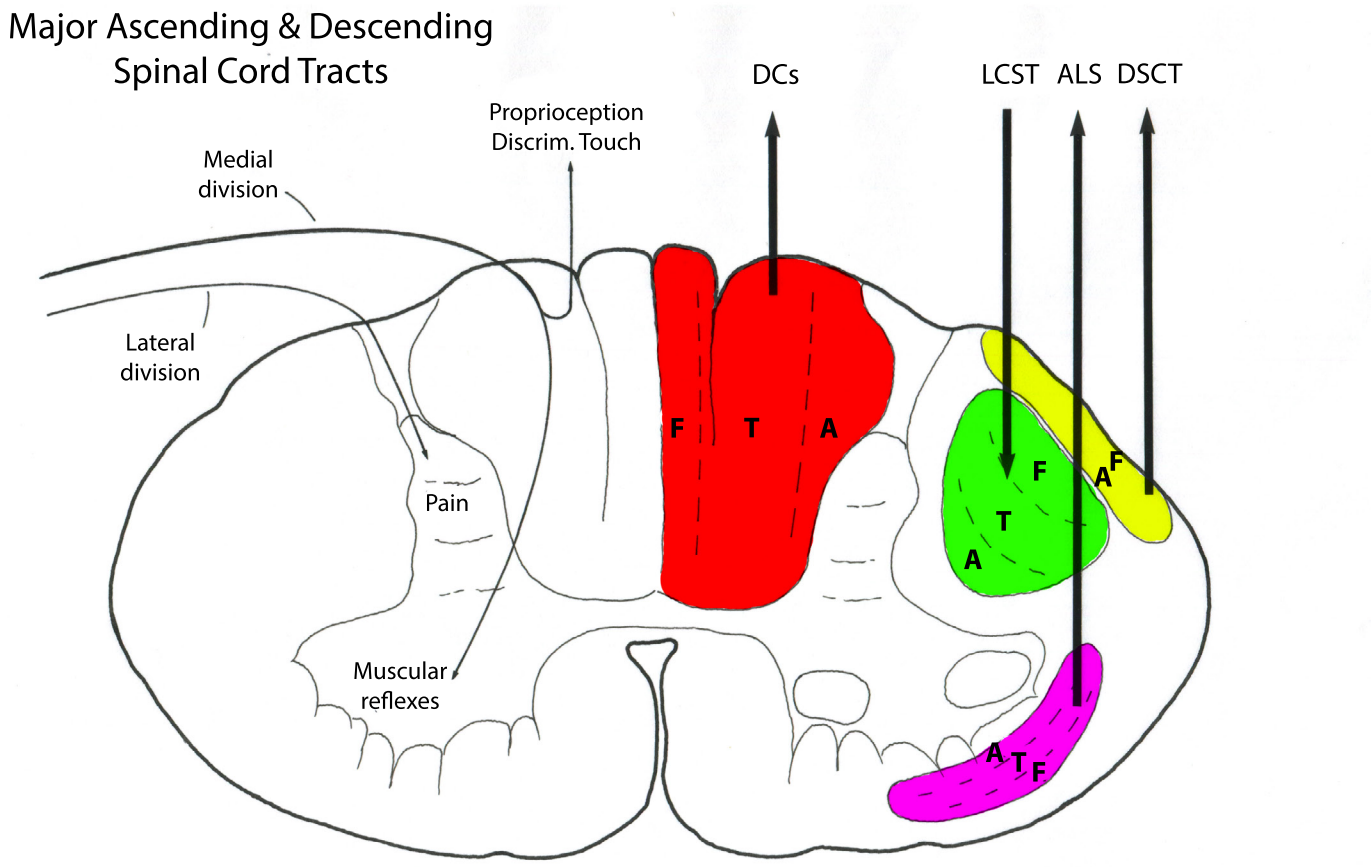


Figure 3-9. Diagram of the clinically important spinal cord pathways and nuclei. The left side of the diagram illustrates the segmental division of the primary afferent fibers to the spinal cord and their modalities; the right side illustrates the major suprasegmental tracts. The direction of the arrows indicates whether the tract is ascending (up-arrows) or descending (down-arrows). (Abb: A, arms; ALS, anterolateral tract; F, feet; DCs, dorsal columns; LCST, lateral corticospinal tract; T, trunk)

Transition Segment - The cervicomedullary junction

Atlas Plate 05

The rostral end of the spinal cord transitions into the medulla of the brainstem. Unlike the spinal cord, the medulla is bulbous in shape with several external expansions. Dorsally, the midline of the spinal cord opens and falls laterally to form the walls of the fourth ventricle. The medulla contains numerous nuclear structures that are not represented in the spinal cord. Tubercles on the dorsal and lateral surfaces of the medulla house the enlargements created by several of the more prominent nuclei.

This transition segment is best represented by Atlas Plate 05. The thick fiber tracts of the cervical spinal cord are still present on this section. The dorsal columns are well separated by the posterior median septum. In the next section, Atlas Plate 06, large masses of neurons forming the dorsal column nuclei, will be present ventrally in each of these columns.

The corticospinal tract has begun to shift from its lateral position between the dorsal and ventral horns to a ventral position in the medulla. In doing this the tract passes ventrally and medially, separating the ventral from the dorsal horn. Medially in Atlas Plate 05 darkly staining corticospinal axons are seen in clusters moving toward the midline. By Atlas Plate 06, these fibers will cross the midline, a process termed decussation, and form the pyramidal tract of the medulla. These tracts are visible on the external portion of the ventral surface of the medulla.

The nucleus proprius is shifted laterally and dorsally embedding into the base of the substantia gelatinosa. Together, these two structures form the spinal trigeminal nucleus. Essentially, the spi-

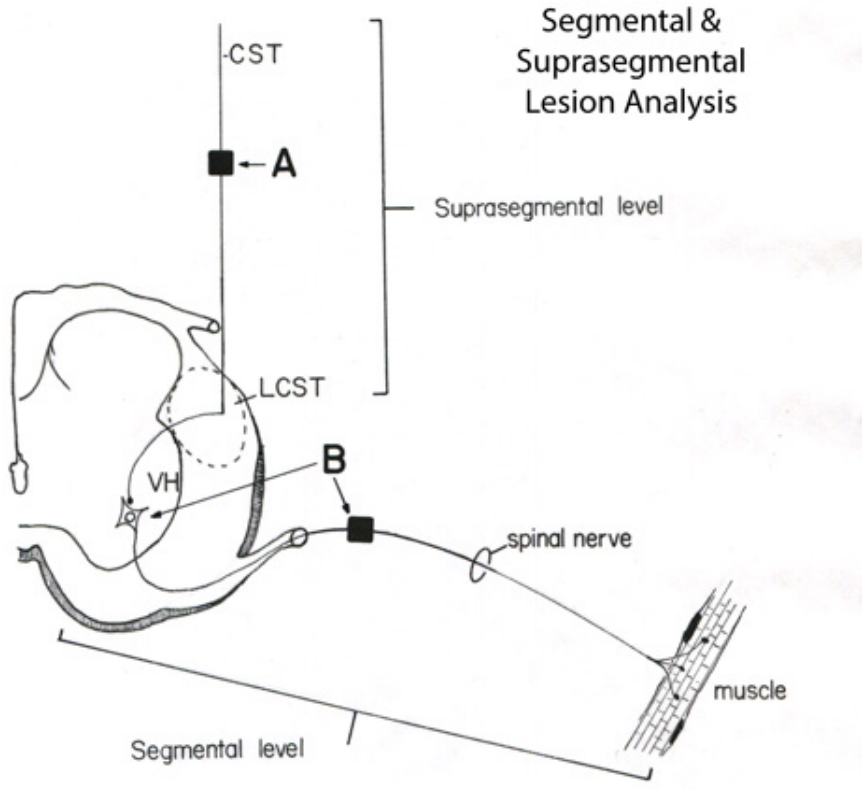


Figure 3-10. Diagram of the spinal cord segment illustrating the pathophysiological differences between spastic and flaccid weakness. A suprasegmental lesion at "A" interrupts descending control of segmental-level circuits and results in spastic paralysis. A segmental-level lesion at "B" (either within the cord or in the peripheral nerve) denervates the muscle and results in flaccid paralysis. (Abb: CST, corticospinal tract; LCST, lateral corticospinal tract; VH, ventral horn)

nal trigeminal nucleus is the dorsal hron of the medulla. As such, the spinal trigeminal nucleus processes nociceptive information (pain, temperature) from the face. Lateral to the spinal trigeminal nucleus lies the spinal trigeminal tract. This tract, which carries small, unmyelinated primary afferent fibers, represented the rostral continuation of the tract of Lissaur in the spinal cord.

Case Study 3-4

Chief Complaint

An 82-year-old, right-handed man with a long history of illness was brought to the emergency room by his family; he was in acute distress with back pain, and unable to walk.

History of Complaint

Two days prior, the patient experienced severe back pain radiating into both legs that remitted promptly when lying down. The next day he experienced similar transient pain in the back and the legs. Later that day, while experiencing an episode of severe back pain, he lost all strength in his legs and was rushed to the hospital.

Medical History

The patient had a previous history of transurethral prostatectomy and bilateral orchiectomy for carcinoma of the prostate, left hemicolectomy for adenocarcinoma of the rectum, and arteriosclerotic heart disease and congestive heart failure.

General Physical Examination

He was stable and reclining in bed. He was awake, cooperative, afebrile, and appeared older than his stated age. Funduscopic examination revealed bilateral ocular opacities obscuring visualization of the fundi. External auditory canals were patent. No cervical lymphadenopathy was detected. Blood pressure was 160/90 mmHg, pulse rate was 48 beats per minute with occasional premature beats. There was a grade 2 blowing apical systolic murmur. Bilateral basilar crackles were present in the lungs on inspiration and bilateral jugular venous distention was demonstrable in the neck. Peripheral pulses were intact and equal at the wrists and ankles. Pitting pretibial edema was present. A colostomy stoma was present in the lower left quadrant of the abdomen. Otherwise the abdomen was soft to palpation with normal bowel sounds and no aortic bruits.

Neurologic Examination

Mental Status. He was alert and oriented to person, place and time; memory and affect were appropriate for his age. Speech was clear and meaningful. He showed appropriate concern for his condition and was a good historian.

Cranial Nerves. His visual fields were intact and eye movements were full; hearing, to finger rub, was diminished bilaterally. His pupillary, corneal, and gag reflexes were intact; facial expressions were appropriate; uvula elevated symmetrically and tongue protruded on the midline. When asked, he could elevate his shoulders symmetrically with appropriate strength.

Motor Systems. His strength and muscle tone were absent in both lower extremities and deep tendon reflexes were absent at the knee and ankle. His strength and reflexes in the upper extremities were appropriate for his age. Grip strength was intact. His urinary bladder was atonic, however, this had been present since his last surgery.

Sensory Exam. There was a well-defined sensory level at T10, below which he had lost sensation to pinprick and temperature. Touch, vibratory, and position sense were intact throughout his body and face.

Follow-up

He was treated with steroids and supportive measures without improvement. Five weeks after the onset of paraplegia he died from a sudden cardiorespiratory arrest.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious? Is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION III

Blood Supply to Spinal Cord

The spinal cord receives its blood supply from an array of spinal arteries. As each spinal artery passes through the intervertebral foramen, it gives off several branches to perfuse the spinal cord, spinal roots, and surrounding meninges (Figure 2-11). Spinal arteries represent a series of branches derived from the vertebral artery, thyrocervical trunk, intercostal arteries, lumbar arteries, and iliolumbar artery. In total, these branches supply the spinal cord, spinal roots, meninges, and vertebral column. As the spinal artery negotiates the intervertebral foramen, it divides into radicular and medullary branches (Gillilan, 1958). Radicular branches follow the nerve roots to the spinal cord supplying the roots, dorsal root ganglia and dura. Eventually the radicular branches end as small contributions to the arterial vasocorona surrounding the cord. These branches do not form major contributions to the blood supply of the spinal cord proper. Medullary branches are larger than the radicular branches and travel along with the spinal nerve and roots to reach the anterior spinal artery or posterior spinal arteries. There are from seven to ten of these arteries; the largest is the great medullary artery of Adamkiewicz, which can occur at vertebral levels T8 to L4, typically on the left side, and supplies the anterior spinal artery.

Three arteries (the anterior and two posterior spinal arteries) are in close juxtaposition to the spinal cord and form the spinal plexus. This plexus distributes small branches internally to perfuse the spinal parenchyma. The posterior spinal artery is in reality a network of small, anastomotic vessels providing penetrating branches into the dorsal columns and a portion of the dorsal horn. The anterior spinal artery is well formed, and its occlusion or rupture can result in a distinct syndrome (Moossy, 1988), termed the Anterior Spinal Artery Syndrome. The major penetrating branch of the anterior spinal artery is the central (or sulcal) artery that perfuses the central portion of the spinal cord supplying the ventral horn and anterior white commissure. The distal extreme of the central arterial territory can include the lateral corticospinal tract. An outer vascular ring called the arterial vasocorona connects the posterior plexus and anterior spinal artery. These vessels form an anastomotic channel surrounding the spinal cord. Venous drainage of the spinal cord occurs through the epidural (Batson's) plexus of veins.

CLINICAL DISCUSSION: Occlusion of a medullary artery can deprive the anterior spinal artery of blood over several segments of the spinal cord. Most notable is that of the medullary artery of Adamkiewicz, where occlusion can deny blood supply to the anterior spinal artery over a large portion of the lumbar spinal cord (Laguna and Cravioto, 1973). The location of the artery of Adamkiewicz becomes an important issue in spine surgery and in surgery involving the posterior body wall such as the repair of an abdominal aortic aneurysm. Since the posterior spinal artery is a narrow anastomotic plexus, a defined posterior spinal artery syndrome has rarely been reported. However, when detectable, the posterior spinal artery syndrome can present with diminished vibratory sense and loss of proprioception (Moossy, 1988). Damage to the anterior spinal artery or its central branch can present as paralysis and paresthesia below the level of the lesion (Moossy, 1988). Initially, the paralysis is flaccid due to the accompanying spinal shock, but subsequently resolves into a spastic form over a few weeks. Infarction of the anterior spinal vessels usually occurs in a watershed area (e.g., the anastomotic region between two medullary arteries). The paresthesia can present as an all-abrupt onset of a girdle of intense pain around the torso. A flaccid paralysis follows within minutes to hours and is bilateral. These symptoms can be accompanied by loss of bowel and bladder function as well as a sensory level to pinprick below the level of the lesion (Biller and Brazis, 1996).

Highlight point:

The initial clinical manifestations of the anterior spinal artery syndrome can include:

Flaccid paralysis below the level of the lesion

Prominent sensory level for analgesia

Loss of bladder and bowel functions

Preservation of discriminative touch, vibratory and position sense

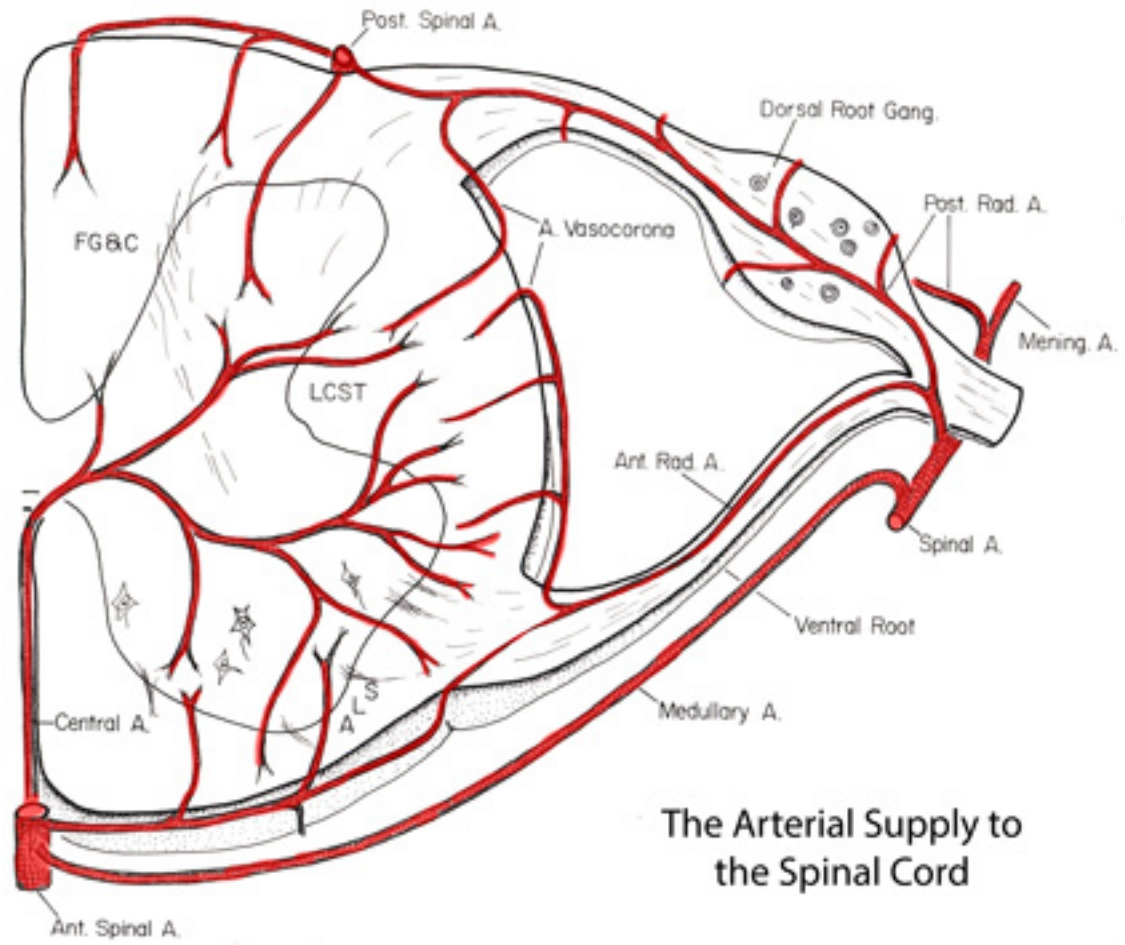


Figure 3-11. Arterial supply of the spinal cord. The spinal cord has been sectioned through a spinal root and dorsal root ganglion and the blood supply has been plotted onto the section.

References

Basbaum AI, Fields HL (1978) Endogenous pain control mechanisms: Review and hypothesis. Ann Neurol 4: 451-462.

Bender MB, Stacy C, Cohen J (1982) Agraphesthesia. J Neurol Sci 53: 531-555.

Biller J, Brazis PW (1996) The localization of lesions affecting the spinal cord. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 79-108. Boston: Little, Brown and Company.

Briner RP, Carlton SM, Coggeshall RE, Chung K (1988) Evidence for unmyelinated sensory fibres in the posterior columns in man. Brain 111: 999-1007.

Davidoff RA (1989) The dorsal columns. Neurol 39: 1377-1385.

Davidoff RA (1990) The pyramidal tract. Neurol 40: 332-339.

Friedman AH, Nashold BS (1986) DREZ lesions for the relief of pain related to spinal cord injury. J Neurosurg 65: 465-469.

Gillilan LA (1958) The arterial blood supply of the human spinal cord. J Comp Neurol 110: 75-103.

Gudesblatt M, Cohn J, Gerber O, Sacher M (1987) Truncal ataxia presumably due to malignant spinal cord compression. Ann Neurol 21: 511-512.

Gybels JM, Tasker RR (1999) Central neurosurgery. In: Textbook of Pain (Wall PD, Melzack R, eds), pp 1307-1339. Edinburgh: Churchill Livingstone.

Jagiella WM, Sung JH (1989) Bilateral infarction of the medullary pyramids in humans. Neurol 39: 21-24.

Kennedy PR (1990) Corticospinal, rubrospinal, and rubro-olivary projections: a unifying hypothesis. Trends Neurosci 13: 474-479.

Krammer KM, Levine AM (1997) Posttraumatic Syringomyelia - A review of 21 cases. Clin Orthop 334: 190-199.

Kuypers HGJM (1981) Anatomy of the descending pathways. In: Handbook of Physiology, Section 1 The Nervous System, Volume II Motor Control, Part 1 (Brookhart JM, Mountcastle VB, Brooks VB, eds), pp 597-666. Bethesda, MD: American Physiology Society.

Laguna J, Cravioto H (1973) Spinal cord infarction secondary to occlusion of the anterior spinal artery. Arch Neurol 28(2): 134-136.

Landau WM (1980) Spasticity: What is it? What is it not? In: Spasticity: Disordered Motor Control (Feldman RG, Young RR, Koella WP, eds), pp 17-24. Chicago: Yearbook Medical Pub.

Lawrence DG, Kuypers HGJM (1968a) The functional organization of the motor system in the monkey I. The effects of bilateral pyramidal lesions. Brain 91: 1-15.

Lawrence DG, Kuypers HGJM (1968b) The functional organization of the motor system in the monkey II. The effects of lesions of the descending brain-stem pathways. Brain 91: 15-36.

Martin GF, Holstege G, Mehler W (1990) Reticular formation of the pons and medulla. In: The Human Nervous System (Paxinos G, ed), pp 203-220. San Diego: Academic Press, Inc.

Moossy J (1988) Vascular diseases of the spinal cord. In: Clinical Neurology (Joynt RJ, ed), pp 1-19. Philadelphia: J.B. Lippincott.

Nathan PW, Smith MC (1982) The rubrospinal and central tegmental tracts in man. Brain 105: 223-269.

Paulson GW, Yates AJ, Paltan-Oritz JD (1986) Does infarction of the medullary pyramid lead to spasticity? Arch Neurol 43(1): 93-95.

Rexed B (1952) The cytoarchitectonic organization of the spinal cord in the cat. J Comp Neurol 96: 415-495.

Ross ED, Kirkpatrick JB, Lastimosa ACB (1978) Postion and vibration sensations: founctions of the dorsal spinocerebellar tracts? Ann Neurol 5: 171-176.

Schoene WC (1985) Degenerative diseases of the central nervous system. In: Textbook of Neuropathology (Davis RL, Robertson DM, eds), pp 788-823. Baltimore: Williams & Wilkins.

Schoenen J (1991) Clinical anatomy of the spinal cord. Neurol Clin N A 9: 503-532.

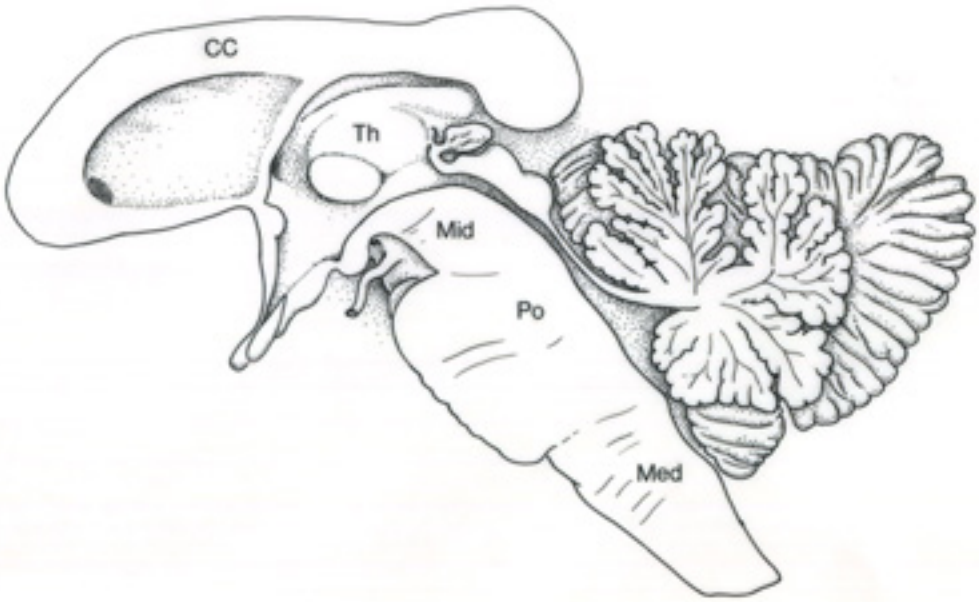
Schoenen J, Faull RLM (1990a) Spinal cord: chemoarchitectural organization. In: The Human Nervous System (Paxinos G, ed), pp 55-75. San Diego: Academic Press, Inc.

Schoenen J, Faull RLM (1990b) Spinal cord: cytoarchitectural, dendroarchitectural and myeloarchitectural organization. In: The Human Nervous System (Paxinos G, ed), pp 19-53. San Diego: Academic Press, Inc.

Smith MC, Deacon P (1984) Topographical anatomy of the posterior columns of the spinal cord in man. Brain 107: 671-698.

Wall PD, Noordenbos W (1977) Sensory functions which remain in man after complete transection of dorsal columns. Brain 100: 641-653.

Chapter 4
The Medulla



▶ INTRODUCTION

The medulla oblongata, the caudal extreme of the brain stem, is located in the posterior cranial fossa. This portion of the brain stem contains neural circuits regulating respiration, blood pressure, and cardiac rhythm, as well as nuclei for five cranial nerves: hypoglossal, accessory, vagus, glossopharyngeal and portions of the acoustico-vestibular. The medulla receives its blood supply from branches of the vertebral and spinal arteries. The medulla is very sensitive to displacement, thus mass-expanding lesions in the posterior cranial fossa can be disastrous. This chapter examines the organization of nuclei and tracts in the medulla. The blood supply to the medulla will be studied and several clinicopathologic cases concerning medullary lesions will be considered.

GENERAL OBJECTIVES

1. To learn the location and function of major nuclei and ascending and descending fiber tracts in the medulla
2. To learn the presenting signs and symptoms consequent to lesions involving major nuclei and tracts in the medulla
3. To apply the preceding knowledge to an understanding of the clinical manifestations of medullary vascular lesions
4. To distinguish between two vascular syndromes: the medial and lateral medullary syndromes

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study is followed by a list of questions that can be answered best by using knowledge of regional and functional neuroanatomy as well as referring to outside reading material. Following the questions is a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer

the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and answer the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human brain stem model
2. An atlas of the human brain stem
3. A medical dictionary

Chapter Four Topics:

Case Study 4-1

Chief Complaint

A 59-year-old, right-handed male was admitted to the hospital with a chief complaint of occipital headaches of 4 days duration accompanied by dizziness and ataxia.

History of Chief Complaint

Three days prior to admission, the patient noted a sudden onset of diplopia on forward gaze and a sensation of dizziness. These complaints resolved within twenty-four hours. He experienced several episodes of dizziness and diplopia over the next 24 hours. One day prior to admission he noted a relatively sudden onset of dizziness, diplopia and clumsiness in the right hand. These complaints have persisted since that time.

Medical History

The patient had been under treatment for hypertension for 6 years duration, with observed blood pressures in the range of 180/110.

General Physical Examination

The patient was alert, oriented, and cooperative; he was a well-nourished man of medium height who appeared his stated age. Funduscopic examination revealed clear optic discs with sharp borders. The external auditory canal was patent and uninflamed. Pharynx and larynx were non-reddened. A grade II/VI bruit was present over the right carotid artery. His blood pressure was elevated (192/96). Peripheral pulses were intact at the ankle and wrist. Respirations were normal. His chest was clear to auscultation; skin was warm and of normal texture; abdomen was soft with no tenderness, lumps, or masses. Extremities were four in number with no edema present; no lymphadenopathy was present in the cervical or inguinal areas.

Neurologic Examination

Mental Status. The patient was awake and oriented with respect to person, place, and time. Memory was appropriate for his age. Speech was hoarse, but articulate and meaningful. He could follow three- and four-step commands.

Cranial Nerves. Extraocular movements were full, but he complained of diplopia made worse by lateral gaze to the left. Nystagmus was present on left lateral gaze. The right pupil measured 3 mm, the left was 5 mm, but both responded to light and accommodation. Ptosis of the right eyelid and decreased sweating on the right side of the face (anhidrosis) were also present. Hearing was diminished in both ears to high frequencies. He admitted to a feeling of dizziness that he described as the world moving around him. Pain, but not touch sensation, was decreased on the right side of the face with the exception of some sparing around the lips and nasal region. The right corneal reflex was diminished. He complained of a paroxysmal tingling sensation on the left side of his face that he described as occasionally being painful. Facial expressions were full and symmetric. The uvula deviated to the left, and there was deficient elevation of the right side of the palate. There was also a suggestion of hoarseness in his speech.

Motor System. Strength was intact throughout his body; deep tendon reflexes were intact and symmetric in all extremities. An ataxia was evident in the right upper extremity on finger-tapping, hand-patting, and finger-to-nose tests. An intention tremor was present. Ataxia was also present in the right lower extremity on heel-to-shin and tibia-tapping tests.

Sensory Exam. He had a mild analgesia to pinprick on the left side of the body, the left arm, and the left leg. Position, vibration, and touch modalities were intact throughout the entire body.

Follow-Up

Examination of the patient two months after this event found most of his complaints have resolved with the exception of a mild right-sided facial analgesia, greatest along the angle of his jaw. Although he no longer complained of clumsiness, finger-to-nose testing demonstrated a mild persistent dysmetria.

QUESTIONS:

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

Medullary Structures

The medulla has several distinctive external features including the pyramids, olivary tubercule and the posterior aspect of the fourth ventricle as well as the roots of the facial, vestibulocochlear, glossopharyngeal, vagus, and hypoglossal cranial nerves. These external features have been described in Chapter 1. Perhaps most characteristic of the medulla is its bulb-like shape, thus its cranial nerves have been termed the bulbar nerves and when they are damaged, it is termed a bulbar palsy.

Internally, the medulla contains several long tracts inter-connecting spinal cord, brain stem, and thalamus as well as numerous intrinsic nuclei related to the medullary cranial nerves and reticular formation. The pertinent internal medullary structures, illustrated on each atlas plate, are described in this chapter. The abbreviation following the name of the structure corresponds to that used on the atlas plate. In reading through the material, you will find that the first time a given structure is encountered, a description will be provided along with comments on its function and, where possible, any clinical deficit consequent to its destruction. For subsequent sections, the structure will be listed by name and abbreviation only, unless significant changes have occurred in its location or composition to merit further comment.

Atlas Plate 6

Go to the Atlas

Atlas Plate 6 is taken from the cervicomedullary junction. Its salient features are the presence of the pyramidal decussation and three major sensory nuclei: spinal trigeminal, gracilis, and cuneatus.

FASCICULUS AND NUCLEUS GRACILIS (FGr AND NuGr) AND FASCICULUS AND NUCLEUS CUNEATUS (Fcu AND NuCu)

The fasciculus gracilis and fasciculus cuneatus (dorsal columns) comprise the large, dorsal funiculus of the spinal cord (Figure 4-1). They contain the central axons of the group I and II primary afferent fibers from the dorsal roots as well as smaller-caliber axons from cells in the ipsilateral dorsal horn. The role of these two fasciculi in carrying discriminative touch and detecting motion, as well as in providing feedback to the corticospinal system, has been discussed in Chapter 2.

Although traditionally described as containing large caliber, heavily myelinated fibers, the segregation of axons by size into the dorsal columns is not as homogeneous as previously thought. In addition to the large group I and II axons, numerous small caliber primary afferent axons are present. These smaller fibers represent around 25% of those present in either fasciculus and are similar in size to fibers found in Lissauer's tract (Briner et al., 1988). Thus, the dorsal columns also carry information concerning noxious stimuli. Recent studies have demonstrated that this system is involved in visceral pain, particularly that from the pelvis (Al-Chaer et al., 1996).

At the cervicomedullary boundary, ascending axons in the fasciculus gracilis form a cusp around the nucleus gracilis. This nucleus is an oblong mass of neurons receiving the synaptic terminals of the axons in the fasciculus gracilis. Because of its large size, it forms the gracile tubercle on the dorsolateral surface of the brain stem. At a slightly more rostral level, the fasciculus cuneatus engulfs its nucleus and terminates. As such, this large nucleus and its surrounding fiber tract form the cuneate tubercle on the dorsolateral surface of the brain stem.

The gracile and cuneate nuclei (dorsal column nuclei) give rise to axons that cross the midline forming the internal arcuate fibers (see Plate 7) and ascend through the brain stem in the medial lemniscus (see Plates 8 to 20). These axons terminate in the ventroposterior lateral thalamic nucleus (see Plate 21). Ultimately, the information that they carry is relayed to the somatic sensory portion of the cerebral cortex.

Highlight Point

Cardinal manifestations of dorsal column system injury:

Diminution of vibratory and discriminative touch

Astereognosis

Agraphesthesia

Topography of the dorsal column system:

Feet medially; arms laterally

CLINICAL DISCUSSION: Pure lesions of either of the dorsal column tracts will reduce, but not completely eliminate vibratory or position sense in the human. It appears that these modalities are also carried by some of the axons in the adjacent dorsolateral fasciculus and in the anterolateral system (Wall and Noordenbos, 1977;Davidoff, 1989) as well as in the dorsal spinocerebellar tracts (Ross et al., 1978). The clinically demonstrable deficit resulting solely from isolated lesions of the dorsal columns appears to be astereognosis. Thus, tests for stereognosis and graph-esthesia have been proposed as the only appropriate clinical tests of dorsal column system integrity (Wall and Noordenbos, 1977;Bender et al., 1982).

SPINAL TRIGEMINAL NUCLEUS (SpTNu) AND TRACT (SpTT)

The spinal trigeminal nucleus is located in the lateral aspect of the medulla, surrounded dorsolaterally by its tract (Figure 3-2). This prominent nucleus is divided into an external marginal portion (labeled g in Plate 6) and an inner magnocellular portion (labeled m in Plate 6); these two regions are continuous with the substantia gelatinosa and nucleus proprius of the spinal cord, respectively. The spinal trigeminal tract is a direct continuation of Lissauer's tract in the spinal cord. Thus, the spinal trigeminal complex of the medulla replaces, in function, the dorsal horn of the cervical spinal cord. This portion of the trigeminal complex is also termed the "medullary dorsal horn."

Axons from neurons in the spinal trigeminal nucleus group together in scattered fascicles, cross the midline in the medulla, and form the ventral trigeminothalamic tract in the pons (see Plate 15 and Figure 4-2). This tract follows the medial lemniscus into the thalamus (see Plates 16 to 20), where it terminates in the ventroposterior medial nucleus (see Plate 21).

The spinal trigeminal system, like its counterpart, the dorsal horn of the spinal cord, processes pain, thermal sense, and crude touch. It receives primary afferent fibers from the trigeminal nerve, carrying information from the face, scalp, oral cavity, ear, mastoid air cells, and sinuses as well as dura mater of the anterior and middle cranial fossae.

CLINICAL DISCUSSION: Damage to the spinal trigeminal system results in loss of pain and thermal sensation from the ipsilateral face. Irritation of the spinal trigeminal complex in the medulla can present as hyperalgesia, taking the form of sharp, stabbing pains in the ipsilateral eye and face (Caplan and Stein, 1986;Caplan, 1989). Irritation of the trigeminothalamic fibers, such as from ischemic lesions, can present as a sensation of "salt and pepper" rubbed into the skin on the contralateral side of the face (Caplan and Gorelick, 1983).

ACCESSORY NUCLEUS (AccNu)

A column of motoneurons is present in the gray matter, lateral to

the pyramidal decussation (Figure 4-3). These neurons, forming the spinal accessory nucleus of cranial nerve XI, represent a rostral continuation of the ventral horn of the cervical spinal cord. Their axons give rise to the spinal portion of the accessory cranial nerve, innervating the ipsilateral sternomastoid and trapezoid muscles. The so-called "cranial portion" of the accessory nerve actually arises from the nucleus ambiguus.

The accessory nucleus receives an innervation from corticonuclear fibers. The suprasegmental control of the trapezoid muscle arises from the contralateral cerebral cortex, whereas that for the sternomastoid muscle appears to be bilateral but has its strongest component from the ipsilateral motor cerebral cortex (Thompson et al., 1997). There is clinical evidence that the ipsilateral connections are quite complex, possibly involving a double-crossing of the corticonuclear axons (Brazis, 1996a). The ipsilateral control of the sternomastoid muscle makes some sense since the left side of the brain, due to the crossing of the corticospinal tract, controls activity in the right side of the body. The left sternomastoid muscle rotates the head and visual attention into the surrounding right hemisphere. Thus, the left side of the brain, by activating the left sternomastoid muscle, directs attention towards the right side of the body and its surrounding environment.

CLINICAL DISCUSSION: Damage to the accessory nucleus or its nerve results in flaccid paralysis of the ipsilateral trapezoid and sternomastoid muscles. Clinically, paralysis of the trapezius presents as an inability to elevate the ipsilateral shoulder and as downward and lateral displacement of the scapula (Haymaker and Kulhlenbeck, 1976). Paralysis of the sternomastoid muscle presents as weakness in rotating the head to the side contralateral to the

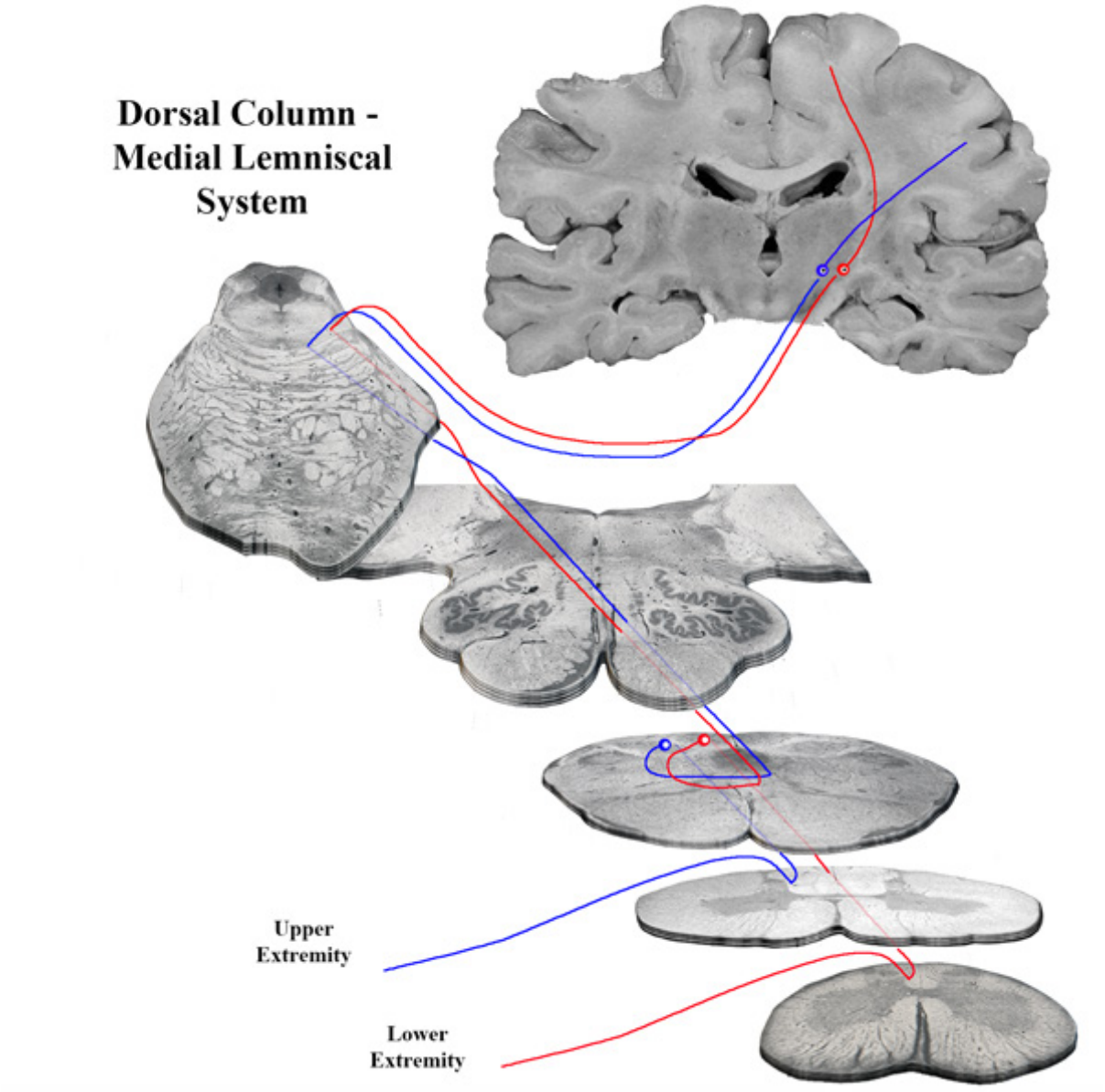


Figure 4-1. The dorsal column-medial lemniscal system

lesion. On attempted flexion of the neck, the chin deviates slightly to the lesioned side because of the unopposed actions of the contralateral muscle. Fasciculations and atrophy can be seen in both of these muscles when damage is done to the accessory nucleus or its nerve.

Suprasegmental lesions (cerebral cortex or descending corticonuclear fibers in the upper brain stem) can result in spastic paresis of the contralateral trapezoid and the ipsilateral sternomastoid muscles (Brazis, 1996a). The patient can present with weakness in the shoulder contralateral to the lesion (trapezoid muscle) and with weakness when turning the head away from the lesion (ipsilateral sternomastoid muscle).

PYRAMIDAL DECUSSATION (decPy)

The corticospinal axons arise in the cerebral cortex and descend past the thalamus in the internal capsule (see Plates 22 to 25) to enter the brain stem. At the level of the medulla (see Plates 7 to 13), these axons are coursing in the medullary pyramids, from which they emerge to cross the midline and form the lateral corticospinal tract. Pyramidal decussation (decPv) is a salient feature of Plate 6, with crossing fibers distributed from the central gray area (CeGy) dorsally to the ventral border of the brain stem. A caudal portion of the decussation can also be seen in Plate 5. Within the decussation, fibers controlling upper-extremity musculature cross rostrally at the level of the hypoglossal nerve; those controlling lower-extremity musculature decussate more caudally at the level of C1-2. Corticospinal tract axons arise in motor portions of cerebral cortex and function to control fine, discriminative movements of the extremities, particularly of the distal musculature.

Highlight Point

The clinical manifestations of spinal trigeminal nucleus and tract and trigeminothalamic tract damage can include:

Ipsilateral facial analgesia

Rostral lesions can involve analgesia across the entire hemiface.

Caudal lesions can involve only a band of analgesia stretching from the tip of the jaw to the vertex of the head.

Contralateral paresthesia and analgesia

A sensation of prickle pain, described as salt and pepper rubbed on the skin is a common paresthesia for this lesion.

CLINICAL DISCUSSION: Destruction of the pyramidal decussation is similar to section of both pyramidal tracts. The initial presentation involves flaccid quadraparesis with eventual resolution into hyperreflexia and spastic paralysis in all four extremities. Contrary to this clinical observation, experimentally placed lesions of the pyramidal tract in monkeys led to permanent hypotonia and flaccid paralysis of the distal extremity muscles (Lawrence and Kuypers, 1968a). The possible distinctions between the result of pyramidal tract section in monkeys and the clinically observable results in humans are discussed in Jagiella and Sung (Jagiella and Sung, 1989).

Rostrally positioned lesions of the decussation, restricted to the midline can result in damage to the crossing fibers related to the upper extremity only (Dickman et al., 1990). The result is bilateral spastic paralysis of the upper extremities and normally functioning lower extremities, a syndrome known as cruciate paralysis. This form of paralysis has been reported in upper cervicomedullary lesions consequent to rheumatoid arthritis (Zeidman and Ducker, 1994).

DORSAL SPINOCEREBELLAR TRACT (DSCT)

The dorsal spinocerebellar tract (DSCT) is a thin band of fibers along the lateral border of the medulla. It contains axons from cells in the dorsal nucleus of Clarke (see Chap. 3); these axons carry proprioceptive information to the cerebellum (Figure 4-4). At the level of the inferior olive (see Plate 8), this tract separates from its position close to the ventral spinocerebellar tract and begins rapidly increasing in size as it receives olivocerebellar fibers from the contralateral inferior olivary nucleus (see Plates 8 to 12). Collectively, these axons contribute to the inferior cerebellar peduncle (or restiform body), which curves superiorly to enter the cerebellum (see Plates 8 to 14).

CLINICAL DISCUSSION: Lesions in the spinal cord that have involved the dorsal spinocerebellar tract, but not the dorsal column system, have presented with diminished position and vibratory sense (Ross et al., 1978) and ataxia (Gudesblatt et al., 1987;Biller and Brazis, 1996a). Damage to the lateral aspect of the brain stem or the inferior cerebellar peduncle can also present with ataxia in the ipsilateral lower extremity (Caplan, 1989;Peterman and Siekert, 1960). The ataxia from medullary lesions presumably results from destruction of dorsal spinocerebellar fibers in the inferior cerebellar peduncle, thus depriving the cerebellum of its proprioceptive input from the lower extremity. Since the cerebellum itself is still functioning correctly, the deficit is termed a "sensory ataxia" as opposed to a cerebellar ataxia.

VENTRAL SPINOCEREBELLAR TRACT (VSCT)

The ventral spinocerebellar tract is a thin band of fibers wrapping around the lateral aspect of the medulla, ventral to the dorsal spinocerebellar tract. These fibers originate from neurons in the contralateral dorsal horn, cross the midline, and ascend to the superior cerebellar peduncle (see Plates 3 to 15), eventually terminating in the cerebellum. Upon entering the cerebellum, many of the spinocerebellar fibers cross back to the opposite side. Thus, functionally the tract influences the cerebellum bilaterally. The ventral spinocerebellar tract carries information concerning the activity of ventral horn motor circuits.

ANTEROLATERAL SYSTEM (ALS)

Fibers of the anterolateral system (ALS) are found in the lateral aspect of the medulla, ventral to the spinal trigeminal complex and rubrospinal tract (Figure 4-5). These axons originate along the entire length of the spinal cord from cells in the first, fourth and fifth laminae of the contralateral dorsal horn. At each segmental level, axons cross the midline in the anterior white commissure and join the anterolateral system, to ascend through the brain stem (see Plates 6 to 20) eventually reaching the ventroposterior lateral nucleus and interlaminar nuclei of the thalamus (see Plate 21). This system contains fibers carrying pain, thermal sense, and crude touch from the contralateral side of the body.

CLINICAL DISCUSSION: Damage to the anterolateral system results in a diminution of pain and thermal sense from the contralateral body. Given the tract's close proximity to the spinal trigeminal complex, vascular lesions can affect both structures; in such cases, the presentation involves decrease of pain and thermal sense from the ipsilateral face (spinal trigeminal system) and contralateral body (anterolateral system), a constellation of signs termed alternating analgesia.

RUBROSPINAL TRACT (RuSp)

The rubrospinal tract (RuSp) is located between the spinal trigeminal complex and the anterolateral system. It contains fibers from the contralateral red nucleus (see Plates 20 and 21) traveling to the ventral horn of the cervical and thoracic spinal cord. This tract is involved in controlling flexor muscle tone in the proximal portion of the upper extremity.

CLINICAL DISCUSSION: The loss of the rubrospinal tract in humans is masked in large part by the function of the corticospinal tract (Kennedy, 1990); in non-human primates its isolated destruction results in some proximal limb weakness that eventually resolves (Lawrence and Kuypers, 1968a). Combined lesions of the corticospinal axons and rubrospinal tract in nonhuman primates can result in a more severe weakness and spastic paralysis.

VESTIBULOSPINAL AND RETICULOSPINAL TRACTS (VesSp ond RetSp)

The vestibulospinal and reticulospinal tracts (VesSp and RetSp) are closely associated in the ventral aspect of the medulla, where they are located between the pyramidal tract and the anterolateral system. The vestibulospinal tract arises in the lateral vestibular nucleus (see Plates 12 to 15), whereas the reticulospinal tract arises in the pontine and medullary reticular formation (see Plates 6 to 16). These tracts innervate the medial aspect of the ventral horn of the spinal cord and modulate tone and posture in axial and proximal limb musculature; thus, they regulate body-limb movements. As such, they represent components of the medial motor system.

CLINICAL DISCUSSION: Isolated lesions of these tracts have not been reported in humans; however, their destruction in monkeys leads to decomposition of body posture (Lawrence and Kuypers, 1968b). Although these primates could still use their arms and hands they lacked a righting reflex and had few orientating reflexes.

MEDIAL LONGITUDINAL FASCICULUS (MLF)

The medial longitudinal fasciculus (MLF) extends from the level of the oculomotor nucleus in the midbrain (see Plate 20) into the cervical spinal cord. It serves to interconnect the vestibular nuclei with the oculomotor, trochlear, and abducens nuclei as well as motoneurons controlling the cervical musculature. Along its route through the brain stem, the fasciculus is located close to the midline; however, at the cervicomedullary junction (see Plate 6),

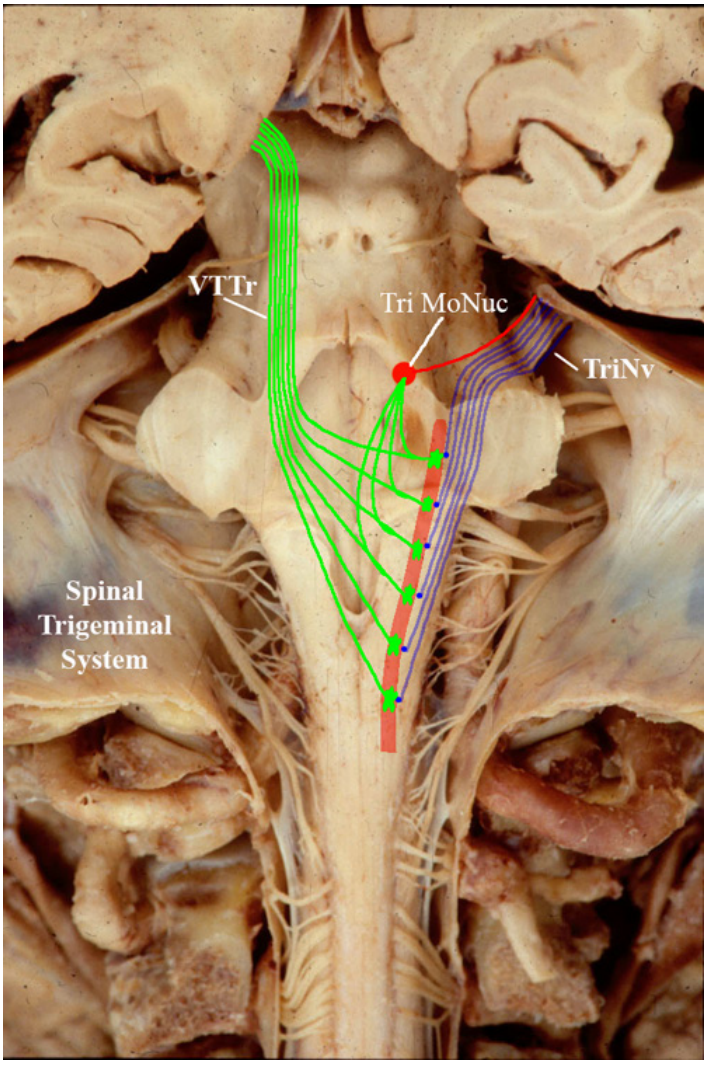


Figure 4-2. Origin of the trigeminal nerve and the trigeminal nuclei in the pons

Highlight Point

The clinical manifestations of damage to the anterolateral system in the brainstem can include:

Contralateral analgesia

it is pushed laterally by the pyramidal decussation. As the medial longitudinal fasciculus enters the cord, its name is often changed to the medial vestibulospinal tract. (In this atlas the term medial longitudinal fasciculus is used throughout the length of this tract, instead of changing nomenclature as the tract enters the spinal cord.)

In the caudal medulla, the medial longitudinal fasciculus contains axons from the medial vestibular nucleus that are destined to innervate the medial aspect of the ventral horn of the ipsilateral cervical spinal cord. Thus, this portion of the tract is a component of the medial motor system controlling axial musculature.

CLINICAL DISCUSSION: Isolated section of the medial longitudinal fasciculus in the brain stem below the abducens nucleus has not been reported in humans. Section of this tract above the level of the abducens nucleus can result in disassociated movements of the eyes, called internuclear ophthalmoplegia. This will be further discussed in Chapter 5.

TECTOSPINAL TRACT (TecSp)

A small cluster of axons close to the medial longitudinal fasciculus represents the tectospinal tract (TecSp). These axons arise from neurons in the deep layers of the contralateral superior colliculus of the midbrain (see Plate 19), cross the midline, and descend through the brain stem into the cervical spinal cord. The tectospinal tract is involved in mediating head and neck reflexes to unexpected stimuli.

CENTRAL GRAY (CeGy)

The gray (cell bodies) area surrounding the central canal of the spinal cord expands at the level of the caudal medulla to form the central gray (CeGy). At slightly more rostral levels the hypoglossal and vagal nuclei will be contained within this region (see Plates 7 to 9).

MEDULLARY RETICULAR FORMATION (MRetF)

The medullary reticular formation (MRetF) is a centrally locat-

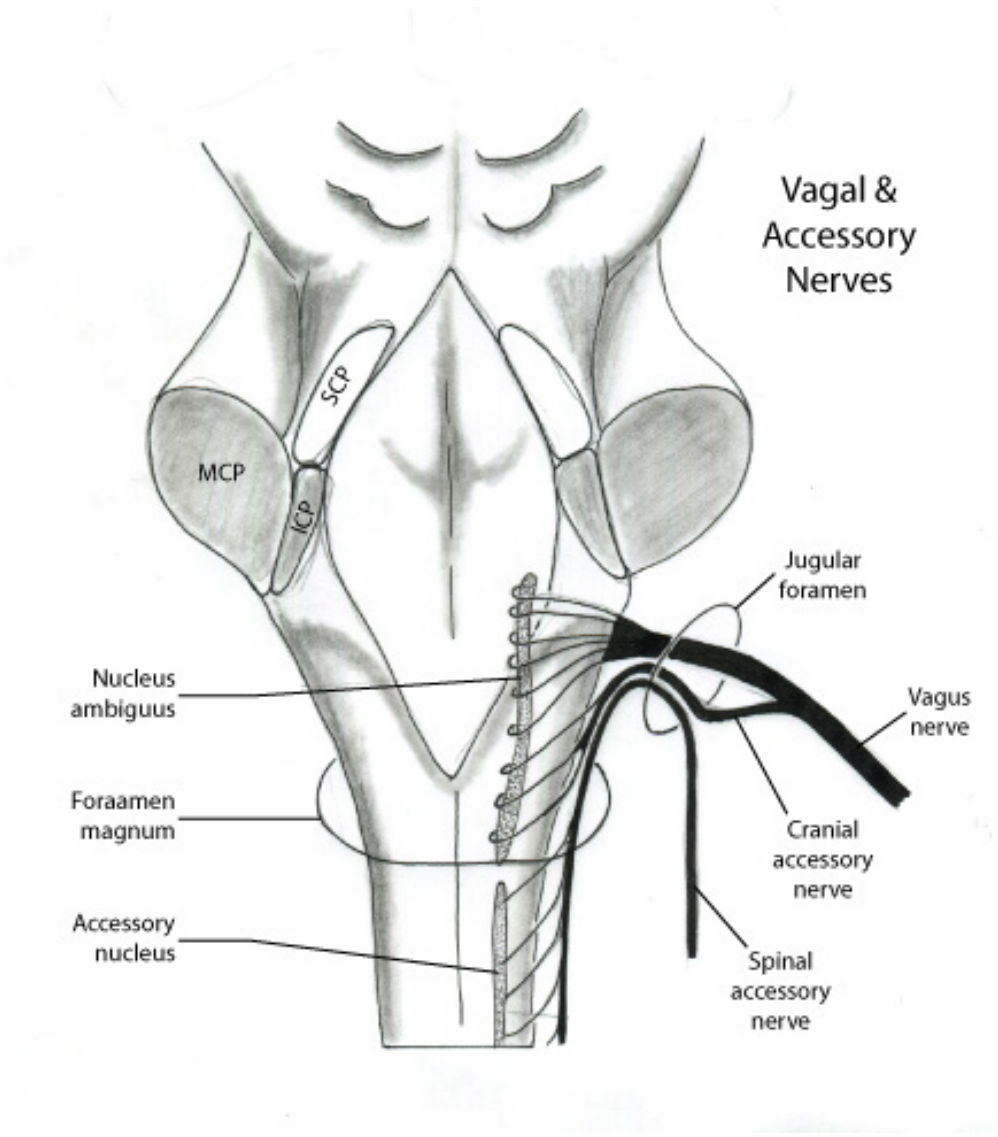


Figure 4-3. The origin of the spinal and cranial portions of the accessory nerve and the origin of portions of the vagus nerve

ed collection of cells and fibers lacking distinct nuclear borders. It extends throughout the rostrocaudal length of the medulla (see Plates 6 to 11), continuing through the pons (see Chapter 5), and into midbrain (see Chapter 7). Clusters of neurons in the reticular formation are involved in regulating cardiovascular and pulmonary functions as well as other autonomic nervous system processes. Descending autonomic fibers are found coursing along the dorsolateral aspect of the reticular formation, in close juxtaposition with the spinal trigeminal complex and the rubrospinal fibers. These fibers originate in the hypothalamus (see Plate 22) and brain stem and terminate in the nucleus intermediolateralis of the thoracic (see Plate 3) and upper lumbar spinal cord. They provide central control over spinally mediated autonomic functions.

CLINICAL DISCUSSION: Lesions of the reticular formation can present with dysautonomia, such as tachycardia and non-rhythmic respiration rates (Caplan, 1989). Lesions of the descending autonomic fibers can present as Horner's syndrome—ptosis, miosis, and anhidrosis—on the ipsilateral face (Caplan and Stein, 1986). Unilateral lesions in the medullary reticular formation, positioned between the inferior olive medially and the inferior cerebellar peduncle laterally at the pontomedullary junction, can interrupt autonomic breathing (Bogousslavsky et al., 1990). Large, unilateral lesions in the medullary reticular formation can disrupt automated breathing control and produce "Ondine's Curse", in which patients cease breathing when they fall asleep. These lesions are invariably lethal at some stage in the disease.

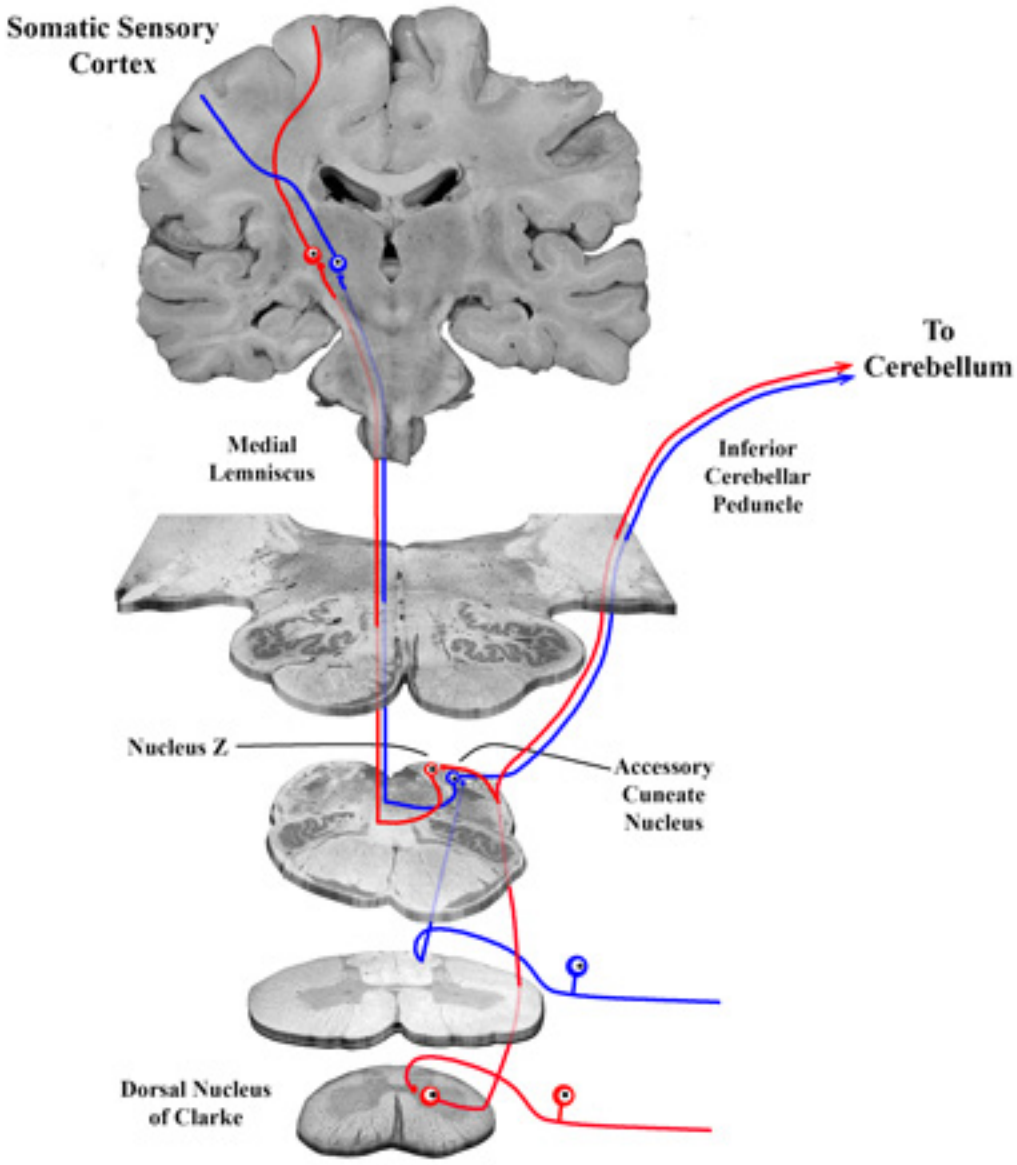


Figure 4-4. The origin and course of the spinocerebellar system

Atlas Plate 7

Go to the Atlas

Atlas Plate 7 is positioned between the pyramidal decussation caudally and the obex (the opening of the central canal into the fourth ventricle) rostrally. The prominent features of this section are three large sensory nuclei located dorsally (nucleus gracilis and cuneatus and the spinal trigeminal nucleus), decussation of the medial lemniscus centrally, and the medullary pyramidal tract ventrally.

NUCLEUS AMBIGUUS (NuAm)

The nucleus ambiguus, a long, thin column of motoneurons in the lateral medulla, is associated with the vagal complex (Figure 3-6 and Figure 4-7). It extends from the level of the decussation of the medial lemniscus (see Plate 7) to the rostral portion of the inferior olive (see Plate 11). Motoneurons in this nucleus provide innervation to muscles in the pharynx and larynx via the ipsilateral vagus and glossopharyngeal nerves (Figure 4-6) and contribute to the cranial portion of the ipsilateral spinal accessory nerve. This nucleus plays a critical role in phonation and de-glutition. Portions of the nucleus ambiguus and the dorsal motor nucleus of the vagus supply parasympathetic innervation to the heart (Natelson, 1985).

CLINICAL DISCUSSION: A unilateral lesion of the vagal complex (including the nucleus ambiguus) or its efferent fibers results in hoarseness or dysphonia (which can be expressed as a nasal twang), dysphagia (difficulty swallowing), dyspnea (difficulty breathing), diminished gag reflex, and perhaps hiccups (Caplan and Stein, 1986). The palatine arch is flattened ipsilateral to the lesion and fails to elevate on that side. A bilateral lesion of the vagal nerve can produce bilateral palatine droop and profound dysphagia and dyspnea to the point of respiratory embarrassment (Bogousslavsky et al., 1990; Brazis, 2001). The feeling of dyspnea or "shortness of breath" secondary to vocal cord hemiparesis has been termed pseudoasthma.

SOLITARY NUCLEUS (SolNu)

The solitary nucleus (SolNu) is a long column of cells oriented caudal-to-rostral and located in the dorsocentral medulla (Figure 4-6 and Figure 4-7), extending from the level of the decussation of the medial lemniscus (see Plate 7) to that of the rostral portion of the inferior olivary nucleus (see Plate 11). In all but the extreme caudal portion of the solitary nucleus, it surrounds the solitary tract. It is through this tract that the solitary nucleus receives afferent fibers carrying visceral sensory information from the facial, glossopharyngeal, and vagus nerves. The rostral pole of the solitary complex, called the gustatory nucleus, receives afferent fibers from taste buds in the tongue through cranial nerves VII, IX, and X. The more caudal portions of the nucleus receive visceral afferent fibers from the pharyngeal and laryngeal walls, as well as from the cardiovascular and gastrointestinal systems. Closely related to the solitary complex are the chemical trigger zone and vomit center.

Rostrally in the medulla, the solitary tract (see Plates 8 to 11) is seen as a compact fiber bundle surrounded by solitary nucleus; caudally, the tract diminishes and the nucleus approaches the midline to fuse with its counterpart from the opposite side (see Plate 7), forming the commissural nucleus of the vagus. The solitary tract is composed of primary afferent fibers from the facial, glossopharyngeal, and vagal nerves.

Cells in the solitary nucleus send axons to many regions of the surrounding brain stem such as the nucleus ambiguus, dorsal motor nucleus of the vagus, and hypoglossal nucleus, as well as ascending projections to the hypothalamus and thalamus. From the thalamus this information is sent to the primary visceral cortex located in the insula of the cerebral cortex. As such, the solitary nucleus is a major relay of visceral sensory information to the upper brainstem and ventral forebrain.

CLINICAL DISCUSSION: Dyspnea, pseudoasthma, vomiting and possibly coughing due to interruption of the vagal reflex arcs are signs of damage in the vicinity of the solitary nucleus or its connections. Diminution or loss of the gag reflex can result from lesions of the vagal afferent fibers or the solitary nucleus or tract. Loss of taste can result from damage to the gustatory component of the solitary nucleus.

Highlight Point

The clinical manifestations of unilateral damage to the nucleus ambiguus or its radiations, or the vagus nerve, can involve:

Dysphonia

Dysphagia

Dyspnea

DORSAL MOTOR NUCLEUS OF THE VAGUS (DMNu)

The dorsal motor nucleus (DMNu) is a long column of cells located in the central gray area between the solitary complex and the hypoglossal nucleus (Figure 4-6 and Figure 4-7). It extends from the caudal medulla (see Plate 7) to the level of the rostral portion of the inferior olivary nucleus (see Plate 10). The dorsal motor nucleus is composed of preganglionic, parasympathetic neurons of the vagus nerve and provides innervation to the viscera of the thoracic and abdominal cavities. It receives afferent fibers from the solitary nucleus as well as descending fibers from the hypothalamus.

CLINICAL DISCUSSION: Bilateral lesions involving the dorsal motor nucleus can result in loss of parasympathetic outflow to the viscera. Clinical indications of this are tachycardia and dilation of the stomach.

HYPOGLOSSAL NUCLEUS (HyNu)

The hypoglossal nucleus (HyNu) is a long column of motoneurons located in the ventral aspect of the central gray and extending from the caudal border of the medulla (see Plate 7) to the midpoint on the long axis of the inferior olivary nucleus (see Plate 9 and Figure 4-8). Its cells constitute the motoneurons of cranial nerve XII, providing innervation to the intrinsic muscles of the tongue. Portions of this nucleus receive a bilateral innervation from corticonuclear fibers; however, those motoneurons controlling the genioglossus muscle are predominantly innervated by the contralateral cerebral cortex.

CLINICAL DISCUSSION: Damage to the hypoglossal nucleus (or the radiations of its nerve) results in denervation of the tongue. Clinically, the tongue deviates toward the side of the lesion on attempted protrusion. In addition, atrophy and fasciculations

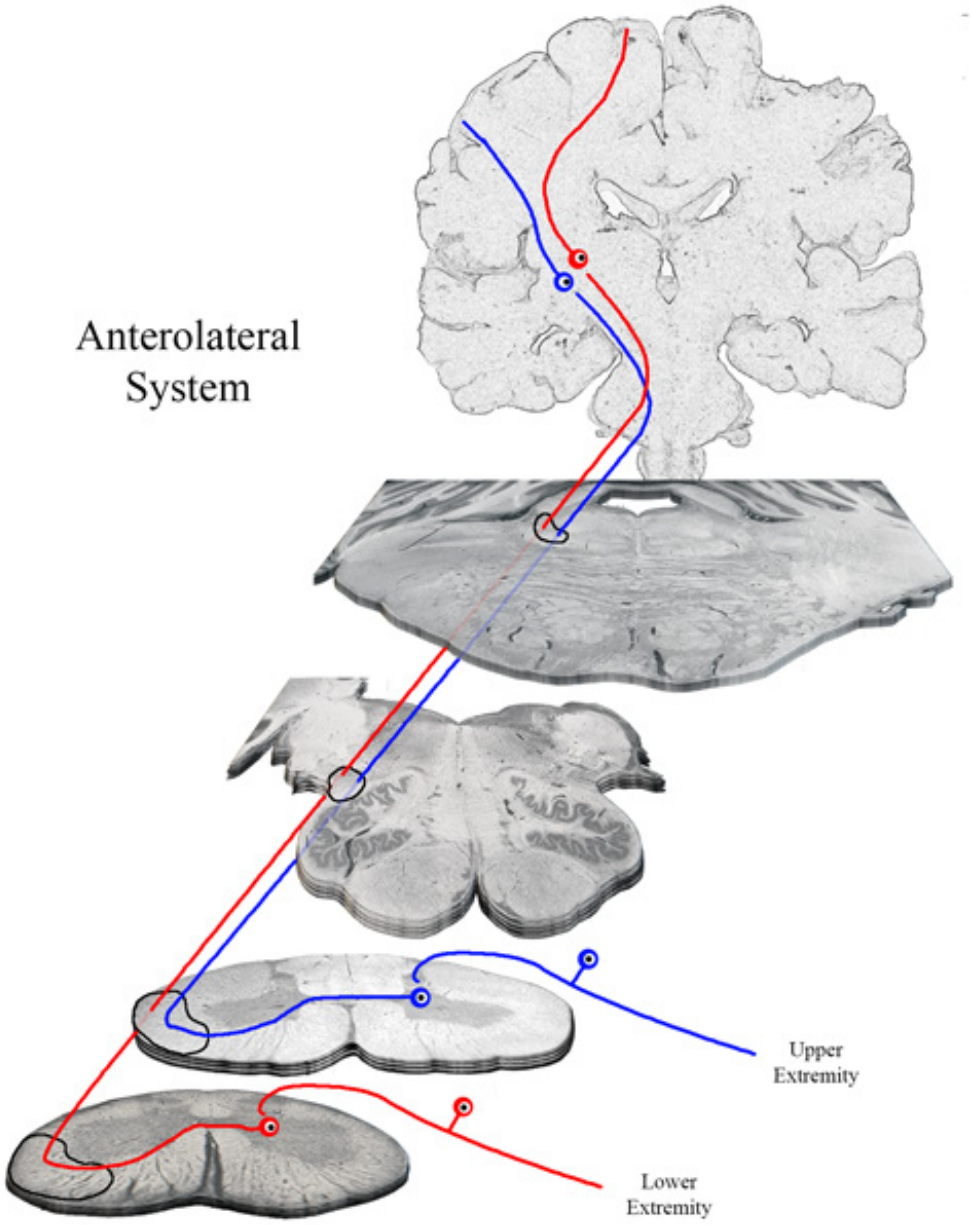


Figure 4-5. The origin and course of the anterolateral system in the brainstem

are present in the muscles of the tongue on the side of the lesion (Haymaker and Kulhlenbeck, 1976).

Lesions of the cerebral cortex or corticonuclear fibers can also cause dysfunction in the hypoglossal nucleus. The genioglossus muscle is mainly innervated by crossed corticonuclear fibers; it will weaken with supranuclear lesions. The tongue deviates to the side opposite the supranuclear lesion; however, fasciculations and atrophy are not present (Brazis, 1996b).

PYRAMIDAL TRACT (Py)

The pyramidal tract (Py) is located in the ventromedial aspect of the medulla next to the medial accessory olivary nucleus. Its fibers originate from neurons in the motor area of the cerebral cortex. These fibers control the mastery of fine, discriminative movements of the extremities, particularly the distal musculature (Kennedy, 1990). At the cervicomedullary junction (see Plate 6), the pyramidal tract decussates to the contralateral side and divides to form the lateral and anterior corticospinal tracts (see Plate 5).

CLINICAL DISCUSSION: A lesion of the pyramidal tract in humans can initially result in flaccid paralysis that eventually resolves into hypertonia and spastic paralysis (Jagiella and Sung, 1989;Paulson et al., 1986;Milandre et al., 1990), as well as the Babinski sign. The deficits appear in the limbs on the side contralateral to the lesion. In the medulla, the pyramidal tract passes close to the radiations of the hypoglossal nerve. Damage to one can involve damage to the other simultaneously. The clinical scenario for this situation features ipsilateral flaccid paralysis of the tongue and contralateral paralysis of the extremities, a presentation termed medial medullary syndrome or inferior alternating hemiparesis.

Highlight Point

The clinical manifestations of damage to the hypoglossal nucleus, its radiations or the hypoglossal nerve can include:

Ipsilateral flaccid paralysis of the tongue

Deviation of the tongue to the injured side on attempted protrusion

Fasciculations of the surface of the tongue

INTERNAL ARCUATE FIBERS (IAF)

The dorsal column nuclei (nucleus gracilis and cuneatus; Plates 6 to 8) project axons to the contralateral thalamus. As these axons leave the ventral surface of their nucleus, they swing medially in a

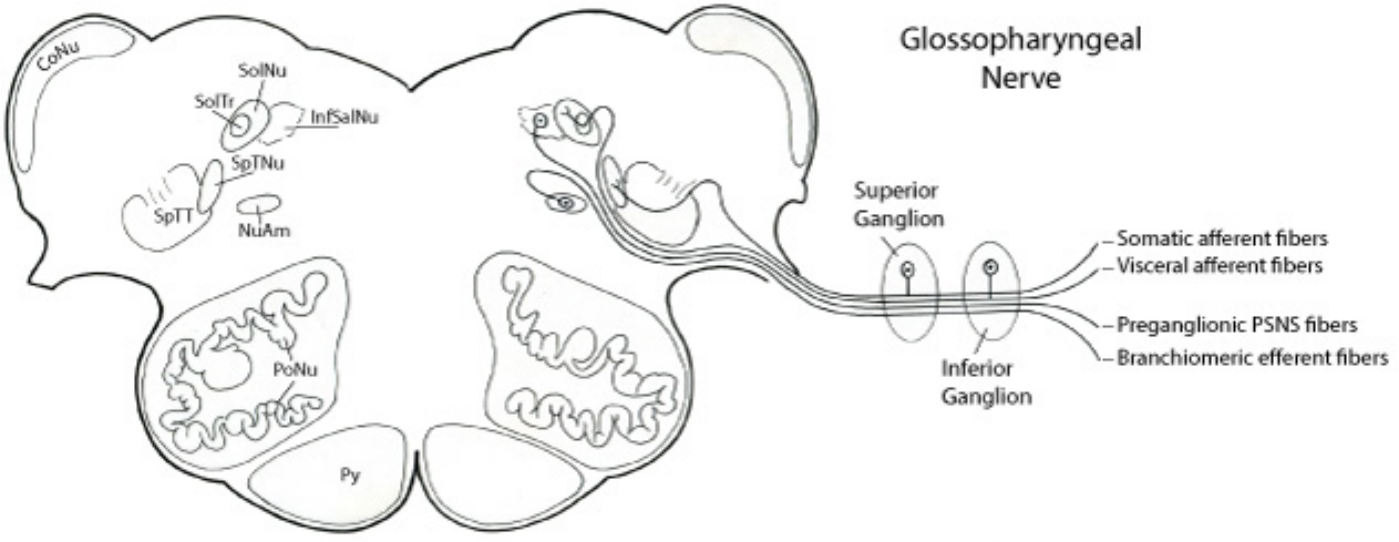


Figure 4-6. A medullary section (similar to Plate 11) illustrating the origin of the motor and sensory components of the glossopharyngeal nerve (modified from Barr and Kiernan, 1988)

prominent arc, forming the internal arcuate fibers (IAF), decussate over the midline, and gather into the medial lemniscus (see Plate 8). This latter tract ascends through the brain stem to reach the ventroposterior lateral nucleus of the thalamus (see Plate 21).

CLINICAL DISCUSSION: Damage to the internal arcuate fibers can present with loss of discriminative touch and vibratory sense as well as a loss of position sense without the accompanying ataxia. These results are similar to those involving damage to the medial lemniscus, however, unlike the situation with the medial lemniscus, the clinical signs all appear ipsilateral to the lesion. Damage to the decussation of the medial lemniscus on the midline can result in deficits that present bilaterally.

MEDIAL LONGITUDINAL FASCICULUS (MLF)

The medial longitudinal fasciculus (MLF or medial vestibulospinal tract) has moved from its lateral position on the previous plate (see Plate 6) into its more typical position along the midline of the brain stem, dorsal to the tectospinal tract. For the remaining sections through the rostral medulla (see Plates 7 to 11), these two tracts, plus the medial lemniscus and pyramidal tract, form a midline column of white matter.

MEDIAL ACCESSORY INFERIOR OLIVARY NUCLEUS (MAONu)

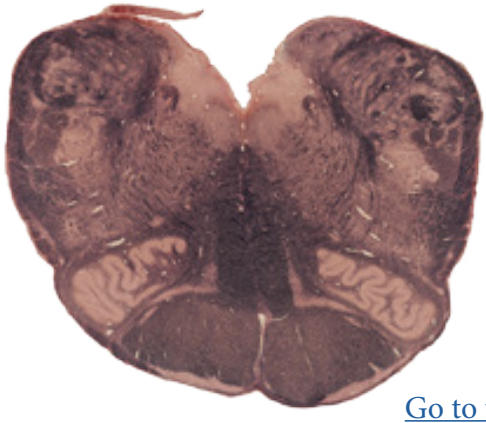
A thin, angular band of cells in the ventral medulla is the first indication of the large inferior olivary complex (see Plates 8 to 12). The medial accessory inferior olivary nucleus (MAONu), visible in Plate 7, will be replaced laterally, at more rostral levels by the principal nucleus of the inferior olive. Like the principal nucleus, the medial accessory nucleus projects its axons to the cerebellum.

Review Structures From Preceding Plates

Identify the following structures from preceding sections:

- Gracile fasciculus and nucleus (FGr and NuGr)
- Cuneate fasciculus and nucleus (FCu and NuCu)
- Spinal trigeminal nucleus (SpTNu) and tract (SpTT)
- Anterolateral system (ALS)
- Dorsal spinocerebellar tract (DSCT)
- Ventral spinocerebellar tract (VSCT)
- Rubrospinal tract (RuSp)
- Tectospinal tract (TecSp)
- Vestibulospinal and reticulospinal tracts (VesSp and RetSp)

Atlas Plate 8



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The section in Plate 8 is located in the caudal medulla, rostral to the obex and passing through the olivary tubercle. Its salient features are the opening of the fourth ventricle and the presence of the

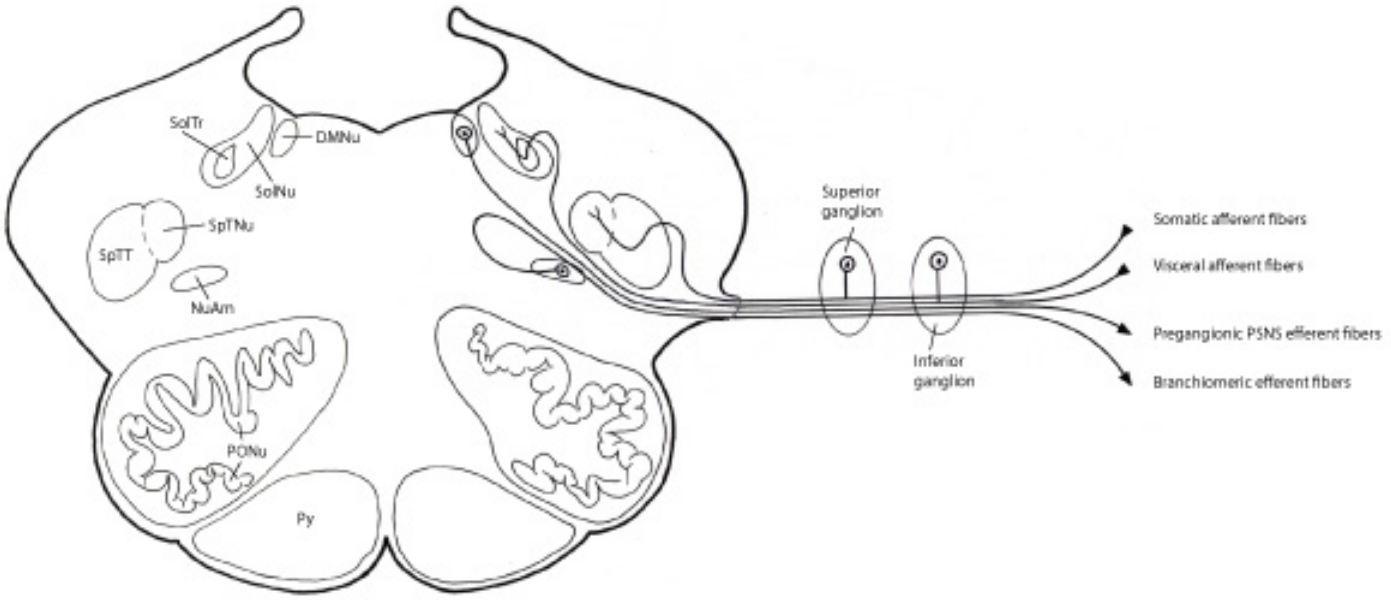


Figure 4-7. A medullary section (similar to Plate 10) illustrating the origin of the motor and sensory components of the vagus nerve in the medulla (modified from Barr and Kienan, 1988)

principal inferior olivary nucleus.

LATERAL (ACCESSORY OR EXTERNAL) CUNEATE NUCLEUS (LCNu)

The lateral cuneate nucleus appears as swirled masses of gray embedded in the lateral portion of the fasciculus cuneatus. It receives large-caliber, primary afferent fibers from peripheral nerves in the ipsilateral upper extremity. These fibers convey proprioceptive information from individual muscles. Lateral cuneate neurons give rise to axons that join the ipsilateral inferior cerebellar peduncle (see Plates 8 to 14) and terminate in the cerebellum. The lateral cuneate nucleus performs a function similar to that of the dorsal nucleus of Clarke in the spinal cord (see Plate 3), with the exception that its source of proprioception is large-caliber primary afferent fibers from the upper extremity, whereas the dorsal nucleus of Clarke receives its sensory information from the lower extremity.

CLINICAL DISCUSSION: Damage to the lateral aspect of the spinal cord or to the inferior cerebellar peduncle in which lateral cuneocerebellar fibers course can result in ataxia in the upper extremity on the side ipsilateral to the lesion (Peterman and Siekert, 1960).

PRINCIPAL INFERIOR OLIVARY NUCLEUS (PONu)

The highly convoluted principal inferior olivary nucleus (PONu) extends throughout most of the ventrolateral medulla (see Plates 8 to 12). The massive expansion in size of this nucleus in primates has created an enlargement, the olivary tubercle, on the external surface of the medulla. Two additional structures are in close juxtaposition with the principal nucleus: the dorsal accessory nucleus and the medial accessory nucleus of the inferior olive.

The principal nucleus receives input ipsilaterally from the red nucleus, contralaterally from the spinal cord and dorsal column nuclei, and bilaterally from the cerebral cortex. Its axons, known as

Highlight Point

The clinical manifestations of damage to the pyramidal tract can involve:

Contralateral weakness
and spasticity

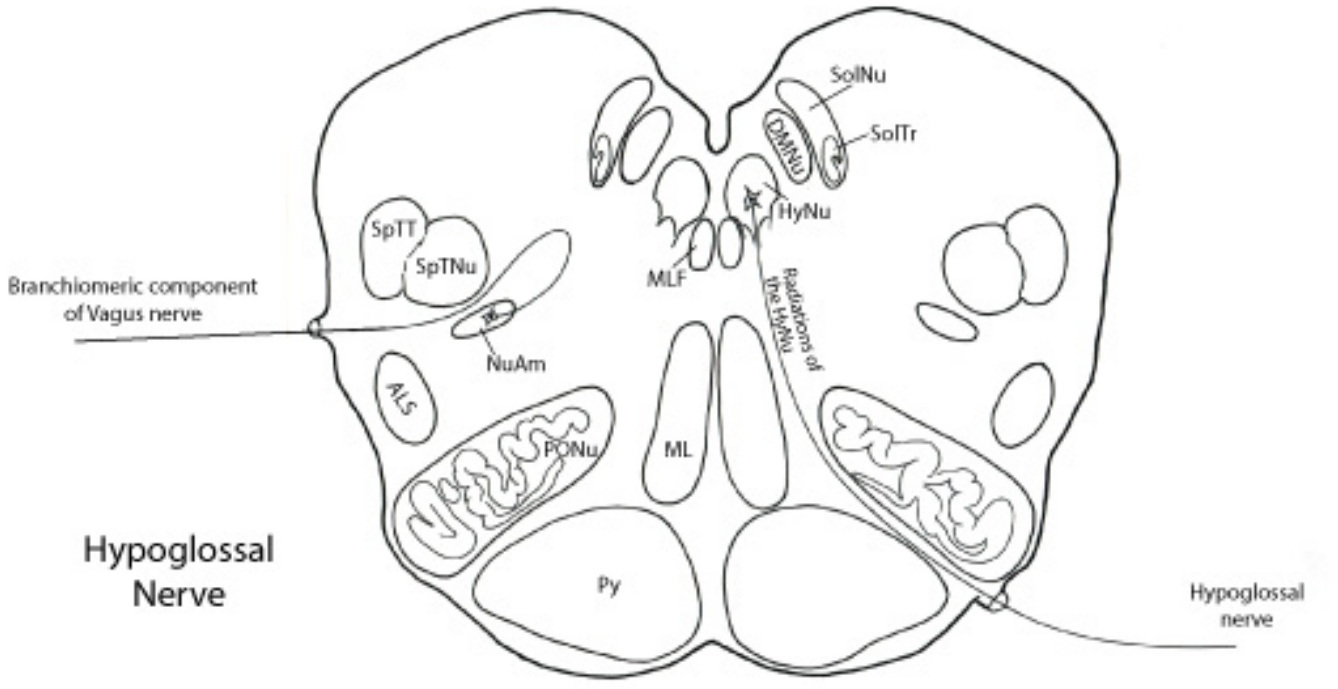


Figure 4-8. The origin of the hypoglossal nerve and cranial portion of the accessory nerve from the caudal medulla

climbing fibers, have a powerful influence on the activity of Purkinje cells in all parts of the contralateral cerebellum. It is part of the cerebellar system of motor control and training.

CLINICAL DISCUSSION: Clinical evaluation of the inferior olive in humans is not done routinely. Destruction of the inferior olivary nucleus in nonhuman primates diminishes the ability of the animal to learn new skilled motor activities (Ito, 1984).

The concept that the inferior olive is involved in motor learning has received additional support in recent studies where motor learning defects were described in patients with degenerative disease of the inferior olive (Sanes et al., 1990;Thach et al., 1992).

MEDIAL LEMNISCUS (ML)

Large, myelinated axons from cells in the dorsal column nuclei cross the midline as the internal arcuate fibers and coalesce into a long, narrow bundle called the medial lemniscus (ML). These fibers are joined by axons from nucleus Z in the caudal medulla (Figure 4-4). The fibers of the medial lemniscus proceed rostrally (see Plates 8 to 20) through the medulla, pons, and midbrain to terminate in the ventroposterior lateral nucleus of the thalamus (see Plate 21), contralateral to its origin. Throughout most of its course, the medial lemniscus occupies a position dorsal to the pyramidal tract and close to the midline. Since this tract is composed of output from the dorsal column nuclei and nucleus Z, it contains most of the ascending information on two-point discrimination as well as vibratory and position sense.

CLINICAL DISCUSSION: The medial lemniscus contains the output from the dorsal column nuclei and nucleus Z. Thus, damaging this tract is similar to combined lesions of the dorsal columns of the spinal cord and the cuneo- and dorsal spinocerebellar tracts. The patient experiences loss of two-point discrimination, position, and vibratory sense. Since, however, the axons of the medial lemniscus have crossed the midline in the internal arcuate fibers, its clinical signs localize on the side of the body contralateral to the lesion. Finally, the finding of a small lesion in the ventral portion of the medial lemniscus has been used to demonstrate the topographic order of the medial lemniscal fibers (Lee et al., 2001). The ventral portion of the fiber pathway contains representation of the lower extremity and the dorsal portion, the upper extremity.

CENTRAL TEGMENTAL TRACT (CTT)

The central tegmental tract (CTT) is a large bundle of fibers forming the major ascending and descending pathways for intrinsic structures of the brain stem. It links the rostral brain stem with the medulla. Among other things, the tract carries axons from the gustatory nuclei in the rostral portion of the solitary complex to the thalamus.

The caudal extreme of this tract surrounds the inferior olivary nucleus (see Plate 8); rostrally, it extends beyond the red nucleus of the midbrain to reach the intralaminar nuclei of the thalamus (see Plate 21). Throughout the brain stem, it courses approximately in the center of the reticular formation.

CLINICAL DISCUSSION: Destruction of the central tegmental tract is reported to result in palatal myoclonus, which presents as rhythmic contractions of the palate.

INFERIOR CEREBELLAR PEDUNCLE (ICP)

The inferior cerebellar peduncle (ICP) is a massive fiber bundle formed by the union of the dorsal spinocerebellar tract and the olivocerebellar fibers from the contralateral inferior olive, that passes upward from the dorsolateral surface of the medulla to enter the cerebellum (see Plates 8 to 14). In its ascent it is joined by cuneocerebellar axons from the accessory cuneate nucleus. These fiber tracts carry proprioceptive information from the musculoskeletal system and terminate primarily in the anterior lobe of the cerebellum.

CLINICAL DISCUSSION: The destruction of the inferior cerebellar peduncle can result in ataxic movements of the extremities on the ipsilateral side of the body (Adams et al., 1997). Clinically, this presents as veering or leaning to the side of the lesion, and clumsiness with the ipsilateral hand (Caplan and Stein, 1986).

DORSAL LONGITUDINAL FASCICULUS (DLF)

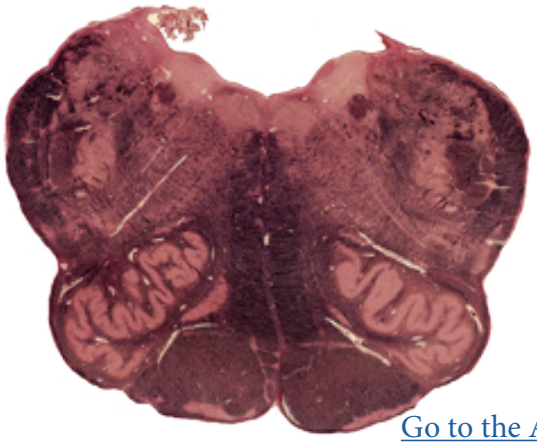
A small fiber bundle located in the dorsal and medial portion of the medulla represents the dorsal longitudinal fasciculus (DLF). This composite tract extends from the hypothalamus (see Plate 22) to the caudal aspect of the medulla. Fibers from the hypothalamus, descending in this fasciculus, influence the brain stem nuclei involved in regulating the autonomic nervous system.

Review Structures From Preceding Plates

Identify the following structures from preceding sections:

- Cuneate nucleus (NuCu) and fasciculus (FCu)
- Nucleus ambiguus (NuAm)
- Hypoglossal nucleus (HyNu)
- Spinal trigeminal nucleus (SpTNu) and tract (SpTT)
- Pyramidal tract (Py)
- Internal arcuate fibers (IAF)
- Anterolateral System (ALS)
- Rubrospinal tract (RuSp)
- Vestibulospinal and reticulospinal tracts (VesSp and RetSp)
- Medial longitudinal fasciculus (MLF)
- Tectospinal tract (TecSp)
- Dorsal motor nucleus of the vagus (DMNu)
- Medial accessory nucleus of the inferior olive (MAONu)
- Ventral spinocerebellar tract (VSCT)

Atlas Plates 9 and 10



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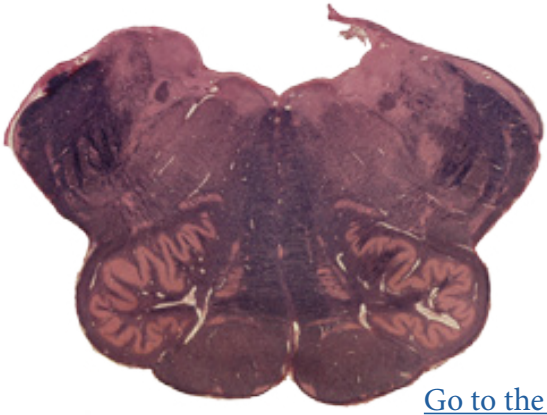

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Atlas Plates 9 and 10 are taken from the central portion of the medulla. The salient features of these sections are the expanded size of the inferior cerebellar peduncle and the prominent inferior olive.

MEDIAL VESTIBULAR NUCLEUS (MVNu)

The medial vestibular nucleus (MVNu) is located dorsolateral to the dorsal motor nucleus and solitary complex of the vagus. It is involved in coordinating head, neck, and eye movements. The nucleus receives primary afferent fibers from the semicircular canals of the ipsilateral vestibular apparatus and projects ascending and descending fibers into the medial longitudinal fasciculus. The descending fibers are distributed bilaterally to the spinal cord. At the cervicomedullary junction, this fiber tract is often renamed the medial vestibulospinal tract. Some of the ascending fibers from the medial vestibular nucleus reach the contralateral abducens nucleus; this connection is a major component of vestibular control over horizontal gaze (see Chapter 5).

CLINICAL DISCUSSION: Damage to the medial vestibular spinal tract in the medulla has been noted to produce a nystagmus.

SPINAL VESTIBULAR NUCLEUS (SpVNu)

The spinal (or inferior) vestibular nucleus (SpVNu) is located between the medial vestibular and the lateral cuneate nuclei. It is the most caudal nucleus of the vestibular complex. Primary afferent fibers to the spinal vestibular nucleus arise in the saccule and utricle of the ipsilateral vestibular apparatus; the efferent fibers of this nucleus enter the inferior cerebellar peduncle and terminate in the ipsilateral cerebellum. It also innervates the ipsilateral inferior olivary nucleus.

CLINICAL DISCUSSION: Damage to the vestibular nuclei or their tracts in the medulla can result in the central vestibular syndrome. The three signs are nystagmus, vertigo, and the presence of a Romberg sign. Unlike the peripheral vestibular syndrome, the central vestibular syndrome is said to be more permanent in nature. It also differs in the consistency of its presentation. The nystagmus can be of multiple different types: unilateral, bilateral, horizontal, rotary, or vertical. Nystagmus of central vestibular origin usually is not altered by visual fixation. The vertigo experienced in central vestibular syndrome can be ill defined and continuous, and the Romberg sign, elicited by closing the eyes while standing, can occur to either side (Biller and Brazis, 1996b).

LATERAL RETICULAR NUCLEUS (LRNu)

The lateral reticular nucleus (LRNu) is found in the ventrolateral medulla, positioned between the rubrospinal tract (dorsally) and the anterolateral system (ventrally). It receives fibers from a variety of sources (e.g., the spinal cord, cerebral cortex, and red nucleus) and projects its axons, via the inferior cerebellar peduncle, to the ipsilateral cerebellum.

PREPOSITUS HYPOGLOSSAL NUCLEUS (NuPP)

The nucleus prepositus hypoglossi (NuPP; Plates 10 and 11) is located in the dorsal medulla between the hypoglossal (see Plate 9) and abducens nuclei (Plate 12). It receives information from the cerebellum, accessory optic nuclei in the midbrain, and vestibular nuclei. It projects to all the extraocular eye muscle motor nuclei: abducens, trochlear, and oculomotor, as well as to the paramedian pontine reticular formation, a region that controls conjugate horizontal eye movements (see Chapter 4). The prepositus hypoglossal nucleus participates in controlling eye movements, possibly by stabilizing the eyes in their new position following a saccade. Electrical stimulation of the nucleus results in ipsilateral conjugate horizontal movement of the eyes.

CLINICAL DISCUSSION: Lesions in this area of the brain stem, of nonhuman primates, disturb optokinetic eye movements (Bender, 1980).

DORSAL ACCESSORY INFERIOR OLIVARY NUCLEUS (DAONu)

The dorsal inferior accessory nucleus is a narrow band of olivary neurons on the dorsomedial border of the inferior olive. Like the principal nucleus of the olive, it projects its axons to the cerebellum.

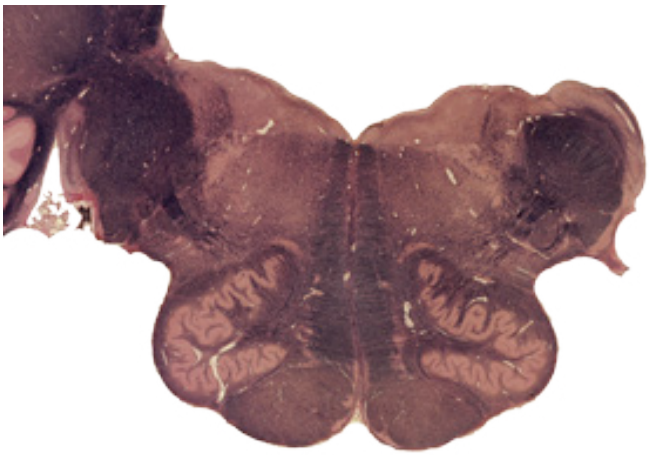
Review Structures From Preceding Plates

Identify the following structures from preceding sections:

- Lateral cuneate nucleus (LCNu)
- Solitary nucleus (SolNu) and tract (SolTr)
- Dorsal motor nucleus of the vagus (DMNu)

- Nucleus ambiguus (NuAm)
- Hypoglossal nucleus (HyNu)
- Spinal trigeminal nucleus (SpTNu) and tract (SpTT)
- Principal olivary nuclei (PONu)
- Inferior cerebellar peduncle (ICP)
- Central tegmental tract (CTT)
- Pyramidal tract (Py)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Rubrospinal tract (RuSp)
- Vestibulospinal and reticulospinal tracts (VesSp and RetSp)
- Medial longitudinal fasciculus (MLF)
- Dorsal longitudinal fasciculus (DLF)
- Tectospinal tract (TecSp)

Atlas Plate 11



Go to the Atlas

Atlas Plate 11 passes through the medulla as the inferior cerebellar peduncle begins its ascent into the cerebellum. The cochlear nucleus, overhanging the inferior cerebellar peduncle, is a prominent feature of this section.

COCHLEAR NUCLEUS (CoNu)

The cochlear nucleus (CoNu) is the first nucleus in the central auditory pathways. It receives primary afferent fibers from the ipsilateral auditory nerve and its projections reach the superior olivary nuclei bilaterally (Plate 14) as well as the contralateral inferior colliculus (Plate 17).

CLINICAL DISCUSSION: Destruction of a cochlear nucleus can result in unilateral sensorineural deafness, ipsilateral to the lesion.

SUPERIOR VESTIBULAR NUCLEUS (SVNu)

The superior vestibular nucleus (SVNu) is a small cluster of neurons positioned dorsal to the lateral vestibular nucleus along the lateral wall of the fourth ventricle. The superior vestibular nucleus receives primary afferent fibers from the semicircular canals of the ipsilateral vestibular apparatus as well as axons from the cerebellum. It projects ascending axons into the medial longitudinal fasciculus to innervate the extraocular eye muscle motor nuclei. This nucleus and its connections are a part of the vestibular system involved in coordinating head and eye movements.

INFERIOR SALIVATORY NUCLEUS (ISNu)

The inferior salivatory nucleus (ISNu) is located at the rostral end of the dorsal motor nucleus of the vagus and ventral to the medial vestibular nucleus. It contains preganglionic, parasympathetic neurons that innervate the otic ganglion and control secretions of the parotid gland.

CLINICAL DISCUSSION: Lesion of the inferior salivatory nucleus or of its efferent fibers in the glossopharyngeal nerve results in loss of salivary release from the ipsilateral parotid gland.

RAPHE NUCLEI (RaNu)

The raphe nuclei (RaNu) are located along the midline of the medulla, sandwiched between the two fiber bundles of the medial lemniscus. Many cells in this complex produce the neuromodulator serotonin. Their fibers form diffuse tracts that descend in the dorsolateral funiculus of the spinal cord and innervate the dorsal and ventral horns. One function of the raphe-spinal system is to modulate the processing of pain in the dorsal horns. Appropriate production of serotonin also seems to be necessary for the onset of sleep.

CLINICAL DISCUSSION: Information on isolated lesions of the raphe nuclei or raphe-spinal system in humans is unavailable; however, chemically blocking this system with naloxone in human subjects can decrease their threshold of pain (Basbaum and Fields, 1978).

Review Structures from Preceding Plates

Identify the following structures from preceding sections:

- Nucleus ambiguus (NuAm)
- Principal olivary nucleus (PONu)
- Solitary nucleus (SolNu) and tract (SolTr)
- Spinal trigeminal nucleus (SpTNu) and tract (SpTT)
- Spinal vestibular nucleus (SpVNu)
- Medial vestibular nucleus (MVNu)
- Prepositus hypoglossal nucleus (NuPP)
- Inferior cerebellar peduncle (ICP)

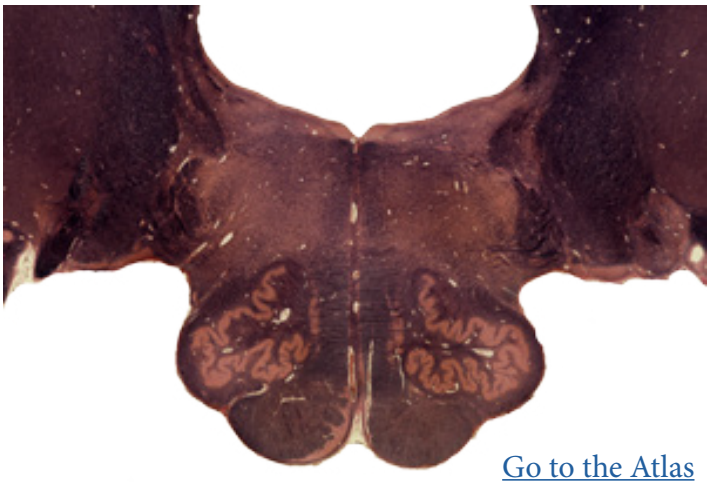
Highlight Point

The clinical manifestations of the peripheral vestibular system can involve:

Vertigo
Nystagmus
Limb drift
Rhomberg sign
Tinnitus

- Central tegmental tract (CTT)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Pyramidal tract (Py)
- RubrospinaI tract (RuSp)
- Medial longitudinal fasciculus (MLF)
- Dorsal longitudinal fasciculus (DLF)
- Dorsal accessory olivary nucleus (DAONu)

Atlas Plate 12



Go to the Atlas

Atlas Plate 12 straddles the pontomedullary junction. The dorsal portion of the section, containing the abducens motor nucleus and facial motor nucleus, enters the pons; the ventral portion passes through the olivary tubercle and pyramids of the medulla. The pontine portion will be examined in Chapter 5.

VESTIBULOCOCHLEAR NERVE ROOT (VCNr)

The vestibulocochlear nerve (VCNr) can be seen entering the brain stem laterally. It is positioned ventral to the middle cerebellar peduncle and in close juxtaposition with the pontobulbar nucleus. This nerve carries primary afferent fibers from the cochlea and the vestibular apparatus (utricle, sacculus, and three ampullae of the semicircular canals) to the brain stem. The cell bodies of origin for axons in this composite nerve are found in the spiral ganglion (cochlear portion of the nerve) and Scarpa's ganglion (vestibular portion of the nerve).

CLINICAL DISCUSSION: Damaging the vestibulo-cochlear nerve or the roots of the nerve as it enters the brainstem can result in unilateral deafness sometimes accompanied by tinnitus; it also can result in the peripheral vestibular syndrome featuring nystagmus, vertigo, limb drift, and a Romberg sign. Unlike the previously described central vestibular syndrome, vestibular syndrome arising from peripheral damage is usually short-lived, but can be accompanied by a severe, paroxysmal vertigo. Also, all of its signs tend to be aligned in one direction. The slow component of the ocular drift in nystagmus, the fall in the Romberg test, and the drift in the outstretched arm are to the side of the lesioned nerve (Biller and Brazis, 1996b).

LATERAL VESTIBULAR NUCLEUS (LVNu)

The lateral vestibular nucleus (LVNu) is wedged between the medial vestibular nucleus and the inferior cerebellar peduncle. It is penetrated by myelinated fibers and hence appears darkened in myelin-stained preparations. This nucleus receives primary afferent fibers from the utricle of the ipsilateral vestibular apparatus; it also receives a significant projection from the Purkinje cells in the ipsilateral cerebellum. Its axons innervate motoneurons in the limb portions of the ventral horn of the spinal cord via the lateral vestibulospinal tract. These fibers convey information with regard to posture and gravity to the motoneurons of the limb extensor muscles.

CLINICAL DISCUSSION: Isolated lesions of the lateral vestibular nucleus or its tract in humans have not been reported. However, damage done to this system in experimental situations with nonhuman mammals decreases the tone in the extensor muscles of the extremities (Lawrence and Kuypers, 1968b).

PONTOBULBAR NUCLEI (PBNu)

A thin band of cells under the inferior cerebellar peduncle is seen at the pontomedullary border. These cells form the pontobulbar nucleus (PBNu) and represent the caudal extension of the pontine nuclei. The nucleus receives axons from the contralateral cerebral cortex and forms projections to the contralateral cerebellum (Olszewski and Baxter, 1982). Its function is similar to that of the pontine nuclei and will be discussed in Chapter 5.

Review Structures From Preceding Plates

Identify the following structures from preceding sections:

- Principal olivary nuclei (PONu)
- Spinal trigeminal nucleus (SpTNu) and tract (SpTT)
- Cochlear nucleus (CoNu)
- Medial vestibular nucleus (MVNu)
- Superior vestibular nucleus (SVNu)
- Prepositus hypoglossal nucleus (NuPP)
- Inferior cerebellar peduncle (ICP)
- Central tegmental tract (CTT)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Pyramidal tract (Py)
- Rubrospinal tract (RuSp)
- Medial longitudinal fasciculus (MLF)
- Dorsal longitudinal fasciculus (DLF)
- Medial accessory inferior olivary nucleus (MAONu)

Case Study 4-2

Chief Complaint

This was a 43-year-old, right-handed man with a chief complaint of headaches, slurred speech, and weakness in his right arm and leg.

History of Chief Complaint

The headaches began 3 weeks ago, and 2 weeks ago he noticed the onset of limb weakness and slurred speech. These symptoms resolved in 12 hours and reccurred several times in the next 48 hours. Twelve days ago the neurologic symptoms reappeared rapidly. Currently, the headaches have abated, but the weakness and dysarthria remain.

Medical History

The patient was an accountant in a large business firm and regularly worked 60 to 70 hours per week. He was being treated for hypertension, but admitted to recently decreasing his medications without the consent of his physician. He had a 30-pack-year history of smoking and consumed several ounces of alcohol daily. He denied the use of alcohol during the past 24 hours.

General Physical Examination

This a stable, well-nourished, alert, oriented man who appeared his stated age. He could comprehend spoken and written language, but had dysarthria. His speech was thickened, as if his tongue was swollen. Heart sounds were normal, blood pressure was high (150/99). Pulse rate and respirations were normal; chest was clear to auscultation and percussion. Abdomen was soft with no lumps, masses, or tenderness.

Neurologic Examination

Mental Status. He was alert and oriented with respect to person, time and place. His speech was dysarthric; however, word-finding ability, comprehension, and repetition were all normal. His reading and writing were appropriate. His fund of knowledge was intact.

Cranial Nerves. His tongue deviated to the left on attempted protrusion. The surface of the tongue on the left side was wrinkled, and muscular fasciculations were present. All other cranial nerves were intact.

Motor Systems. His right upper and lower limbs were noticeably weaker than those on the left. He had elevated deep tendon reflexes in the right limbs and increased muscle tone in both right limbs. A Babinski reflex was present on the right. All other regions were intact.

Sensory. All sensory systems were intact. There was no loss of pinprick or thermal sensation, no loss of vibratory, discriminative sensation, and no loss of proprioception throughout his body.

Follow-up

Re-examination at 3 months following discharge finds that his speech has completely cleared and gross motor strength has returned to normal. His deep tendon reflexes remain elevated on the right upper and lower extremities.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious,? Is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problemIf the origin is vascular, what arterial supply is involved with the lesion in this patient?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

Medullary Vasculature

The medullary vasculature is derived from the vertebral and spinal arteries. These two sources represent the posterior circulatory contributions to the circle of Willis. Plates 6 through 12 illustrate the general distribution of these vessels in the medulla. Each vessel has perforating branches that perfuse a longitudinal zone of tissue. Although the spinal cord has only two vascular zones—anterior and posterior—supplied by separate arteries, a third or lateral zone has developed in the medulla (Duvernoy, 1978). Although sharp boundaries have been depicted for these zones in the atlas plates, it should be understood that considerable overlap and anastomosis could exist in vivo.

The anterior zone (fine screen shading, Plates 6 to 12) is perfused by medial branches of the anterior spinal artery caudally and medial branches of the basilar artery rostrally. This zone can be partitioned into anteromedial and anterolateral bundles of penetrating arteries. In total, the anterior zone supplies the midline structures, including the pyramidal tract, medial lemniscus, medial longitudinal fasciculus, and hypoglossal nucleus and its radiations.

In the caudal medulla, the lateral zone (no shading, Plates 6 to 12) receives its perfusion by the lateral branches from the vertebral and posterior inferior cerebellar artery. At more rostral levels, the circumferential or lateral branches of the basilar artery and the anterior inferior cerebellar artery perfuse this zone. The lateral circulation supplies the nucleus ambiguus of the vagus, portions of the spinal trigeminal nucleus and tract, ventral portions of the inferior cerebellar peduncle, the anterolateral system, and portions of the medullary reticular formation, including the descending fibers modulating the autonomic nervous system of the spinal cord.

The posterior zone (small crosses, Plates 6 to 12) is perfused by the posterior spinal artery and by posterior branches of the posterior inferior cerebellar artery caudally. Rostrally this zone is absent (Plate 13). The posterior circulation supplies the dorsal columns and their nuclei (gracilis and cuneatus), the caudal portion of the vestibular nuclei, the dorsal motor nucleus of the vagus, the inferior cerebellar peduncle, and portions of the spinal trigeminal nucleus and its tract.

Medullary Vascular Syndromes

Infarction or occlusion of a specific artery can lead to loss of function in the zone serviced by the damaged vessel and its branches. When this occurs in a penetrating vessel in a non-cortical portion of the cerebrum or brain stem, it is called a lacunar infarction. There are numerous constellations of presenting neurologic signs and symptoms that can be related to lacunar infarctions in the distribution of specific arteries. Such constellations are referred to as arterial syndromes. Adams and Victor present a detailed review of brain stem arterial or neurovascular syndromes (Adams et al., 1997). Four vascular-related sets of neurologic constellations are described in the clinical literature for the medulla: the medial, lateral, and unilateral medullary syndromes plus a lateral pontomedullary syndrome.

Medial Medullary Syndrome

Medial medullary syndrome (Table 4-1) involves reduced perfusion in the anterior zone of the medulla. It can result from damage to the vertebral or anterior spinal artery or their medial branches. Tissue destruction centers on midline structures. The neurologic presentation can involve spastic paralysis, weakness, and elevated tendon reflexes in the extremities on the contralateral side; flaccid paralysis, weakness, and fasciculations in the ipsilateral musculature of the tongue; and loss of primary sensory systems (tactile and proprioceptive sense) from the contralateral side of the body

(Adams et al., 1997). The combination of ipsilateral tongue paralysis and contralateral limb paralysis is referred to as inferior alternating hemiplegia. Presentation of the medial medullary syndrome is rare; however, when it does occur it can be bilateral in distribution (Bassetti et al., 1997;Gan and Noronha, 1995;Ho and Meyer, 1981;Kim et al., 1995;Toyoda et al., 1996). It also has been observed to occur consequent to intervenous injection of nonprescription drugs (Mizutani et al., 1980).

Lateral Medullary Syndrome

Lateral medullary syndrome (Table 4-2) involves reduction in perfusion to the lateral and/or posterior zones in the medulla. It can result from damage to the vertebral artery or its lateral branches, such as the posterior inferior cerebellar artery. The focus of tissue destruction lies in the upper lateral quadrant of the medulla (Baker, 1961). The neurologic presentation can involve numerous structures in the upper lateral quadrant of the medulla, such as the inferior cerebellar peduncle, spinal trigeminal complex, nucleus ambiguus, vestibular nuclei and anterolateral tract (Peterman and Siekert, 1960;Currier et al., 1961). The patient can present with any or all of the following: loss of pain and temperature sensation from the ipsilateral face and contralateral body, Horner's syndrome, hoarseness and dysphagia, ataxia of the ipsilateral limbs, vertigo, diplopia, nausea and vomiting, and nystagmus. The initial presentation may also include sharp, burning pains from the face presumably due to irritation of the trigeminothalamic fibers (Caplan and Gorelick, 1983). The loss of pain and temperature sensation from the ipsilateral face and contralateral body is called alternating analgesia.

Unilateral Medullary Syndrome

The unilateral medullary syndrome can result from complete occlusion of a vertebral artery. A caudal hemisection of the medulla is involved in the lesion, with restricted perfusion to all three zones: anterior, lateral, and medial. The neurologic presentation combines part or all of the medial and lateral medullary syndromes.

Lateral Pontomedullary Syndrome

The lateral pontomedullary syndrome can result from occlusion of the lateral perfusion branches of the basilar artery rostrally, at the pontomedullary junction. It presents with many of the same signs as seen in the lateral medullary syndrome: alternating analgesia, appendicular ataxia, and dysarthria; however, an ipsilateral facial paresis (facial nerve or nucleus) as well as vestibular dysfunction such as nystagmus (Fisher, 1989) and/or diminished hearing functions (cochlear nucleus and its efferent fiber tracts) can also occur (Brazis, 1996c).

NEUROLOGIC SIGN	ANATOMIC SOURCE
CONTRALATERAL	
Spastic paralysis	Medullary corticospinal tract
Diminished tactile and proprioceptive sense	Medial Lemniscus
Nystagmus	Medial Longitudinal Fasciculus
IPSILATERAL	
Tongue hemiparalysis with atrophy	Hypoglossal nucleus, radiations or nerve
Nystagmus	Medial longitudinal fasciculus

Table 3-1. Possible origins of neurological signs in the **medial medullary syndrome** (modified from Adams and Victor, 1997; Caplan and Stein, 1986)

NEUROLOGIC SIGN	ANATOMIC SOURCE
CONTRALATERAL	
Body hemianalgesia	Medullary corticospinal tract
IPSILATERAL	
Hemifacial analgesia	Spinal trigeminal nucleus and tract
Limb ataxia	Inferior cerebellar peduncle or spinocerebellar tracts
Nystagmus with diplopia	Medial Longitudinal Fasciculus
Horner's syndrome	Descending fibers controlling the autonomic nervous system
Hiccups	Medullary respiratory control system
Dysphagia, dysphonia and dyspnea	Vagal and glossopharyngeal structures
Body hemiparesthesias	Irritation of the dorsal column-medial lemniscal system
Headache in upper cervical region	Arterial irritation

Table 3-2. Possible origins of neurologic signs in the **lateral medullary syndrome** (modified from Adams and Victor, 1997; Caplan and Stein, 1986)

References

Amarenco P, Hauw J-J (1990) Cerebellar infarction in the territory of the superior cerebellar artery: a clinicopathologic study of 33 cases. Neurol 40: 1383-1390.

Aston-Jones G, Foote S, Bloom FE (1984) Anatomy and physiology of locus coeruleus neurons: functional implications. In: Norepinephrine (Ziegler MG, Lake CR, eds), pp 92-116. Baltimore: Williams and Wilkins.

Autret A, Laffont F, de Toffol B, Cathala HP (1988) A syndrome of REM and non-REM sleep reduction and lateral gaze paresis after medial tegmental pontine stroke. Arch Neurol 45: 1236-1242.

Basbaum AI, Fields HL (1978) Endogenous pain control mechanisms: Review and hypothesis. Ann Neurol 4: 451-462.

Beitz AL (1990) Central gray. In: The Human Nervous Sytem (Paximos G, ed), pp 307-329. San Diego, CA: Academic Press, Inc.

Bender MB (1980) Brain control of conjugate horizontal and vertical eye movements. A survay of the structural and function correlates. Brain 103: 23-69.

Biller J, Brazis PW (1996) The localization of lesions affecting cranial nerve VIII (The vestibulocochlear nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 293-314. Boston: Little, Brown and Company.

Brazis PW (1996b) The localization of lesions affecting cranial nerve V (The trgeminal nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 251-270. Boston: Little, Brown and Company.

Brazis PW (1996a) The localization of lesions affecting cranial nerve VII (The facial nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 271-292. Boston: Little, Brown and Company.

Brugge JF, Geisler CD (1978) Auditory mechanisms of the lower brainstem. Ann Rev Neurosci 1: 363-394.

Caplan LR (1988) Posterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 409-415.

Cascino GD, Adams RD (1986) Brainstem auditory hallucinosis. Neurol 36: 1042-1047.

Chan-Palay V, Asan E (1989b) Alterations in catecholamine neurons of the locus coeruleus in senile dementia of the Alzheimer type and in Parkinson's disease with and without dementia and depression. J Comp Neurol 287: 373-392.

Chan-Palay V, Asan E (1989a) Quantitation of catecholamine neurons in the locus coeruleus in human brains of normal young and older adults and in depression. J Comp Neurol 287: 357-372.

Davidoff RA (1990) The pyramidal tract. Neurol 40: 332-339.

Duvernoy HM (1978) Human Brainstem Vessels. Berlin: Springer-Verlag.

Escobedo F, Solis G (1979) Vascular compression of cranial nerves at the posterior fossa. Adv Neurol 25: 243-250.

Fisher CM (1961) Clinical syndromes in cerebral hemorrhage. In: Pathogenesis and Treatment of Cerebrovascular Disease (Fields WS, ed), pp 318-342. Springfield, Illinois: CHarles C. Thomas Publishers.

Fisher CM (1978) Ataxic hemiparesis. Arch Neurol 35: 126-128.

Fisher CM (1982) Lacunar strokes and infarcts: a review. Neurol 32: 871-876.

Fisher CM (1989) Lacunar infact of the tegmentum of the lower lateral pons. Arch Neurol 46: 566-567.

Glass JD, Levey AI, Rothstein JD (1990) The dysarthria-clumsy hand syndrome: a distinct clinical entity related to pontine infarction. Ann Neurol 27: 487-494.

Goebel H, Komatsuzaki A, Bender M, Cohen B (1971) Lesions of the pontine tegmentum and conjugate gaze paralysis. Arch Neurol 24: 431-440.

Gold PW, Goodwin FK, Chrousos GP (1988a) Clinical and biochemical manifestations of depression: relation to the neurobiology of stress Part I. N Engl J Med 319: 348-353.

Gold PW, Goodwin FK, Chrousos GP (1988b) Clinical and biochemical manifestations of depression: relation to the neurobiology of stress Part II. N Engl J Med 319: 413-420.

Gray JA (1982) The Neuropsycology of anxiety. Oxford: Clarendon Press.

Helweg-Larsen S, Larsson H, Henriksen O, Sorensen PS (1988) Ataxic hemiparesis: three different locations of lesions studied by MRI. Neurol 38: 1322-1324.

Holtzman RN, Zablozki V, Yang WC, Leeds NE (1987) Lateral pontine tegmental hemorrhage presenting as isolated trigeminal sensory neuropathy. Neurol 37(4): 704-706.

Jannetta PJ (1980) Neurovascular compression in cranial nerve and systemic disease. Annals of Surgery 192: 518-525.

Jenkins WM, Masterton RB (1982) Sound localization: effects of unilateral lesions in central auditory system. J Neurophysiol 47: 987-1016.

Keane J (1976) Bilateral sixth nerve palsy. Arch Neurol 33: 681-683.

Kemper TL, Romanul FC (1967) State resembling akinetic mutism in basilar artery occlusion. Neurol 17(1): 74-80.

Kennedy PR (1990) Corticospinal, rubrospinal, and rubro-olivary projections: a unifying hypothesis. Trends Neurosci 13: 474-479.

Kushner MJ, Bressman SB (1985) The clinical manifestations of pontine hemorrhage. Neurol 35(5): 636-643.

Masdeu JC, Brazis PW (1996) The localization of lesions in the ocular motor system. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 155-250. Boston: Little, Brown and Company.

Nabatame H, Fukuyama H, Akiguchi I, Kameyama M, Nishimura K, Torizuka K (1987) Pontine ataxic hemiparesis studied by a high-resolution magnetic resonance imaging system. Ann Neurol 21: 204-207.

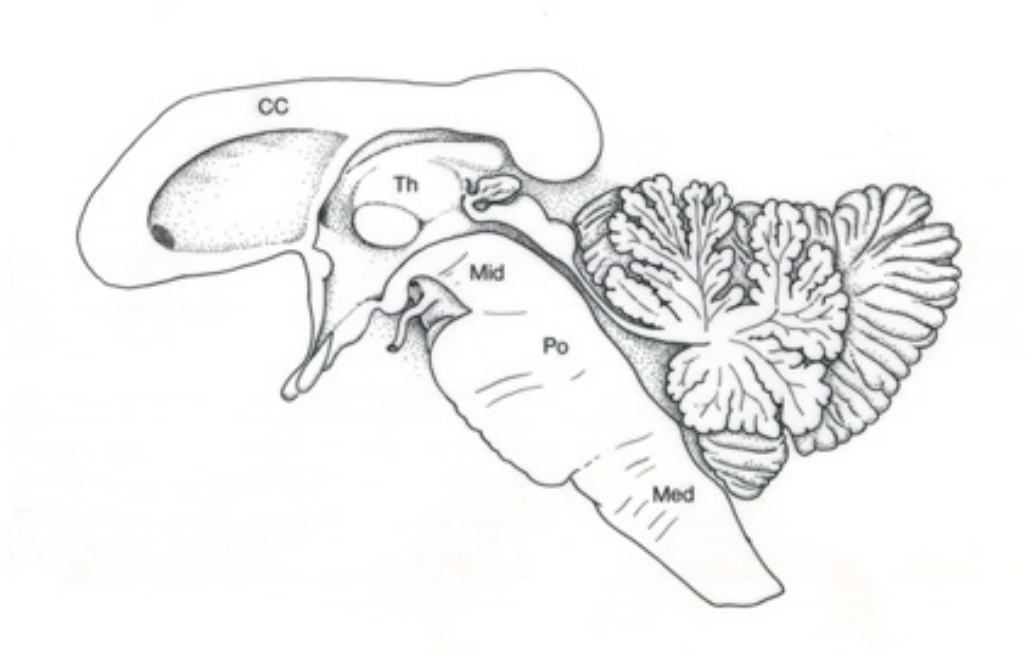
Olszewski J, Baxter D (1982) Cytoarchitecture of the Human Brain Stem. Basel: S. Karger.

Parker W, Decker R, Richards NG (1968) Auditory function and lesions of the pons. Archives of Otolaryngology 87: 26-38.

Parker W, Decker RL, Gardner WH (1976) Auditory function and intercranial lesions. Arch Neurol 76: 425-435.

Plum F, Posner JB (1982) The Diagnosis of Stupor and Coma. Philadelphia: F.A. Davis Company.

Chapter 5
The Pons



▶ INTRODUCTION

The word pons means "bridge," an image evoked in reference to the middle cerebellar peduncle, which forms a prominent span across the ventral aspect of this portion of the brain stem. Within the pons are longitudinal fiber tracts connecting the spinal cord with midbrain and thalamus as well as the nuclei and radiations of four cranial nerves: trigeminal, abducens, facial, and portions of the vestibulocochlear. Pontine functions include the control of horizontal eye movements and participation in the ascending activation system, which controls cerebral cortical neural activity. The major blood supply to the pons arises from branches of the basilar artery and creates a series of perfusion zones similar to those present in the medulla. Cerebrovascular accidents in specific perfusion zones of the basilar arterial branches can present as recognized pontine syndromes. In this chapter the nucleus and tracts of the pons will be examined, its blood supply will be studied, and several clinicopathologic cases related to the pons will be considered.

GENERAL OBJECTIVES

1. To learn the location and function of major ascending and descending fiber tracts in the pons
2. To learn the location and function of the cranial nerves and their nuclei in the pons
3. To learn the presenting signs and symptoms consequent with lesions involving major tracts and cranial nuclei in the pons
4. To apply the preceding knowledge to an understanding of the clinical manifestations of major pontine vascular lesions

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using a knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before attempting to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming fa-

miliar with the material, reexamine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources, such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human brain stem or model
2. An atlas of the human brain stem
3. A medical dictionary

Chapter Five Topics:

Case Study 5-1

DISCUSSION I

Pontine Structures

Atlas Plate 12

MIDDLE CEREBELLAR PEDUNCLE (MCP)

ABDUCENS NUCLEUS (AbNu) AND ITS RADIATIONS

FACIAL NUCLEUS (FacNu) AND ITS RADIATIONS (FacNr)

COCHLEAR NUCLEUS (VCNu)

PONTINE RETICULAR FORMATION (PRetF)

Atlas Plate 13

SUPERIOR SALIVATORY NUCLEUS (SSNu)

SUPERIOR OLIVARY NUCLEI (SONu)

TRAPEZOID BODY (TrapB)

MESENCEPHALIC TRIGEMINAL NUCLEUS AND TRACT (MesNu and Tr)

SUPERIOR CEREBELLAR PEDUNCLES (SCP)

ARCUATE NUCLEUS (ArcNu)

CENTRAL TEGMENTAL TRACT (CTT)

INFERIOR CEREBELLAR PEDUNCLE (ICP)

Atlas Plate 14

PONTINE NUCLEI (PonNu)

PONTOCEREBELLAR FIBERS (PCeF)

RADIATIONS OF THE ABDUCENS NERVE (AbNr)

CHIEF SENSORY NUCLEUS OF THE TRIGEMINAL NERVE (CSNu)

TRIGEMINAL MOTOR NUCLEUS (TriMoNu)

SUPERIOR OLIVE (MSO, LSO)

LATERAL LEMNISCUS (TRACT AND NUCLEI) (LL)

PARAMEDIAN PONTINE RETICULAR FORMATION (PPRF)

CORTICOSPINAL TRACT (CST)

Atlas Plate 15

CENTRAL GRAY (CeGy)

LOCUS COERULEUS (LoCer)

RAPHE COMPLEX (RaNu)

VENTRAL TRIGEMINOTHALAMIC TRACT (VTTr)

VENTROSPINOCEREBELLAR TRACT (VSCT)

RADIATIONS OF THE TRIGEMINAL NERVE (TriNr)

Atlas Plate 16

SUPERIOR CEREBELLAR PEDUNCLE (SCP)

LATERAL LEMNISCUS AND NUCLEI (LL, LLNu)

TRIGEMINAL NERVE (TriNr)

CORTICONUCLEAR FIBERS (CoNF)

Atlas Plates 17 to 20

CORTICOPONTINE FIBERS (CoPF)

Case Study 5-2

DISCUSSION II

Pontine Vasculature

Arterial Distribution

Arterial Anastomosis

Arterial Syndromes

- Medial Pontine Syndrome
- Lateral Pontine Syndrome

Compression Syndromes

Reference List

Case Study 5-1

Chief Complaint

A 55-year-old right-handed man was brought to the emergency room by his wife because of the sudden onset of slurred speech and extreme difficulty in walking.

History of Chief Complaint

He had experienced several episodes of weakness over a two-day period prior to his presentation. On the morning of his presentation he experienced a sudden onset of weakness and had fallen in the bathroom. He was unable to get up without his wife's assistance. Once he was upright, he found that his right leg felt very weak and dragged slightly as he attempted to walk. He also found that his right arm would not support him as he attempted to lean on the wall. He also complained of difficulty looking to the left, but he denies any double vision. His wife stated that the left side of his face looked different.

Medical History

The patient was a professional accountant involved in management. He was married, with three children, one of whom was still living with him. He had enjoyed good health except for elevated blood pressure since turning 45 years of age. He had a 10-pack-year history of smoking but quit all smoking at age 47. He is currently taking no medication.

Family History

His father died at 52 from cardiovascular disease and his mother at 49 from breast cancer. He has a 57-year-old brother who had coronary artery bypass surgery at age 53.

General Physical Examination

This was a stable, alert, oriented, cooperative, male, appearing his stated age and reclining in bed. He demonstrated appropriate concern about his condition. He had an asymmetric facial expression. His eyes were clear with no papilledema; his chest was clear to auscultation and percussion; his respirations and temperature were normal. His blood pressure was 193/98 and pulse rate was 90. Peripheral pulses were present at the wrists but absent bilaterally at the ankles. His abdomen was soft with no signs of tenderness or masses; a large scar in the lower right quadrant of the abdomen was residual from an old appendectomy. His skin was soft and warm, with normal turgor.

Neurologic Examination

Mental Status. The patient was alert, oriented for person, place and time, and cooperative. His speech was dysarthric but fluent. Memory, language, and comprehension were intact. He could follow three-step commands. He gave a coherent history.

Cranial Nerves. There was no evidence of double vision, and his visual fields were intact to confrontation. His pupils were 3 to 4 mm in diameter and reactive to light, both direct and consensual. The patient had volitional conjugate vision vertically in both directions and to the right, but not to the left. Both eyes could be deflected to the left with the doll's head maneuver. Convergence movements in both eyes were intact. He had normal hearing (tested to finger rub) in both ears. His corneal reflex was present on the right but diminished on the left; however, brushing the left cornea was painful to him. His facial expression was asymmetric. The left side of his mouth was open slightly and did not move when he spoke, his left eyelid would not shut as tightly as the right, and the wrinkles of the left side of the forehead were less pronounced than those on the right. When he attempted to puff out his cheeks, air escaped from the left side of his mouth. The jaw-jerk and gag reflexes were intact. His palate elevated along the midline

Motor Systems. Strength was reduced in both extremities on the right compared to those on the left. Tendon reflexes were elevated at the wrist, elbow, knee, and ankle on the right (+3/4) and were normal in all places in the left extremities. Plantar reflexes were extensor on the right and flexor on the left. No past-pointing was present on the left, and finger-to-nose and heel-to-shin tests were normal for that extremity. He was unable to execute these tests with the right extremities. His right upper extremity was flexed at the elbow and resisted passive movement; his right lower extremity was extended and resisted flexion, even as he attempted to walk. Normal tone and station were present in the left limbs.

Sensation. Pinprick, light touch, and position and vibratory senses were intact throughout body and face.

Follow-up

He remained in the hospital for 3 days and was discharged home with assistance from a day nurse. A re-evaluation

done at 2.5 months post hospital discharge found almost complete recovery of gross motor strength in the right extremities with power at +4/5 for flexion and extension at the elbow, wrist, knee, and ankle. Grip strength was +4/5 on the right and 5/5 on the left. Deep tendon reflexes remained elevated at +3/4 at the elbow, wrist, knee and ankle. There was a very mild lack of coordination in the fine motor control of the right arm. Eye movements were complete in all fields. He had a mild residual facial asymmetry involving the area around his eye and his mouth.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, and is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

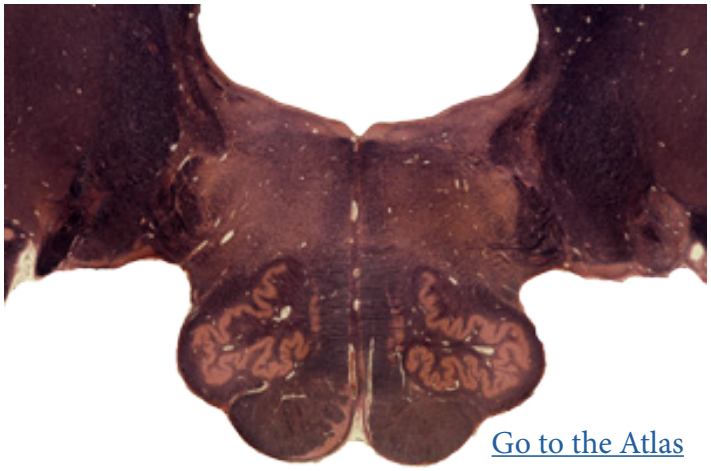
9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

▶ DISCUSSION I

Pontine Structures

The word "pons" means bridge, and the pons is a bridgelike structure that spans the brainstem between the two cerebellar hemispheres (see Chapter 1). The pons is traversed by several of the long ascending and descending tracts; in addition, there are numerous intrinsic nuclei related to the trigeminal, abducens and vestibulocochlear cranial nerves, and the surrounding reticular formation. These items are listed on the slides described later; the abbreviation following the name of each item corresponds to that used to identify the structure on the atlas plate. The first time you encounter a given structure, its description will be provided along with comments on function and any clinical deficit consequent to its destruction. For subsequent sections, the structure will be mentioned by name only unless significant changes have occurred in its location or composition.

Atlas Plate 12



Go to the Atlas

Atlas Plate 12 straddles the pontomedullary junction. The dorsal portion of the section, containing the abducens and facial nuclei, has passed through the pons. The ventral portion of the section, containing the olivary tubercle and pyramidal tract, has remained in the medulla. The medullary portion has been examined in Chapter 3.

MIDDLE CEREBELLAR PEDUNCLE (MCP)

The middle cerebellar peduncle (MCP) is a thick band of fibers visible on the external surface of the pons. It is composed of axons that arise in the pontine nuclei (see Plates 14 to 20) and innervate the contralateral cerebellar hemisphere. As these fibers cross the midline they are called the pontocerebellar or transverse pontine fibers. Laterally, they coalesce to form the middle cerebellar peduncle (as seen on this plate). The transverse pontine fibers are intersected at right angles by bundles of the descending corticospinal and corticonuclear axons (see Plates 14 to 20). The ventral portion of the pons, containing the pontine nuclei, pontocerebellar fibers, and corticospinal fibers, is referred to as the basis pontis or basilar pons.

Information from the cerebral cortex passes through corticopontine axons to reach the pontine nuclei. From here it is projected across the midline and into the cerebellar hemispheres through the middle cerebellar peduncle. This circuit is referred to as the cortico-ponto-cerebellar pathway. It serves as a conduit through which the cerebral cortex instructs the cerebellum of impending movements.

CLINICAL DISCUSSION: Damage to the middle cerebellar peduncle is similar to that of the cerebellar hemisphere and presents with limb ataxia on the side ipsilateral to the lesion. Small lesions in the basis pontis, close to the midline, can produce a complicated syndrome of contralateral hemiparesis and hemiataxia (Fisher, 1978). In such cases, the extremity contralateral to the lesion is both weakened and ataxic. Additional information on cerebellar dysfunction can be found in Chapter 5.

ABDUCENS NUCLEUS (AbNu) AND ITS RADIATIONS

The abducens nucleus (AbNu) is a short column of motoneurons in the dorsal pons, lying along the floor of the fourth ventricle, in close juxtaposition with the medial longitudinal fasciculus (Figure 5-1). Its radiations proceed ventrally across the pons where they exit the brainstem in close juxtaposition with the fiber bundles of the corticospinal tract (Figure 5-1). The abducens nucleus receives bilateral projections from the medial vestibular nuclei and ipsilateral projections from the paramedian pontine reticular formation (see Plate 14). Primary afferent fibers to the medial vestibular nu-

Highlight Point

The clinical manifestations of isolated lesions in the middle cerebellar peduncle can include:

Ipsilateral limb ataxia

clei arise in the ampulla of the ipsilateral horizontal semicircular canals. Motoneurons in the abducens nucleus innervate the lateral rectus muscle of the ipsilateral eye. Other neurons in abducens nucleus project axons via the medial longitudinal fasciculus to the contralateral oculomotor nucleus (Figure 5-2), where they specifically target that portion of the nucleus controlling the medial rectus muscle.

The abducens nucleus serves to coordinate conjugate horizontal movements of the eyes (Figure 5-2). Stimulation through vestibular input to the ipsilateral (right) abducens nucleus excites the right lateral rectus muscle and, through its projections to the contralateral oculomotor nucleus, the left medial rectus muscle. As both muscles contract, the eyes are deflected to the right, maintaining conjugate vision.

CLINICAL DISCUSSION: Damage to the abducens nerve results in an infranuclear (segmental or lower motoneuron) form of paralysis of the lateral rectus muscle and failure of the ipsilateral globe to abduct on attempted lateral gaze to the side of the lesion (lesion 1, Figure 5-2). This is termed a lateral rectus palsy. Since the contra-lateral medial rectus is still receiving a signal from abducens nucleus via the oculomotor nucleus, it adducts on attempted lateral gaze, conjugate vision is compromised, and the patient reports diplopia on attempted lateral gaze.

Damage to the abducens nucleus is more complicated (lesion 2, Figure 5-2). Such a lesion can remove control of the ipsilateral lateral rectus by denervation (segmental level). In addition, loss of the communication from abducens to contralateral oculomotor nucleus results in a supranuclear (suprasegmental level) form of paralysis expressed in the contralateral medial rectus muscle.

The result is horizontal gaze paresis to the ipsilateral side, as both globes fail to move into that visual hemisphere. The patient experiences diminished ability to look into the field of vision ipsilateral to the damaged abducens nucleus, but should not experience diplopia. This eye movement disorder is called lateral gaze palsy. Since the oculomotor nucleus or its radiations are not damaged, the patient should be able to demonstrate convergence movements.

Finally, damage to the medial longitudinal fasciculus produces a third type of eye movement palsy (lesion 3; Figure 5-2). If the lesion damages the medial longitudinal fasciculus on the left, axons from the right abducens nucleus to the left oculomotor nucleus are disrupted. The patient still has conjugate gaze to the left; however, when attempting gaze to the right, the medial rectus on the left fails to respond, producing diplopia on attempted right lateral gaze.

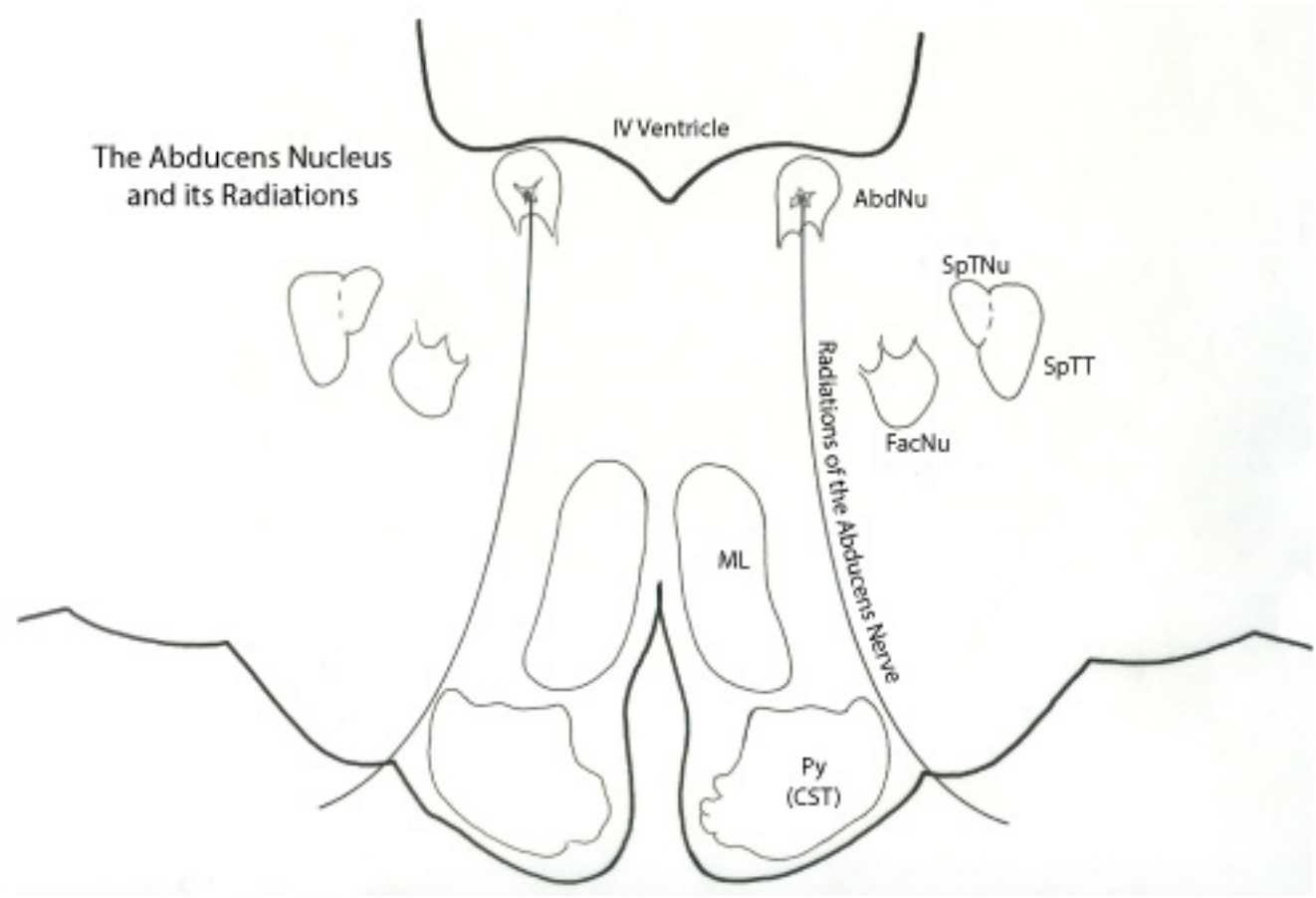


Figure 5-1. A caudal pontine section (similar to Plate 13) illustrates the location of the abducens nucleus and the course of its radiations across the pons to form the abducens nerve as it exits the brainstem.

This type of supranuclear palsy of the oculomotor nucleus is called intranuclear opthalmo-plegia (Masdeu and Brazis, 1996).

FACIAL NUCLEUS (FacNu) AND ITS RADIATIONS (FacNr)

A large cluster of motoneurons lying dorsomedial to the spinal trigeminal nucleus and anterolateral systems represents the facial nucleus (FacNu). These neurons innervate the muscles of facial expression and the stapedius, auricularis, and stylohyoid muscles as well as the posterior belly of the digastric muscle. Axons of these neurons form the radiations of the facial nucleus. The radiations of the facial nucleus (FacNr) leave the nucleus and pass dorsally to reach the floor of the fourth ventricle (Figure 5-3 and Plate 13), from which they turn in a ventrolateral direction—forming the internal genu—to course diagonally across the pons and exit the brain stem in close juxtaposition with the acousticovestibular nerve (see Plate 14).

As the fibers of the facial nerve begin their ventral descent from the floor of the fourth ventricle they pass by the superior salivatory, gustatory, and spinal trigeminal nuclei. It is from these nuclei that the facial nerve acquires its additional somatic and visceral sensory as well as visceral motor components (Figure 5-3).

Concerning volitional movement of the facial muscles, the facial nucleus is innervated by corticonuclear fibers from the frontal (motor) cortex (A in Figure 5-4). Neurons controlling the musculature in the lower half of the face are innervated primarily by fibers from the contralateral cortex (E in Figure 5-4). Those neurons innervating muscles in the upper portion of the face receive a bilateral cortical innervation (D in Figure 5-4). Conversely emotional control of the facial muscles is accomplished through a different pathway, which passes from the prefrontal cortex, through the hypothalamus, to the facial nucleus in the brainstem. Separation of the volitional and emotional control of the facial muscles means that these two pathways can be differentiated clinically.

CLINICAL DISCUSSION: The most notable deficit in lesions of the facial nucleus, its radiations within the brain stem, or its nerve peripherally, is paralysis of the ipsilateral muscles of facial expression—termed a peripheral-type cranial nerve seven palsy (Brazis, 1996a). Lesions affecting the corticonuclear fibers to the facial nucleus produce paralysis of muscles in the lower half of the contralateral face, with much less involvement of the upper half of the face (Figure 5-4). Maintenance of muscle function in the upper portion of the face consequent to cortical destruction is due to

Highlight Point

The clinical manifestations of a lesion in the *radiations of the abducens nucleus* can involve:

Ipsilateral lateral rectus palsy

Diplopia worsening on ipsilateral gaze

The clinical manifestations of a lesion in the *abducens nucleus* can involve:

Ipsilateral horizontal gaze palsy

Diplopia is not necessarily associated

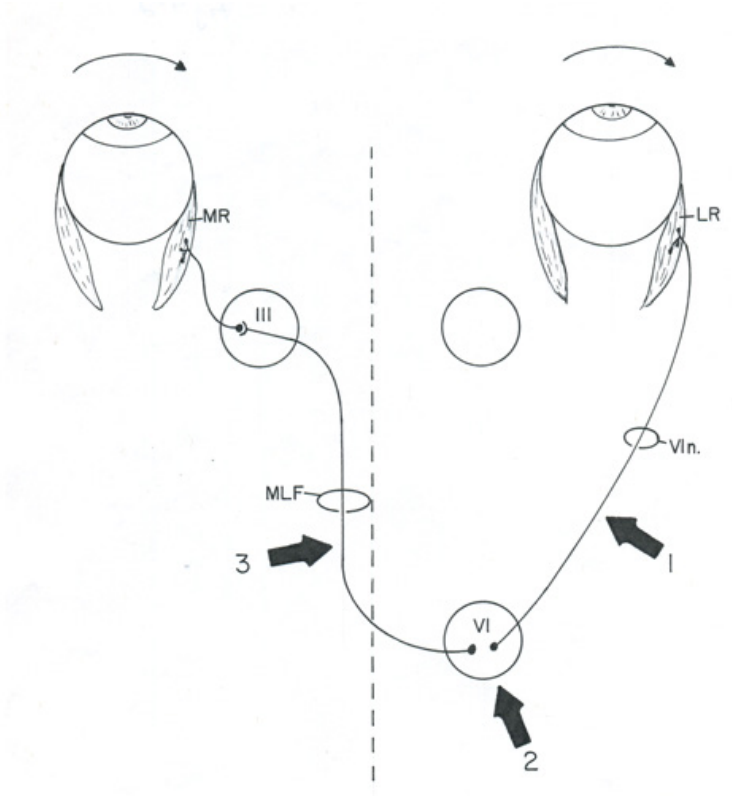


Figure 5-2. Schematic diagram of the efferent fibers from the abducens nucleus illustrates their control of conjugate lateral gaze (see the text for explanation).

the bilateral innervation of these motoneurons by corticonuclear fibers. In this situation, emotional facial movements can be preserved since they involve a spatially separate pathway. Thus, hemifacial paralysis in a patient suggests a segmental-level lesion involving the ipsilateral facial nerve or nucleus, whereas lower-quadrant facial paralysis suggests a suprasegmental-level lesion of the contralateral cerebral cortex or its corticonuclear fibers to the facial nucleus. Finally, lesions in the hypothalamus can damage the pathway involved in emotional control of the facial musculature. The patient can demonstrate facial emotions on command but fails to show them spontaneously.

COCHLEAR NUCLEUS (VCNu)

A small cluster of cells forming the rostral pole of the cochlear nucleus (VCNu) is embedded in the fibers of the vestibuloacoustic nerve. The cochlear nucleus receives primary afferent fibers from the auditory nerve and has efferent projections to the superior olivary nuclei (bilaterally) and the inferior colliculus (contralaterally; Figure 5-5).

CLINICAL DISCUSSION: Lesions of the lateral pons affecting the cochlear nucleus can result in ipsilateral diminution of hearing functions (Parker et al., 1976). This is referred to as sensorineural hearing loss (Biller and Brazis, 1996).

Highlight Point

The clinical manifestations of a lesion in the facial nucleus or its radiations involve:

Ipsilateral hemifacial paralysis

Loss of volitional and emotional facial movements

Inability to close the ipsilateral eye

Inability to close the ipsilateral corner of the mouth

PONTINE RETICULAR FORMATION (PRetF)

The reticular formation (PRetF) of the medulla extends rostrally into the pons. It is composed of a collection of nuclei embedded in a dense matrix of fibers in the core of the brain stem. Descending

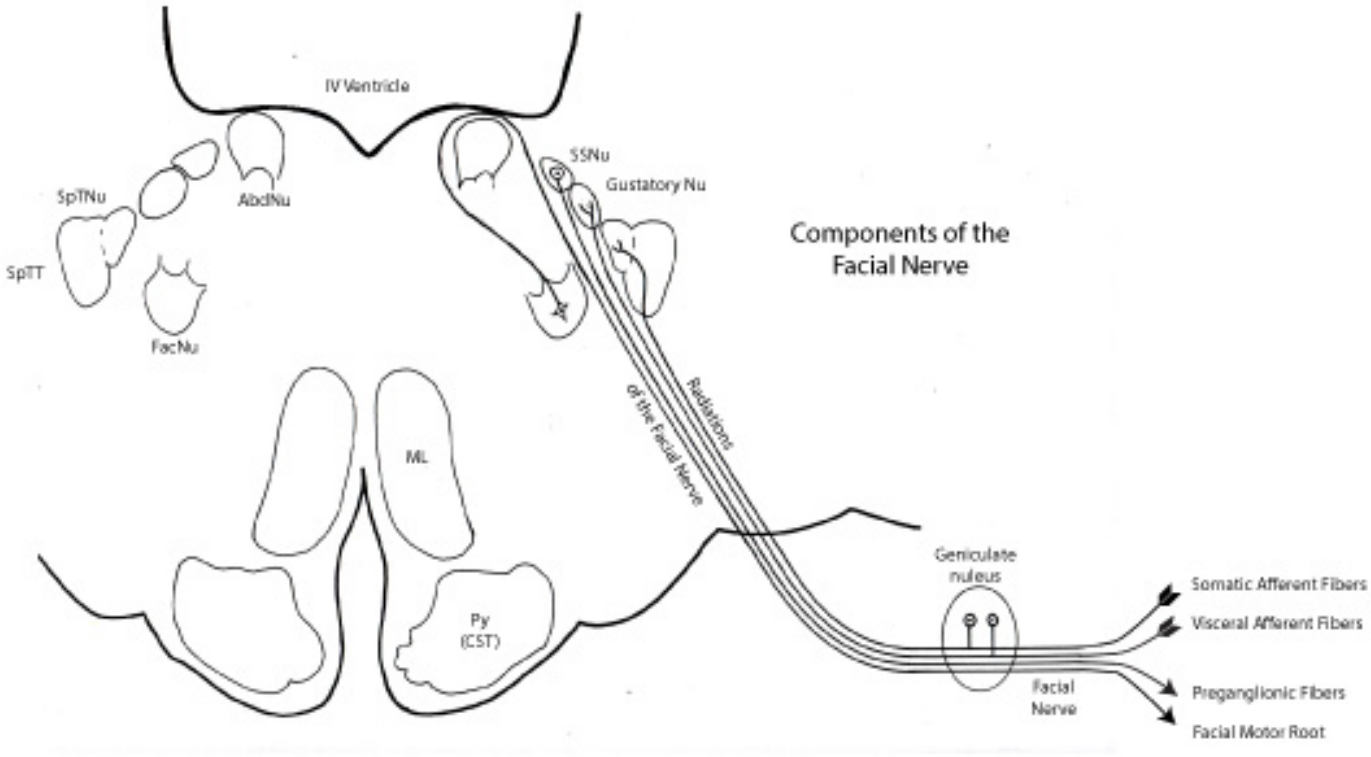


Figure 5-3. A pontine section (similar to Plate 13) illustrates the origin of the motor sensory components in the facial nerve.

pontine reticulospinal projections from these nuclei are involved in control of autonomic functions and motor activity. In addition, ascending efferent fibers from the rostral portion of the reticular formation participate in the ascending reticular activating system. This latter system serves to regulate neural activity in the thalamus and cerebral cortex; it also influences the sleep-wake cycle.

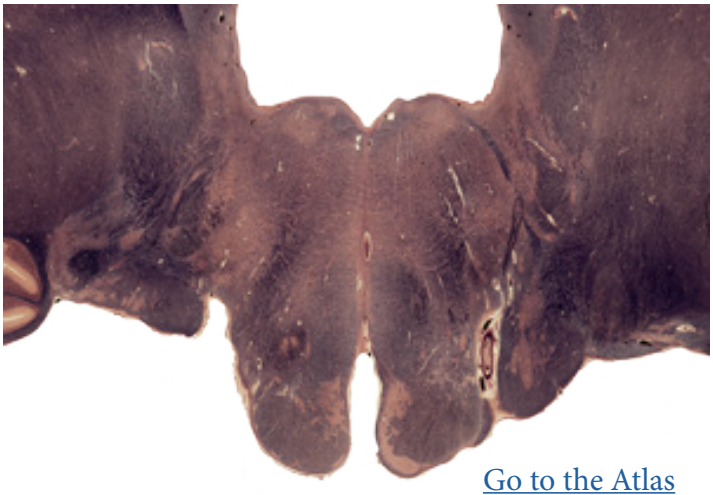
CLINICAL DISCUSSION: Lesions of restricted size in the pontine reticular formation can present with disturbances in paradoxical (REM) sleep (Autret et al., 1988). Large lesions of the pontine reticular formation, especially those disrupting the ascending reticular activating system, can result in coma often culminating in death (Kushner and Bressman, 1985;Plum and Posner, 1982). Fatal outcome is more common for lesions occurring in the rostral portion of the pons.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Lateral vestibular nucleus (LVNU)
- Medial vestibular nucleus (MVNU)
- Superior vestibular nucleus (SrNu)
- Medial longitudinal fasciculus (MLF)
- Dorsal longitudinal fasciculus (DLF)
- Spinal trigeminal nucleus and tract (SpTNu, SPTT)

Atlas Plate 13



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The dorsal portion of this section is midpontine in location, passing through the facial colliculus (a mound on the floor of the fourth ventricle for the abducens nucleus and the radiations of the facial nerve). The ventral portion of the section is located at the pontomedullary junction. Critical to recognizing this section is the close juxtaposition of the radiation of the facial nerve and the abducens nucleus.

SUPERIOR SALIVATORY NUCLEUS (SSNu)

The superior salivatory nucleus (SSNu) is a small cluster of cells lying along the radiations of the facial nerve, just distal to its internal genu. This nucleus is considered a rostral extension of the dorsal motor nucleus of the vagus and is composed of preganglionic, parasympathetic neurons. Axons from this nucleus exit the brain stem in conjunction with the facial nerve (Figure 5-3) and innervate the submandibular and pterygopalatine ganglia.

CLINICAL DISCUSSION: Loss of the superior salivatory nucleus can result in diminished production of saliva in the oral cavity and reduced lacrimation in the ipsilateral eye. Aberrant regeneration of these autonomic systems can lead to fibers previously involved in salivation reinnervating postganglionic cells that control lacrimation. The result is the formation of "crocodile tears" in response to attempted salivation.

SUPERIOR OLIVARY NUCLEI (SONu)

Ventral to the facial nucleus are several clusters of cells called the superior olivary nuclei (SONu) (Figure 5-5), which are involved in the process of sound localization. Afferent fibers to the superior olive come from the cochlear nuclei bilaterally; efferent projections from these nuclei innervate primarily the contralateral superior olive and the inferior colliculus of the midbrain.

CLINICAL DISCUSSION: Pontine lesions involving the superior olivary nuclei in humans diminish hearing functions in the ipsilateral ear; in cats, lesions of the superior olive produce a deficit in the ability to localize sound (Jenkins and Masterton, 1982).

TRAPEZOID BODY (TrapB)

The trapezoid body (TrapB) is located between the two superior olivary nuclei, dorsal to the basilar pons. It is composed of decussating auditory fibers from the cochlear and superior olivary nuclei (Figure 5-5).

CLINICAL DISCUSSION: Section of the trapezoid body interrupts the ascending fibers of the auditory pathways and results in bilateral diminution of hearing functions (Parker et al., 1968). Lesions positioned caudal to the trapezoid body present as diminished hearing in the ipsilateral ear, whereas those rostral to the trapezoid fibers present as diminished hearing in the contralateral ear. Thus, the trapezoid body is described as functioning somewhat similar to the optic chiasm of the visual system or the decussation of the medial lemniscus in the somatic sensory system (Jenkins and Masterton, 1982). Lesions in the pontine tegmentum, near or involving trapezoid body fibers from the cochlear nuclei, can present with unilateral auditory hallucinations (Cascino and Adams, 1986).

MESENCEPHALIC TRIGEMINAL NUCLEUS AND TRACT (MesNu and Tr)

The mesencephalic trigeminal nucleus (MesNu) is a thin column of cells extending rostrally along the lateral wall of the fourth ventricle from the pons (Figure 5-6 and Plate 13) into the midbrain (also see Plate 16). This nucleus is surrounded by primary afferent axons from the trigeminal nerve, which form the tract (Me-

sTr) of the mesencephalic trigeminal nucleus. The neurons of the mesencephalic trigeminal nucleus represent displaced trigeminal ganglion cells (primary afferent neurons) with peripheral processes innervating mechanoreceptors in the periodontal tissue, teeth, hard palate, and joint capsules as well as the spindle-organs in the muscles of mastication. Their central processes innervate the trigeminal motor nucleus. Thus, the neurons of the mesencephalic trigeminal nucleus form a monosynaptic reflex arc controlling the force exerted by the jaw during chewing.

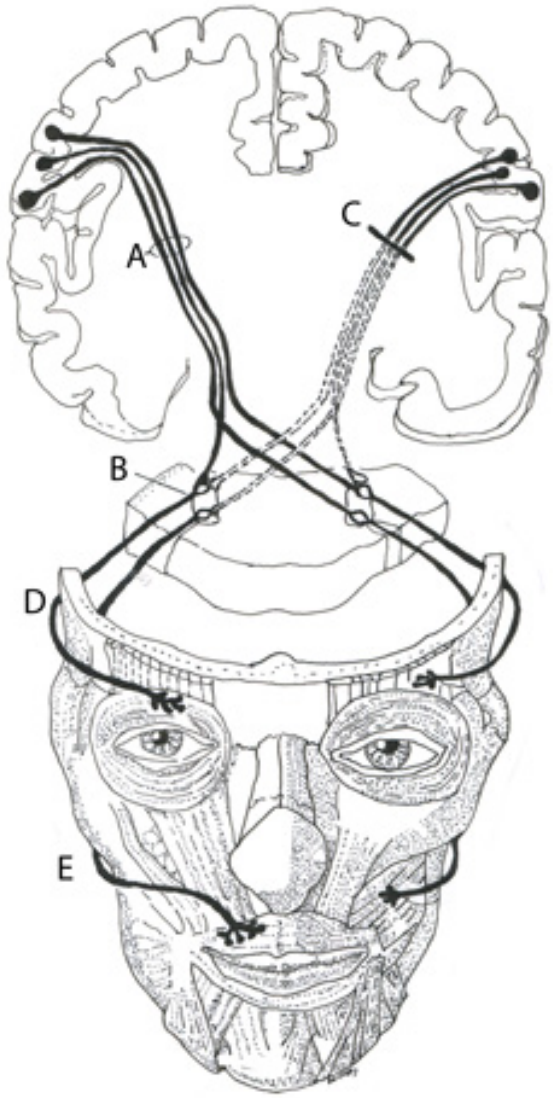


Figure 5-4. Diagram illustrates the organization of the facial nerve and nucleus. (A) Corticonuclear fibers innervating the facial nucleus (B) Facial nucleus (C) Lesion of corticonuclear fibers (D) Innervation of upper face (E) Innervation of lower face (Modified from Po-

CLINICAL DISCUSSION: Damage to the mesencephalic trigeminal nucleus or its tract results in a diminished jaw-jerk reflex ipsilateral to the lesion (Olszewski and Baxter, 1982).

SUPERIOR CEREBELLAR PEDUNCLES (SCP)

The superior cerebellar peduncle (SCP) forms the major output pathway for the cerebellum. It arises in the dentate nucleus of the cerebellum (see Chapter 5), courses along the roof of the fourth ventricle through the pons (see Plates 13 to 16), and descends into the reticular formation of the midbrain to decussate (see Plates 17 to 19) before extending into the thalamus as the cerebellothalamic fibers (CThF), which contribute to the thalamic fasciculus (ThaFas; see Plates 20 to 22).

CLINICAL DISCUSSION: Lesions of the superior cerebellar peduncles produce neurologic sequelae similar to those of the cerebellar hemisphere: ataxia and clumsiness expressed in the extremities. Deficits from lesions in the portions of the peduncle caudal to the decussation (nearest the cerebellum) present on the ipsilateral side. Conversely, lesions rostral to the decussation of the peduncle (closest to the thalamus, Plates 18 to 21) present on the contralateral side of the body.

ARCUATE NUCLEUS (ArcNu)

The arcuate nucleus (ArcNu) is located at the caudal end of the pons and extends around the medial aspect of the pyramidal tract. It represents displaced cells from the pontine nuclei and shares similar connections to those of the pontine nuclei.

CENTRAL TEGMENTAL TRACT (CTT)

At this level, the central tegmental tract (CTT) is a diffuse bundle of fibers, positioned lateral to the medial lemniscus and coursing along the long axis of the brain stem. It extends from the inferior olivary nuclei (see Plate 8) to the red nucleus of the midbrain (see Plate 20). Its connections and functions are discussed in Chapter 4.

INFERIOR CEREBELLAR PEDUNCLE (ICP)

The inferior cerebellar peduncle (ICP) has passed dorsally into the cerebellum. At this level, it is located lateral to the walls of the fourth ventricle. It will terminate in the anterior lobe of the cerebellum. Its connections and functions are discussed in Chapter 4.

Highlights Point

The clinical manifestations of a lesion in the superior cerebellar peduncle can involve:

Ipsilateral Limb Ataxia

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Lateral vestibular nucleus (LVNu)
- Medial vestibular nucleus (MVNu)
- Superior vestibular nucleus (SvNu)
- Inferior olivary nucleus (IONu)
- Pyramidal tract (Py)
- Medial lemniscus (ML)
- Medial longitudinal fasciculus (MLF)
- Anterolateral system (ALS)
- Rubrospinal tract (RuSp)
- Ventral spinocerebellar tract (VSCT)
- Middle cerebellar peduncle (MCP)
- Dorsal longitudinal fasciculus (DLF)
- Spinal trigeminal nucleus and tract (SpTNu, SpTT)

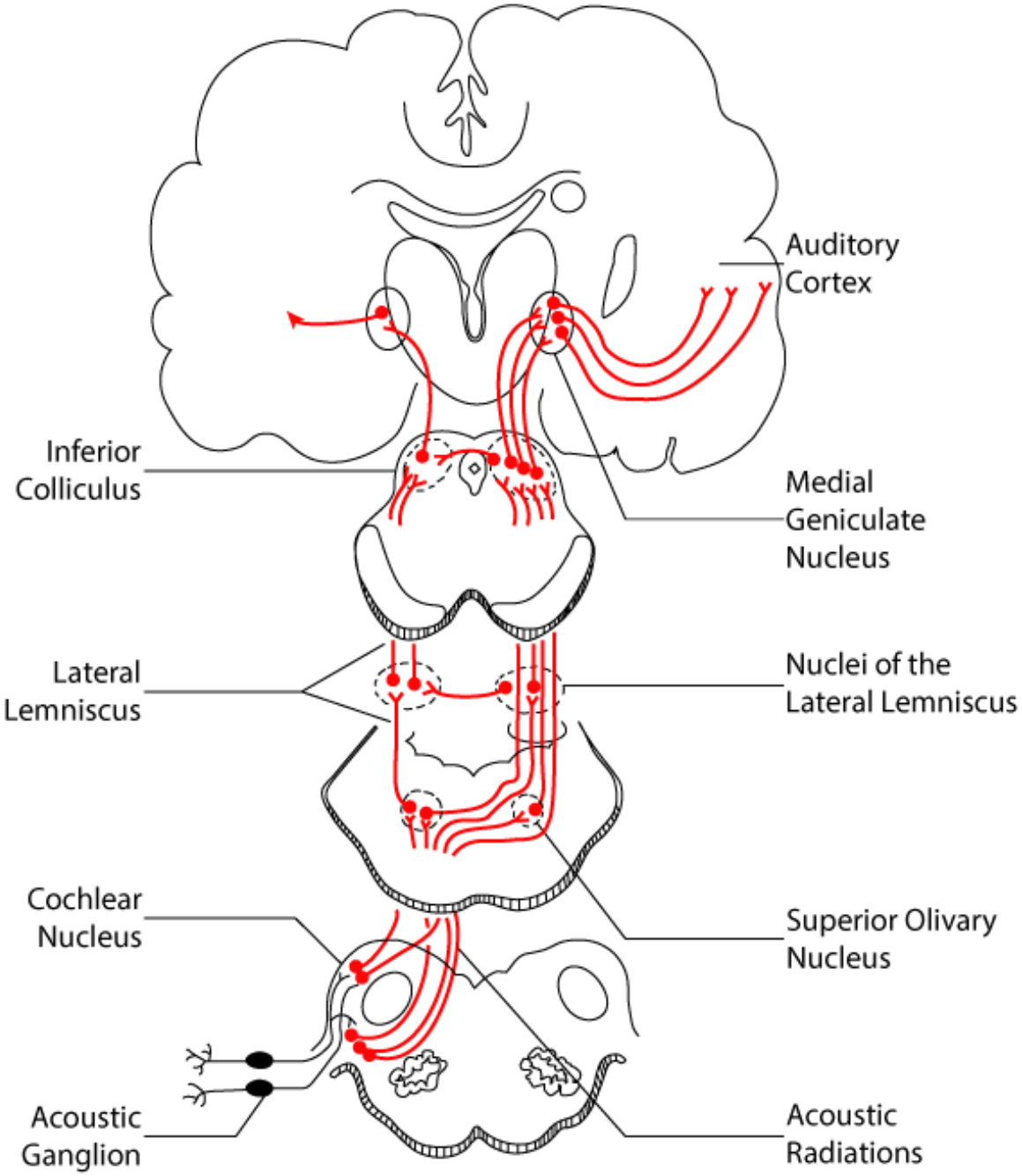
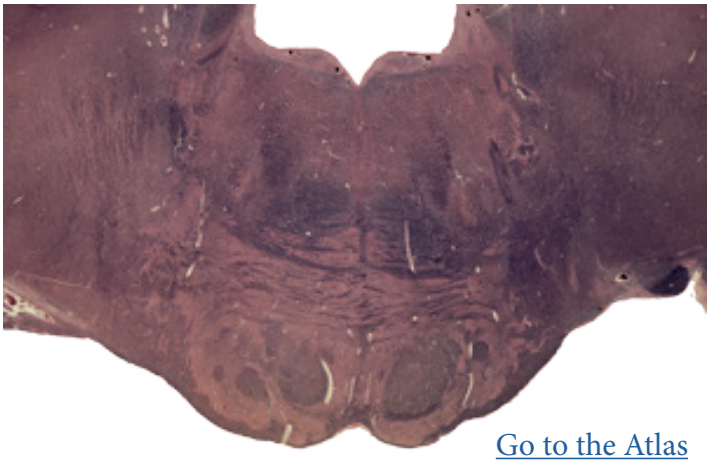


Figure 5-5. The organization of the auditory pathways (Barr ML, Kiernan JA. The human nervous system: An anatomical viewpoint. 5th ed. Philadelphia: JB Lippincott, 1988:320)

Atlas Plate 14



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This section is taken through the caudal portion of the pons. Distinguishing features of the section are the rearrangement of the medial lemniscus from its vertical orientation in the previous section to a horizontal disposition, and the appearance of pontocerebellar fibers.

PONTINE NUCLEI (PonNu)

The pontine nuclei (PonNu) form the large mass of gray surrounding the pontocerebellar and corticospinal fibers in the basilar pons. Pontine neurons receive projections (corticopontine fibers) from most regions of neocortex. Their axons form the pontocerebellar (transverse pontine) fibers that cross the midline, traverse the contralateral pontine nuclei, and at the lateral border of the pons, coalesce to form the middle cerebellar peduncle. The cortico-ponto-cerebellar pathway has been discussed previously.

CLINICAL DISCUSSION: Section of the middle cerebellar peduncles (which contain pontocerebellar fibers from the contralateral pontine nuclei) results in ataxia of the limbs ipsilateral to the lesion, similar to the situation when the cerebellar hemisphere is damaged (see Chapter 6). Lesions involving the pontine nuclei are more complex in their clinical presentation. Unilateral lesions involving cell bodies in the pontine nuclei should result in contralateral limb ataxia, because these axons will cross the midline to affect the opposite cerebellar hemisphere. However, such a lesion can also damage the descending corticospinal tract in the pons, with the resulting contralateral hemiparalysis masking any expression of ataxia in the affected limb.

In a few cases small lacunar infarcts have occurred in the dorsolateral basilar pons, neurons of the pontine nuclei were destroyed, but the underlying corticospinal fibers, although compromised by the ischemia, were not completely destroyed. These patients presented with a mild, contralateral pure motor hemiparesis, because of the partially damaged corticospinal axons, and accompanying hemiataxia in the paretic limb, due to the damaged pontine nuclei (Fisher, 1978;Fisher, 1982;Nabatame et al., 1987). This presentation of hemiparesis and hemiataxia in the same extremities is called ataxic hemiparesis (Nabatame et al., 1987).

PONTOCEREBELLAR FIBERS (PCeF)

The neurons of the pontine nuclei give rise to the pontocerebellar fibers (PCeF), which cross the midline of the brain stem and pass laterally to form the middle cerebellar peduncle. These fibers, also called the transverse pontine fibers, constitute the large mass of the pons.

CLINICAL DISCUSSION: The complex presentations that accompany lesions in and around the pontocerebellar fibers have been discussed with the pontine nuclei.

RADIATIONS OF THE ABDUCENS NERVE (AbNr)

Axons from motoneurons in the abducens nucleus form the radiations of the abducens nerve (AbNr). These axons pass ventrally from the nucleus along the lateral border of the medial lemniscus and corticospinal fibers to exit the brain stem at the pontomedullary junction (Figure 5-1).

CLINICAL DISCUSSION: Lesions affecting the abducens radiations result in paresis of the lateral rectus muscle on the same side. The patient complains of diplopia on attempted lateral gaze to the lesioned side. Unlike damage to the abducens nucleus, pure involvement of the nerve does not affect adduction of the contralateral eye (Figure 5-2). Bilateral abducens nerve palsies are possible and can occur with mass-occupying lesions (tumors), degenerative demyelinating diseases, subarachnoid hemorrhage, or infection (Keane, 1976).

CHIEF SENSORY NUCLEUS OF THE TRIGEMINAL NERVE (CSNu)

The chief sensory nucleus (CSNu), located at the rostral end of the spinal trigeminal nucleus (Figure 5-6), receives Aß (group II) primary afferent fibers from mechanoreceptors in the tissues of the ipsilateral face. This nucleus is analogous in function to the dorsal column nuclei of the medulla. Axons from neurons in the chief trigeminal nucleus cross the midline to join the ventral trigeminothalamic tract and terminate in the contralateral thalamus. A few ascending trigeminal axons remain uncrossed and travel in the dorsal trigeminothalamic tract to reach the ipsilateral thalamus; they represent the region around the mouth that receives bilateral representation in each thalamic hemisphere. The segregation of function between the chief sensory and spinal trigeminal nuclei is incomplete; the chief sensory nucleus, along with the spinal trigeminal nucleus, processes some nociceptive information from Aδ (group III) and C (group IV) afferent fibers.

CLINICAL DISCUSSION: Lesion of the chief sensory nucleus can result in loss of discriminatory touch, vibratory sense, two-point discrimination, and stereognosis in the ipsilateral face; however, these lesions can also produce some analgesia. An extremely restricted hemorrhage in the dorsolateral pons in the area of the chief trigeminal sensory nucleus has been reported and documented with CT scan (Holtzman et al., 1987). The patient presented with facial numbness featuring analgesia and hypoesthesia in the V2 and V3 dermatomes.

TRIGEMINAL MOTOR NUCLEUS (TriMoNu)

The trigeminal motor nucleus (TriMoNu) is a cluster of large neurons medial to the chief sensory nucleus (Figure 5-6). This motor nucleus receives primary afferent fibers from the ipsilateral mesen-

cephalic trigeminal nucleus and bilateral input from the cerebral cortex (corticonuclear fibers). The axons of these motoneurons leave the pons in the trigeminal nerve and innervate the ipsilateral muscles of mastication.

CLINICAL DISCUSSION: Destruction of this nucleus or its radiations causes paralysis of the ipsilateral muscles of mastication. This is seen clinically as deviation of the jaw to the weakened side with attempted opening under resistance. Bilateral supranuclear lesions of the corticonuclear fibers can result in paresis of the jaw with hyperactive jaw-jerk reflex (Brazis, 1996b); an example being pseudobulbar palsy, where bilateral degeneration of the corticonuclear fibers can result in elevation of the jaw-jerk reflex.

SUPERIOR OLIVE (MSO, LSO)

The superior olive can be resolved into several nuclei, two of which are illustrated on this plate: the medial (MSO) and lateral (LSO) superior olivary nuclei (Figure 5-5). The medial superior olivary nucleus is most responsive to low-frequency sounds and is involved in localizing sound at the low end of the frequency spectrum. Conversely, the lateral superior olive is more responsive to the higher frequencies and is involved in localizing sound at the high end of the acoustic spectrum (Brugge and Geisler, 1978). The results of damage in and around the area of the superior olivary nuclei have been discussed previously in this chapter.

LATERAL LEMNISCUS (TRACT AND NUCLEI) (LL)

The lateral lemniscus (LL) is a prominent fiber bundle passing rostrally from the superior olivary complex, along the lateral aspect of the brain stem, into the inferior colliculus (see Plate 17 and Figure 5-5). This fiber tract represents a major ascending pathway in the auditory system. Embedded in the fiber tract are the nuclei of the lateral lemniscus (see Plate 16), which act as a relay for some of the ascending auditory fibers in passage to the midbrain and thalamus.

CLINICAL DISCUSSION: Unilateral section of lateral lemniscus diminishes hearing bilaterally; however, the loss is greatest from the contralateral ear. Lesions in the pons in close juxtaposition with the lateral lemniscus can produce auditory hallucinations (Cascino and Adams, 1986).

PARAMEDIAN PONTINE RETICULAR FORMATION (PPRF)

The paramedian pontine reticular formation (PPRF) is a specialized region of the pontine reticular formation defined more by function than by cytology. It is an elongated cluster of cells located ventral to the medial longitudinal fasciculus and extending between the oculomotor-trochlear complex and the abducens nucleus; its exact boundaries have not been determined. It receives bilateral afferent projections from the cerebral cortex (frontal eye fields), from the contralateral superior colliculus, and from the ipsilateral vestibular nuclei. The efferent connections of the PPRF control the ipsilateral abducens nucleus and the rostral interstitial nucleus of the medial longitudinal fasciculus in the midbrain (see Plate 20). The paramedian pontine reticular formation coordinates conjugate horizontal eye movements (Bender, 1980).

CLINICAL DISCUSSION: Damage to the paramedian pontine reticular formation presents as loss of ipsilateral conjugate horizontal gaze, called horizontal gaze paresis or lateral gaze palsy (Goebel et al., 1971). The patient can look into the contralateral hemisphere, but cannot volitionally deviate the globes into the ipsilateral visual hemisphere. Since gaze remains conjugate, the patient should not experience diplopia. Horizontal gaze paresis can also result from damage of the contralateral corticonuclear fibers to the paramedian pontine reticular formation.

CORTICOSPINAL TRACT (CST)

The corticospinal tract (CST) originates in the cerebral cortex and projects through the internal capsule (see Plates 21 to 25), crus cerebri (see Plates 19 and 20), and brain stem to decussate at the cervicomedullary junction (see Plate 6) and enter the spinal cord, terminating in the ventral horn (see Plates 1 to 4). Throughout its brain stem course it is topographically arranged with the upper-extremity representation located nearest the midline. As the tract passes through the basilar pons, it separates into numerous, small fascicles, which rejoin in the pyramidal tract of the medulla. The corticospinal tract is involved with volitional control of fine motor behavior, especially with respect to novel movements (Kennedy, 1990).

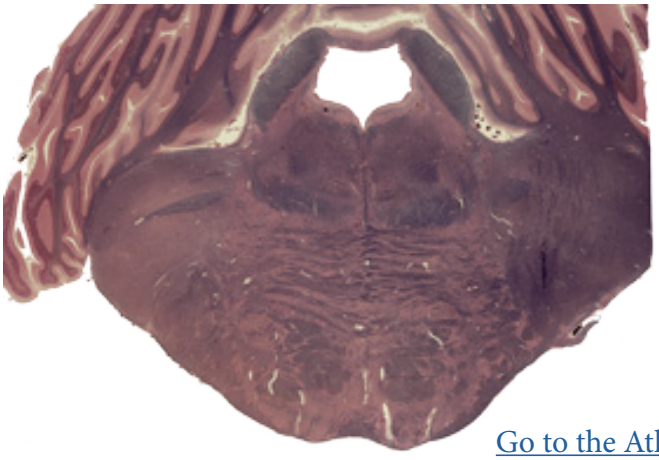
CLINICAL DISCUSSION: According to classic neurology, lesions affecting the corticospinal tracts in the human brain stem can present initially with contralateral flaccidity, mainly affecting the muscles of the distal portions of the extremities. With time, the affected limbs resolve into a spastic condition. There is considerable confusion concerning this concept in the literature. An opposing view claims that lesions truly confined to the corticospinal tract will present with mild hypotonia (Davidoff, 1990). The clinical presentation subsequent to corticospinal tract sections is further discussed in Chapter 4.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Lateral vestibular nucleus (LVNU)
- Medial vestibular nucleus (MVNU)
- Superior vestibular nucleus (SVNU)
- Spinal trigeminal nucleus and tract (SpTNu, SPTT)
- Trapezoid body and nucleus (TrapB)
- Medial lemniscus (ML)
- Medial longitudinal fasciculus (MLF)
- Anterolateral system (ALS)
- Rubrospinal tract (RuSp)
- Ventral spinocerebellar tract (VSCT)
- Middle cerebellar peduncle (MCP)
- Inferior cerebellar peduncle (ICP)
- Superior cerebellar peduncle (SCP)
- Central tegmental tract (CTT)
- Radiations of the facial nerve (FacNr)
- Dorsal longitudinal fasciculus (DLF)

Atlas Plate 15



Go to the Atlas

The dorsal portion of this section transects the pontomesencephalic border, whereas the ventral portion passes through the basilar pons. Prominent features of this section are the well-developed pontocerebellar fibers and middle cerebellar peduncle, the shift in position of the superior cerebellar peduncles to form the walls of the fourth ventricle, and the tapering of these walls to form the cerebral aqueduct.

CENTRAL GRAY (CeGy)

The central, or periaqueductal, gray (CeGy) extends out of the pons along the cerebral aqueduct to reach the caudal thalamus (see Plates 16 to 20). This is a continuation of the band of gray matter that both surrounds the rostral end of the central canal of the spinal cord (see Plate 6) and extends around the obex along the floor of the fourth ventricle. Numerous structures are embedded in the central gray, such as the vagal nuclei, locus coeruleus, and vestibular nuclei. Rostral portions of the central gray are known to contain neurons with opiate receptors and axons that innervate the raphe nuclei of the brain stem. In turn, raphe nuclei give rise to the raphe-spinal tract, which can modulate the activity of the anterolateral system in the dorsal horn of the spinal cord. This network of descending projections mediates opiate-dependent control of pain input through the spinal cord (Basbaum and Fields, 1978).

Portions of the central gray may also play a role in the motor system, especially control over vocalizations and certain types of eye movements. Other studies suggest additional functions in the limbic system involving sexual behavior, rage, and fear reactions. Finally, the central gray also appears to have a role in the control of the autonomic nervous system (Beitz, 1990).

CLINICAL DISCUSSION: Although there is not yet a well-accepted clinical sign related to lesions of the central gray, its destruction in monkeys can increase their sensitivity to painful stimuli. Depression of the chemical systems in the central gray decreases the threshold of pain in volunteer human subjects (Basbaum and Fields, 1978).

LOCUS COERULEUS (LoCer)

The locus coeruleus (LoCer) is a small cluster of cells on the inferolateral angle of the central gray, extending from the pontomesencephalic border, rostrally into the midbrain (see Plate 16). Its neurons produce norepinephrine, and their axons have wide-ranging projections reaching most portions of the central neuraxis.

The locus coeruleus is involved in learning and reinforcement processes, the sleep-wake cycle, and nociception (Aston-Jones et al., 1984) as well as in altering endocrine functions and thereby influencing such emotional states as anxiety and depression (Gold et al., 1988a;Gold et al., 1988b). As such, this nucleus has been implicated in a "behavioral inhibition system" that offers protection by using anxiety to inhibit specific behaviors while increasing arousal and attention (Gray, 1982).

CLINICAL DISCUSSION: Small lesions of the locus coeruleus in primates can reduce their anxious behavior. Pharmaceutical suppression of neural activity in the locus coeruleus is used to modify anxiety in humans (Aston-Jones et al., 1984). Recently, the neurons of the locus coeruleus have been demonstrated to undergo

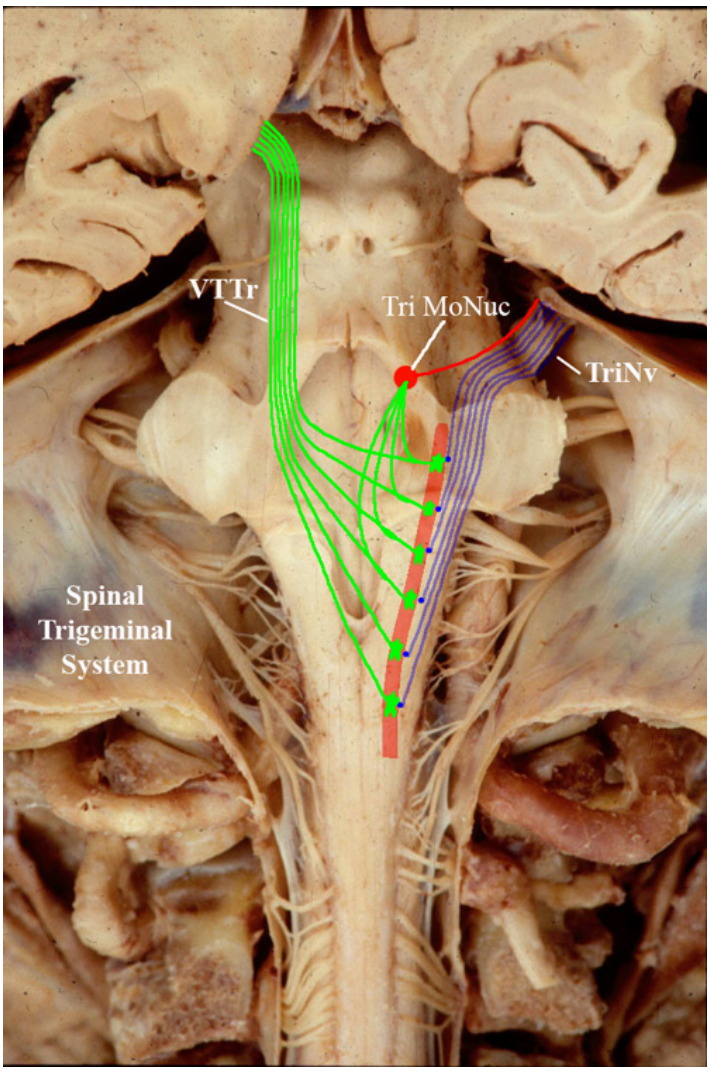


Figure 5-6. Origin of the trigeminal nerve and the trigeminal nuclei in the pons (Barr ML, Kiernan JA. The human nervous system: An anatomical viewpoint. 5th ed. Philadelphia: JB Lippincott, 1988:131)

age-related changes in number and morphology. These alterations can be greatly exacerbated in neurodegenerative diseases such as Alzheimer-type senile dementia and Parkinson disease (Chan-Palay and Asan, 1989a;Chan-Palay and Asan, 1989b).

RAPHE COMPLEX (RaNu)

The raphe complex (RaNu) extends along the midline of the brain stem from medulla (see Plate 11), through pons to midbrain (see Plate 18). It is composed of a cluster of nuclei related to each other in their production of the neurotransmitter serotonin. The pontine raphe nuclei project serotonergic axons to the dorsal horn of the spinal cord and the spinal trigeminal nucleus of the caudal brain stem. In both targets, raphe axons terminate on enkephalinergic cells that can inhibit transmission in the pain pathways. Through these projections, the raphe nuclei play a role in mediating opiate-dependent control over nociception (Basbaum and Fields, 1978).

CLINICAL DISCUSSION: Specific lesions of the raphe system have not been documented in the clinical literature. However, pharmaceutical suppression of the raphe-spinal and trigeminal systems will decrease the threshold of pain in volunteer subjects (Basbaum and Fields, 1978).

VENTRAL TRIGEMINOTHALAMIC TRACT (VTTr)

The ventral trigeminothalamic tract (VTTr) contains ascending fibers from the contralateral spinal trigeminal nucleus (Figure 5-6). The tract courses in close juxtaposition with the medial lemniscus to reach the thalamus, where it terminates in the ventroposterior medial nucleus (see Plate 21). It contains fibers carrying the modalities of crude touch, pain, and thermal sense from the face.

CLINICAL DISCUSSION: Section of the ventral trigeminothalamic tract can result in the loss of crude touch, pain, and thermal sensation from the contralateral face. Note that since the tract has crossed the midline before reaching the pons, its deficit is now in register with that of damage to the anterolateral system (loss of crude touch, pain, and thermal sensation from the contralateral body). Consequently, unilateral pontine lesions affecting both tracts present with diminished sensation across the contralateral face and body (Kushner and Bressman, 1985). This is in contrast to laterally placed lesions in the medulla that affect the spinal trigeminal nucleus (ipsilateral deficit) and anterolateral tract (contralateral deficit), producing alternating analgesia (see Chapter 4).

VENTROSPINOCEREBELLAR TRACT (VSCT)

The ventral spinocerebellar tract (VSCT) has shifted from its ventrolateral position on previous sections (see Plates 3 to 14) and is rising toward the superior cerebellar peduncle. In the caudal midbrain, it joins the peduncle and passes into the cerebellum.

RADIATIONS OF THE TRIGEMINAL NERVE (TriNr)

Fibers of the trigeminal nerve (TriNr) pass through the middle cerebellar peduncle to reach the trigeminal nuclei in the pontine tegmentum (Figure 5-6). This nerve contains primary afferent fibers from sensory receptors in the ipsilateral face as well as efferent axons from the trigeminal motor nucleus to the ipsilateral muscles of mastication. Additional information concerning this structure and its dysfunction is presented previously (see Chap. 4).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Trigeminal motor nucleus (TriMoNu)
- Trigeminal sensory nucleus (CSNu)
- Pontine nuclei (PonNu)
- Corticospinal tract (CST)
- Medial lemniscus (ML)
- Medial longitudinal fasciculus (MLF)
- Anterolateral system (ALS)
- Rubrospinal tract (RuSp)
- Middle cerebellar peduncle (MCP)
- Superior cerebellar peduncle (SCP)
- Central tegmental tract (CIT)
- Pontocerebellar fibers (PCeF)
- Dorsal longitudinal fasciculus (DLF)

Atlas Plate 16

Go to the Atlas

The ventral portion of this section passes through the midpons; the dorsal portion passes, through the caudal midbrain. Its salient features are the exit of the trigeminal nerve from the lateral aspect of the basilar pons and the reduction in size of the fourth ventricle as it tapers to form the cerebral aqueduct. The midbrain structures will be discussed in Chapter 7.

SUPERIOR CEREBELLAR PEDUNCLE (SCP)

The ventral border of the superior cerebellar peduncle (SCP) has begun to curl medialward; this is the first sign of the impending decussation of the superior cerebellar peduncle that will occur in the midbrain (see Plate 18).

LATERAL LEMNISCUS AND NUCLEI (LL, LLNu)

The lateral lemniscus (LL) and its associated nuclei (LLNu) have shifted dorsally into a position lateral to the superior cerebellar peduncle. Here it will remain until reaching the base of the inferior colliculus in the midbrain (see Plate 17).

TRIGEMINAL NERVE (TriNr)

The root of the trigeminal nerve (TriNr) is seen exiting the ventrolateral aspect of the basilar pons (Figure 5-6). Contained within these fibers are the ophthalmic, maxillary, and mandibular divisions of the sensory root and the motor root to the muscles of mastication.

CLINICAL DISCUSSION: Damage to the radiations of the trigeminal nerve or to the trigeminal root in its preganglionic course can result in the loss of sensation, paresthesia, or numbness from the ipsilateral face, loss of the corneal reflex, and flaccid paralysis of the ipsilateral muscles of mastication. This presentation can be accompanied by signs of damage to surrounding structures, such as ataxia (middle cerebellar peduncle), nystagmus (cerebellum), vertigo (vestibular system), tinnitus (auditory system), and facial palsy (facial nerve) (Brazis, 1996b).

CORTICONUCLEAR FIBERS (CoNF)

Axons from the cerebral cortex innervate most of the brain stem nuclei. Collectively, these axons are called the corticonuclear fibers (CoNF) and mediate cerebral control over the brain stem functions. Corticonuclear fibers begin leaving the crus cerebri medially as this massive fiber bundle enters the midbrain (see Plate 19). Specific names are given to these corticonuclear fibers contingent on their brain stem targets: Corticomesencephalic fibers innervate the midbrain, corticopontine fibers innervate the pons, and corticomedullary fibers innervate the medulla (Figure 5-7).

CLINICAL DISCUSSION: The results of a lesion in the corticonuclear fibers are complex because of the varying innervation patterns that these fibers establish. The portions of the brain stem controlling horizontal eye movements (paramedian pontine reticular formation) receive a contralateral corticonuclear input; hence, unilateral lesions can result in horizontal gaze palsies involving the

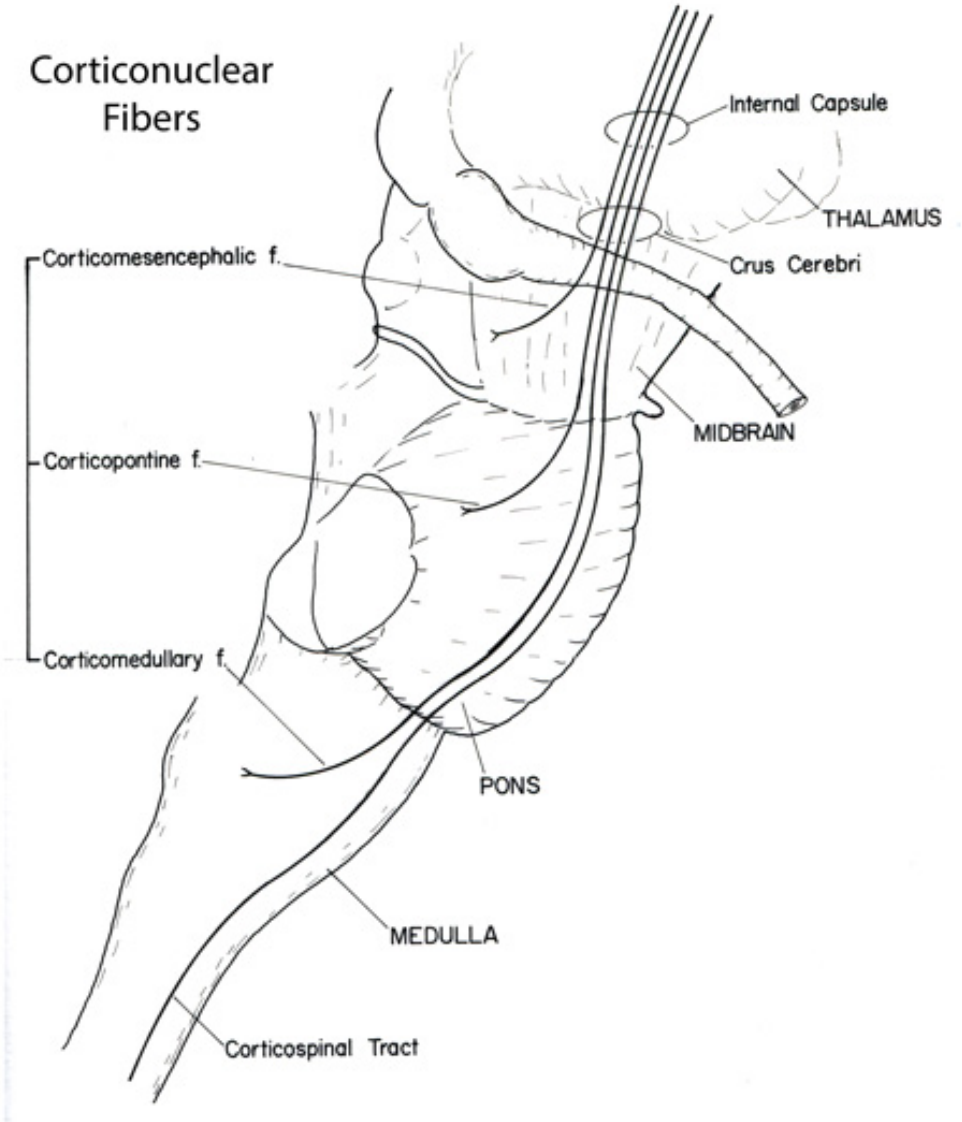


Figure 5-7. This diagram illustrates the corticonuclear fibers overlaid on a lateral view of the brain stem.

side opposite the lesion. The trigeminal motor nucleus and nucleus ambiguus, as well as structures controlling the oculomotor nucleus, receive bilateral corticonuclear innervation. Hence, they experience more subtle deficits in unilateral lesions of these fibers. The neurons of the hypoglossal nucleus innervating the genioglossus muscle of the tongue receive a contralateral cortical input. Consequently, the tongue can exhibit weakness following unilateral corticonuclear lesions. The corticonuclear innervation of the facial nucleus has already been presented previously.

Extensive vascular damage to the ventral pons, interrupting the corticospinal and corticonuclear tracts bilaterally, can produce the "locked-in syndrome" (Kemper and Romanul, 1967;Plum and Posner, 1982). The patient is unable to move extremities or truncal musculature due to loss of the corticospinal fibers, and cannot control muscles innervated by the trigeminal or facial nerves because of loss of the corticonuclear fibers. Communication with such an akinetic and mute patient can be obtained through the only remaining muscles they can move: those controlled by the oculomotor nucleus. As such, these vertical eye movements have been used to establish that the patient is not unconscious.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Locus coeruleus (LoCer)
- Raphe complex (central superior) (RaNu)
- Pontine reticular formation (PRetF)
- Pontine nuclei (PonNu)
- Corticospinal tract (CST)
- Medial lemniscus (ML)
- Medial longitudinal fasciculus (MLF)
- Anterolateral system (ALS)
- Rubrospinal tract (RuSp)
- Middle cerebellar peduncle (MCP)
- Superior cerebellar peduncle (SCP)
- Central tegmental tract (CTT)
- Dorsal longitudinal fasciculus (DLF)
- Pontocerebellar fibers (PCeF)
- Ventral trigeminothalamic fibers (VTTr)

Atlas Plates 17 to 20

Although Atlas Plates 17 to 20 (see Chap. 7) mainly concern the midbrain, portions of the ventral pons are also represented. The prominent features are the massive pontocerebellar fibers, the pontine nuclei, and the condensation of the corticospinal and corticonuclear fibers to form the crus cerebri. The midbrain structures will be considered in Chapter 7.

CORTICOPONTINE FIBERS (CoPF)

The pontine nuclei receive input from many areas of the ipsilateral cerebral cortex. Specific components of these corticopontine fibers (CoPF) are named based on their origin in the cortex: frontopontine, occipitopontine, parietopontine, and temporopontine. The frontopontine fibers travel in the ventral-most portion of the crus cerebri and are the first to innervate the pontine nuclei. The projections from other regions of the cortex are contained in the dorsal portion of the crus cerebri (see Chapter 7).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Pontine nuclei (PonNu)
- Corticospinal tract (CST)
- Middle cerebellar peduncle (MCP)

Case Study 5-2

Chief Complaint

A 49-year-old, right-handed patient called his family physician complaining of clumsiness that began after experiencing a brief loss of consciousness shortly after getting out of bed in the morning.

History of Chief Complaint

He reported that he had suffered severe headaches over the prior 24-hour period and several episodes of instability. This morning he suffered an acute event and now finds it difficult to walk because his left leg is clumsy. He is also complaining of dizziness accompanied by a loud, roaring sound in his left ear. After arranging for his transportation, the physician met him at the emergency room in the community hospital.

Medical History

He was diagnosed with hypertension 10 years previously that has been controlled with medication since that time. He is a heavy smoker (25-pack-year history) and consumes 2 to 3 ounces of alcohol daily. Fifteen years ago he was diagn osed with non-insulin-dependent diabetes, which has been controlled with diet.

Social History

The patient is married, with two children, and works as a salesman for a large pharmaceutical company.

General Physical Examination

This was a stable male sitting upright on the hospital gurney. He was awake, oriented, communicative, and concerned with his problem. He was well nourished, well hydrated, and appeared his stated age. Small hemorrhages were present on the retinal discs. The external auditory canal was patent and clear. Pharynx and larynx were non-reddened. The chest was clear to auscultation, blood pressure was elevated (163/102), and pulse rate and respirations were normal. Peripheral pulses were intact at the wrists but only weakly palpable at the ankles; normal tissue turgor was present. Abdomen was soft, with no masses or tenderness. No lymphadenopathy was detected in the cervical, axillary, or inguinal regions.

Neurologic Examination

Mental Status. He was oriented to person, place and time, with no defect in memory, reading, or writing. Speech was dysarthric, but fluent and meaningful. Word comprehension was good, and he could follow three-step commands.

Cranial Nerves. His visual fields were complete, and he had a full range of eye movements. Horizontal nystagmus was present bilaterally. His pupils were symmetric and reactive to light, both direct and consensual. Convergence movements in both eyes were intact. Hearing was markedly reduced in the left ear, and he had poor word discrimination ability in the left ear compared to that in the right. He complained of a vertiginous sensation of the world drifting around him. He related the change in his hearing and the onset of the vertiginous feeling to his morning event. He had a dense analgesia for pinprick over most of his face on the left except for the perioral region. Some loss of sensation for pinprick was also present on the right, but it was less dense than that on the left. He also complained of a painful paresthesia on the right side of his face that he described as a feeling of having pins and needles on his skin. Corneal reflex was absent on the left and reduced on the right. Jaw-jerk reflex was normal. Two-point discrimination and vibratory sense were normal throughout the face bilaterally. He had no tone in the facial muscles above or below the eye on the left. Creases in his forehead were asymmetric, and only the right side wrinkled on an attempted smile. On attempted upward gaze only the right eyebrow elevated. The left corner of his mouth was open 0.5 cm at rest, and the left eye would not shut completely on attempted blink or squint. Gag reflex was normal, and he denied any dysphagia. Although his speech was slurred, his voice had normal tone, volume, and emotion. His tongue protruded on the midline and appeared normal.

Motor Exam. Strength and reflexes were normal and symmetric in all four limbs, and plantar responses were flexor in both lower limbs. Finger-to-nose and heel-to-shin testing were normal on the right, but grossly abnormal on the left side. Past pointing was present in the left limbs. A left pronator drift was seen when the arms were outstretched.

Sensory Exam. Two-point discrimination, vibratory sense, and proprioception were normal throughout the body. Pinprick and thermal sensations were normal on the left but absent on the right side of the arm, trunk, and leg.

Follow-up

Examination at four months following hospital discharge found the vertigo had resolved and his hearing was normal

in both ears. The past-pointing on the left and sensory loss from the right arm had both resolved. He retained a mild weakness on the left side of his face that presented as a facial asymmetry. He also continued to experience reduced sensation to pinprick on the left side of his face and complained of occasional sharp, stabbing pains in the right side of his face.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious and, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

▶ DISCUSSION II

Pontine Vasculature

Arterial Distribution

The pons can be divided into three vascular perfusion zones: anterior, lateral, and posterior (Duvernoy, 1978). Branches of the basilar artery service each of these vascular zones.

Anterior Zone

Small branches of the basilar artery that quickly penetrate the basilar pons and extend upward along the midline perfuse the anterior vascular zone. Two groups of anterior branches are recognized. The anteromedial (or paramedian) branches extend posteriorly to reach the floor of the fourth ventricle, thus supplying the corticospinal tract, medial lemniscus, medial longitudinal fasciculus, and abducens nucleus. The anterolateral (or short circumferential) branches penetrate through the corticospinal tract, ending in the pontine nuclei and pontocerebellar fibers.

Lateral Zone

Penetrating branches from two groups of vessels perfuse the lateral vascular zone: the pontine arteries (or long circumferential arteries) and the anterior inferior cerebellar artery. These are branches from the basilar artery and supply the lateral half of the pons, including the lateral lemniscus; anterolateral system; the trigeminal, facial, and vestibular nuclei; and the middle cerebellar peduncles. Some of the penetrating branches of the lateral zone also service the lateral aspect of the corticospinal tract.

A small infarction in the lateral vascular zone at the pontomedullary junction was recently reported (Fisher, 1989). The extent of the infarction was confirmed with magnetic resonance imaging. The patient presented with dysarthria, staggering gait, diminished handwriting capability, and ipsilateral appendicular ataxia, all of which could result from damage to the inferior (or caudal portion of the middle) cerebellar peduncle. In addition, the patient displayed ipsilateral facial weakness from damage to the radiations of the facial nerve, nystagmus and ocular overshoot from damage to the vestibular structures, and sensory dissociation of pain and temperature over the contralateral hemibody from damage to the anterolateral system. Since the anterior vascular zone was not involved, there was no paresis (corticospinal tract) and no loss of discriminative sensory capabilities (medial lemniscus).

Posterior Zone

The posterior vascular zone is small and restricted to the rostral end of the pons. It is supplied by penetrating branches of the superior cerebellar artery and perfuses the tissue surrounding the superior cerebellar peduncle.

Arterial Anastomosis

The basilar artery, which arises from the fusion of the two vertebral arteries, plays a key role in the circulation of the pons; however, it is not the sole source of ascending perfusion in all cases. Anastomosis of the posterior and anterior cerebellar arteries with the superior cerebellar artery can, in some individuals, supply blood to the rostral end of the basilar artery when occlusion has occurred in its middle segment (Caplan, 1988).

Arterial Syndromes

Most cerebrovascular accidents in the pons are large and devastating in their presentation. Significant occlusion of the basilar artery or a large hemorrhage into the central portion of the pons results in bilateral damage and presents with a triad of neurologic signs: coma, quadriplegia, and ocular paresis followed by lethal demise (Fisher, 1961). Unilateral hemorrhage into the pons has been documented, and survival in this situation is much greater than that in the bilateral hemorrhages (Kushner and Bressman, 1985). The hemipontine syndromes present with hemiparesis, hemisensory loss, and signs of unilateral involvement of cranial nerves V through VIII, but consciousness can be preserved.

Small lacunar infarctions, although rare, can be restricted to the anterior or lateral vascular zones of the pons, thus creating medial and lateral pontine syndromes. Although usually not lethal, these syndromes can contain a myriad of neurologic deficits (Table 5-1 and Table 5-2).

Medial Pontine Syndrome

The medial pontine syndrome results when disease occludes the paramedian branches of the basilar artery. Damage can be done to the corticospinal tract, transverse pontine fibers, abducens nerve or nucleus, medial longitudinal fasciculus, and portions of the medial lemniscus, particularly the region of arm representation. The patient presentation can involve any or all of the signs listed in Table 5-1.

Lateral Pontine Syndrome

The lateral pontine syndrome results when a vascular accident occurs in the lateral zone, usually perfused by the anterior inferior cerebellar artery. Damage can be done to the middle cerebellar peduncle, anterolateral tract, ventral trigeminothalamic tract, trigeminal nuclei or nerve, facial nerve, and vestibular and cochlear nuclei, as well as the paramedian pontine reticular formation (Amarenco and Hauw, 1990). The neurologic signs presented in this syndrome are listed in Table 5-2. Not all signs have to be present, since the size of the infarction may vary considerably; thus, partial syndromes can occur. Medial branches from this zone can also penetrate into the corticospinal tract; therefore, contralateral hemiparesis can accompany the neurologic sequelae listed in

NEUROLOGIC SIGN	ANATOMIC SOURCE
CONTRALATERAL	
Spastic paralysis	Pontine corticospinal tract
Limb ataxia	Pontine nuclei or transverse pontine fibers
Hypoesthersia in upper extremity	Medial border of the medial lemniscus
IPSILATERAL	
Diplopia on lateral gaze	Abducens nerve
Horizontal gaze palsy	PPRF
Intranuclear ophthalmopelegia	Medial longitudinal fasciculus

Table 5-1. Possible Origins of Neurologic Signs in the Medial Pontine Syndrome (Adapted from Caplan LR, Posterior cerebral artery syndromes. Hdbk Clin Neurol 1988;53(9): 409; and Adams RD, Victor M. Principles of neurology. New York: McGraw-Hill 1989; Chap. 34)

Table 5-2.

The salient signs of the lateral pontine syndrome are loss of nociception from hemiface and body, hemiataxia, and cranial nerve palsies. This syndrome complex can be classified further along the rostral-caudal axis of the brain stem based on the cranial nerve structures involved. Lateral inferior pontine lesions involve the facial nucleus or nerve; the sensory loss is in the form of alternating analgesia. Lateral midpontine lesions involve the trigeminal motor nucleus or nerve, and the sensory loss can involve bilateral analgesia of the face, being more dense on the ipsilateral side. This is due to involvement of the spinal trigeminal system on the ipsilateral side and the ventral trigeminothalamic fibers from the contralateral side. Lateral superior pontine lesions can occur without involving a cranial motor nerve or nucleus, but they infringe on the lateral aspect of the medial lemniscus (see Plate 15), thus producing loss of discriminative touch in the lower extremities. Since the lesion can affect the ventral trigeminothalamic fibers and the anterolateral system, analgesia presents contralateral to the lesion.

FOVILLE'S SYNDROME

A specific subset of the lateral pontine lesion is called Foville's syndrome. It features facial palsy and lateral gaze palsy on the side of the lesion. This is accompanied by a mild, crossed hemiparesis but involves no overt loss of discriminative touch or vibratory sense. This occurs consequent to occlusion of a long circumferential branch of the basilar artery (see Plate 13). The branch supplies the lateral aspect of the corticospinal tract before arching dorsally into the pontine tegmentum to end by perfusing the area around the facial nucleus and pontine reticular formation (including its paramedian region). Since these branches can pass lateral to the medial lemniscus, there can be no affect on discriminative touch.

Comparison of Table 5-1 and Table 5-2 reveals that horizontal gaze palsies can appear in both medial and lateral pontine syndromes. This results from the fact that the paramedian pontine reticular formation and its corticonuclear fibers lie in the overlap between anterior and lateral perfusion zones.

Compression Syndromes

Cranial nerves span the subarachnoid space between the brain stem and the basicranium. Cerebral vessels accompany these nerves in this space; specific relationships are of interest because of the possibility of compression lesions. The trigeminal nerve is

NEUROLOGIC SIGN	ANATOMIC SOURCE
CONTRALATERAL	
Analgesia of body	Anterolateral tract
Analgesia of face	Ventral trigeminothalamic tract
Hypoesthesia in body	Medial lemniscus
IPSILATERAL	
Hypoesthesia of face	Chief sensory trigeminal nucleus
Horizontal gaze palsy	Paramedian pontine reticular formation
Paresis of the jaw	Trigeminal motor nucleus
Facial paralysis	Facial nucleus or radiations
Limb ataxia	Middle cerebellar peduncle

Table 5-2. Possible Origins of Neurologic Signs in the Lateral Pontine Syndrome (Adapted from Caplan LR, Posterior cerebral artery syndromes. Hdbk Clin Neurol 1988;53(9): 409; and Adams RD, Victor

in close juxtaposition with the superior cerebellar, anterior inferior cerebellar, and basilar arteries. The sixth, seventh, and eighth cranial nerves are closely related to the anterior inferior cerebellar artery and sometimes to the posterior inferior cerebellar artery. These vessels are capable of exerting pressure on the associated nerves. This situation is exacerbated as the vessel becomes more tortuous with age and as the aging brain stem sags along the clivus (Jannetta, 1980). Pressure or irritation to these cranial nerves can present as trigeminal neuralgia, hemifacial spasm, deafness, vertigo, or facial paralysis (Escobedo and Solis, 1979).

References

Amarenco P, Hauw J-J (1990) Cerebellar infarction in the territory of the superior cerebellar artery: a clinicopathologic study of 33 cases. Neurol 40: 1383-1390.

Aston-Jones G, Foote S, Bloom FE (1984) Anatomy and physiology of locus coeruleus neurons: functional implications. In: Norepinephrine (Ziegler MG, Lake CR, eds), pp 92-116. Baltimore: Williams and Wilkins.

Autret A, Laffont F, de Toffol B, Cathala HP (1988) A syndrome of REM and non-REM sleep reduction and lateral gaze paresis after medial tegmental pontine stroke. Arch Neurol 45: 1236-1242.

Basbaum AI, Fields HL (1978) Endogenous pain control mechanisms: Review and hypothesis. Ann Neurol 4: 451-462.

Beitz AL (1990) Central gray. In: The Human Nervous Sytem (Paximos G, ed), pp 307-329. San Diego, CA: Academic Press, Inc.

Bender MB (1980) Brain control of conjugate horizontal and vertical eye movements. A survay of the structural and function correlates. Brain 103: 23-69.

Biller J, Brazis PW (1996) The localization of lesions affecting cranial nerve VIII (The vestibulocochlear nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 293-314. Boston: Little, Brown and Company.

Brazis PW (1996b) The localization of lesions affecting cranial nerve V (The trgeminal nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 251-270. Boston: Little, Brown and Company.

Brazis PW (1996a) The localization of lesions affecting cranial nerve VII (The facial nerve). In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 271-292. Boston: Little, Brown and Company.

Brugge JF, Geisler CD (1978) Auditory mechanisms of the lower brainstem. Ann Rev Neurosci 1: 363-394.

Caplan LR (1988) Posterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 409-415.

Cascino GD, Adams RD (1986) Brainstem auditory hallucinosis. Neurol 36: 1042-1047.

Chan-Palay V, Asan E (1989b) Alterations in catecholamine neurons of the locus coeruleus in senile dementia of the Alzheimer type and in Parkinson's disease with and without dementia and depression. J Comp Neurol 287: 373-392.

Chan-Palay V, Asan E (1989a) Quantitation of catecholamine neurons in the locus coeruleus in human brains of normal young and older adults and in depression. J Comp Neurol 287: 357-372.

Davidoff RA (1990) The pyramidal tract. Neurol 40: 332-339.

Duvernoy HM (1978) Human Brainstem Vessels. Berlin: Springer-Verlag.

Escobedo F, Solis G (1979) Vascular compression of cranial nerves at the posterior fossa. Adv Neurol 25: 243-250.

Fisher CM (1961) Clinical syndromes in cerebral hemorrhage. In: Pathogenesis and Treatment of Cerebrovascular Disease (Fields WS, ed), pp 318-342. Springfield, Illinois: CHarles C. Thomas Publishers.

Fisher CM (1978) Ataxic hemiparesis. Arch Neurol 35: 126-128.

Fisher CM (1982) Lacunar strokes and infarcts: a review. Neurol 32: 871-876.

Fisher CM (1989) Lacunar infact of the tegmentum of the lower lateral pons. Arch Neurol 46: 566-567.

Glass JD, Levey AI, Rothstein JD (1990) The dysarthria-clumsy hand syndrome: a distinct clinical entity related to pontine infarction. Ann Neurol 27: 487-494.

Goebel H, Komatsuzaki A, Bender M, Cohen B (1971) Lesions of the pontine tegmentum and conjugate gaze paralysis. Arch Neurol 24: 431-440.

Gold PW, Goodwin FK, Chrousos GP (1988a) Clinical and biochemical manifestations of depression: relation to the neurobiology of stress Part I. N Engl J Med 319: 348-353.

Gold PW, Goodwin FK, Chrousos GP (1988b) Clinical and biochemical manifestations of depression: relation to the neurobiology of stress Part II. N Engl J Med 319: 413-420.

Gray JA (1982) The Neuropsycology of anxiety. Oxford: Clarendon Press.

Helweg-Larsen S, Larsson H, Henriksen O, Sorensen PS (1988) Ataxic hemiparesis: three different locations of lesions studied by MRI. Neurol 38: 1322-1324.

Holtzman RN, Zablozki V, Yang WC, Leeds NE (1987) Lateral pontine tegmental hemorrhage presenting as isolated trigeminal sensory neuropathy. Neurol 37(4): 704-706.

Jannetta PJ (1980) Neurovascular compression in cranial nerve and systemic disease. Annals of Surgery 192: 518-525.

Jenkins WM, Masterton RB (1982) Sound localization: effects of unilateral lesions in central auditory system. J Neurophysiol 47: 987-1016.

Keane J (1976) Bilateral sixth nerve palsy. Arch Neurol 33: 681-683.

Kemper TL, Romanul FC (1967) State resembling akinetic mutism in basilar artery occlusion. Neurol 17(1): 74-80.

Kennedy PR (1990) Corticospinal, rubrospinal, and rubro-olivary projections: a unifying hypothesis. Trends Neurosci 13: 474-479.

Kushner MJ, Bressman SB (1985) The clinical manifestations of pontine hemorrhage. Neurol 35(5): 636-643.

Masdeu JC, Brazis PW (1996) The localization of lesions in the ocular motor system. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 155-250. Boston: Little, Brown and Company.

Nabatame H, Fukuyama H, Akiguchi I, Kameyama M, Nishimura K, Torizuka K (1987) Pontine ataxic hemiparesis studied by a high-resolution magnetic resonance imaging system. Ann Neurol 21: 204-207.

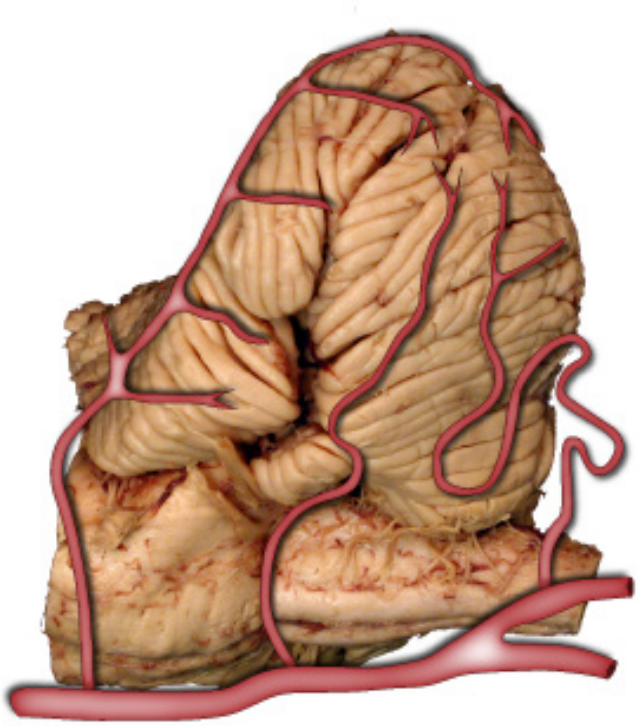
Olszewski J, Baxter D (1982) Cytoarchitecture of the Human Brain Stem. Basel: S. Karger.

Parker W, Decker R, Richards NG (1968) Auditory function and lesions of the pons. Archives of Otolaryngology 87: 26-38.

Parker W, Decker RL, Gardner WH (1976) Auditory function and intercranial lesions. Arch Neurol 76: 425-435.

Plum F, Posner JB (1982) The Diagnosis of Stupor and Coma. Philadelphia: F.A. Davis Company.

Chapter 6
Cerebellum



INTRODUCTION

The cerebellum is a large, foliated structure perched on the dorsal surface of the pons and forming the roof of the fourth ventricle. It is contained in the acute angle created by the brainstem and the central surface of the occipital lobes of the cerebellum. Since the cerebellum is located within the posterior cranial fossa and is separated from the occipital cortex by the tentorium cerebelli, it is by definition an infratentorial structure.

Three large-fiber bundles connect the cerebellum to the brainstem: the superior, middle and inferior cerebellar peduncles. These peduncles contribute to the rostral and lateral walls of the fourth ventricle. The blood supply to the cerebellum is derived from three branches of the vertebrobasilar system: superior, anterior inferior and posterior inferior cerebellar arteries.

In this chapter the organization, connections, and cell structure of the cerebellum will be examined. The vasculature of the cerebellum will be studied and several clinicopathologic cases involving cerebellar lesions will be presented.

General Objectives

1. To define the main divisions of the cerebellum, relating them to specific patterns of afferent and efferent connections
2. To identify the functions of the main divisions of the cerebellum
3. To describe clinical signs and symptoms associated with disease in these cerebellar divisions

Instructions

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can

best be answered by using a knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

Materials

1. A model of the human brain stem
2. A whole human cerebellum and a cerebellum sectioned in the sagittal plane
3. A cerebellum and brain stem with intact vasculature

Chapter Topics:

Case Study 6-1

Chief Complaint

A 36-year-old attorney was referred with a chief complaint of gait imbalance, headaches and vomiting.

History of Chief Complaint

The patient had had frontal and biparietal headaches for approximately one month. He stated that the headaches began in the occipital region approximately two months ago and about a month ago became frontal as well. Coughing, sneezing, or bending precipitated or worsened the headaches. On at least one occasion the patient had been awakened by a headache. He experienced nausea and vomiting independent of the headaches. At times, vomiting occurred suddenly without preceding nausea. For several weeks prior to admission he had been unsteady on his feet with a tendency to fall to the right. He admitted to occasional clumsiness of his right hand. During the week prior to admission he had been excessively drowsy and constantly tired. The headaches had become more frequent, so that they were now occurring three to four times per day.

Medical History

His medical history was unremarkable except for an episode of rheumatic fever at age 6.

Family History

He was unmarried, lived alone, and was employed by a large law firm. His parents were alive and in good health; he had no siblings.

Social History

He professed to be heterosexual and was involved in a monogamous relationship that had lasted for several years. He had a 10-pack-year history of smoking, but had quit 6 years previously. He had been active in outdoor sports since age 31 and had been running up to 4 miles daily until 4 weeks before, when he had to quit because of an unsteady gait and worsening headaches.

General Physical Examination

This is a stable male who is seated upright on an examination table. He is awake, oriented, well-nourished, well-hydrated, and distressed with considerable head pain. He appeares his stated age and is in otherwise good physical condition. His eyes have no cotton wool patches, but papilledema is evident. His chest is clear to auscultation and percussion; his abdomen is soft without lumps or masses. Blood pressure is 135/87 and pulse rate is 69. Temperature and respirations are normal. Peripheral pulses are intact; no extremity edema is present; no cervical, axillary, or inguinal lymphadenopathy is detectable.

Neurologic Examination

Mental Status. He is awake and oriented with respect to person, place, and time. His memory and knowledge base are appropriate for his training. Speech is fluent and meaningful. He is a coherent historian.

Cranial Nerves. A full range of eye movements are present. His pupils are 3 to 4 mm in diameter and reactive to light, both direct and consensual. On funduscopic examination there is evidence of bilateral papilledema. Horizontal nystagmus in the direction of gaze is present on attempted lateral gaze to either side. He denies any double vision. Hearing is normal and equal in both ears. Corneal, jaw-jerk, and gag reflexes are intact. Facial expressions are full and symmetric. Uvula and tongue protrude on the midline. Shoulder shrug is symmetric.

Motor Exam. His strength is intact in all extremities and his deep tendon reflexes are symmetric and physiologic. His plantar responses are flexor. When walking, he maintains a slightly widened base and there is a mild tendency to veer to the right. He is unable to stand on his right leg comfortably. Closing his eyes does not markedly alter the instability on his right leg. He can stand comfortably on his left leg with his eyes open or shut. A very mild end-point tremor is present in the right upper extremity on finger-to-nose testing, and in the right lower extremity on heel-to-shin testing. Alternating movements of the right hand are slightly slower, and with prolonged periods become disorganized.

Sensory Exam. Pinprick, two-point discrimination, vibratory sense, and proprioception are intact throughout body and face.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

Case Study 6-2

Chief Complaint

An 8-year-old girl was brought to her family physician by her mother because the child has become "unsteady" when walking.

History of Chief Complaint

Seven months earlier, she had begun complaining of nausea frequently. She is still complaining of nausea, and is also vomiting frequently. In the past 3 months, the child had begun walking unsteadily with a broad-based gait. When seated, she swayed from side to side and occasionally fell over. Her head rotated from side to side as her body swayed. The mother also noted that the child had recently become extremely irritable.

Developmental and Medical History

The mother had had an uneventful pregnancy and delivery. At birth the child weighed 3.25 kg; by 5.5 months she could maintain a seated, upright posture, and she could roll over at 6 months of age. She could rise to a standing position and take several steps by 15 months, and could climb stairs by 20 months. By 3 years of age she could stand

on one foot, unassisted. For the next 4 years she was active in outdoor play. All of her immunizations were current.

Family History

The mother was a social worker for the state and a single parent; the father was remarried and living out of state. The child's maternal and paternal grandparents were in good health. The mother had a 12-pack-year history of smoking and smoked through the pregnancy; she denied any use of alcohol either at this time or during the pregnancy. No one else in her family had similar or related symptoms.

General Physical Examination

This was an awake, oriented child who was complaining of headaches and dizziness. Face and personality appeared the stated age, but she was underweight and lacked appropriate muscle mass. Edges of optic discs were blurred, but lacked cotton wool patches or papilledema. Nystagmus was evident on lateral gaze to either side. Her chest and abdomen were normal; blood pressure, pulse rate, temperature, and respirations were physiologic. Peripheral pulses were intact, with normal tissue turgor, and no cervical, axillary, or inguinal lymphadenopathy was detected.

Neurologic Examination

Mental Status. The child was awake and oriented with respect to time and place. Memory and knowledge were appropriate for her age. However, response time to questions was protracted and she appeared preoccupied with her headache pain.

Cranial Nerves. She had a full range of eye and facial movements. However, nystagmus was present on horizontal gaze to either side. Hearing was normal in both ears. Corneal, jaw-jerk, and gag reflexes were normal. The facial expressions were complete, the eyes were closed tightly, and the forehead was wrinkled symmetrically when frowning. Uvula and tongue protruded on the midline.

Motor Exam. Strength was normal in all extremities; deep tendon reflexes were physiologic in all extremities. In the seated position, the child swayed from side to side and could not maintain her torso in a vertical position. Her gait was broad-based and reeling. Finger-to-nose and heel-to-shin testing were grossly abnormal unless her torso was supported in a vertical position.

Sensory Exam. Pinprick, thermal, vibratory, two-point discrimination, and proprioceptive senses were normal throughout the body and face.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

Macrostructure of the Cerebellum

The cerebellum consists of a thin, outer veneer of cells, called the cortex, wrapped around a large tuft of fibers or white matter that arises from three peduncles attached to the brain stem. At the base of the peduncles are several cell clusters called the deep nuclei. Cells in the cerebellar cortex receive afferent information from many sources. Axons from the cerebellar cortical neurons are mapped topographically onto the deep nuclei. These nuclei form the main outflow of the cerebellum.

There are several systems of nomenclature for subdividing the cerebellum (Figure 6-1 and Figure 6-2); these are based on gross anatomic features, afferent and efferent connections, and paleontology. At a gross anatomic level, three transversely oriented lobes can be defined. The anterior and posterior lobes are separated by the primary fissure. Inferior to the posterior lobe lies a small, flocculonodular lobe (Figure 6-1). Two longitudinally oriented structures, the midline vermis and the laterally positioned hemispheres transect these three lobes. Thus, the vermis and both hemispheres are represented in the anterior, posterior, and flocculonodular lobes.

The vermis and hemispheres of the cerebellum can be further partitioned based on connectivity into three longitudinal zones (Figure 6-1 and Figure 6-2). Each zone represents an area of the cortex directly related to a specific deep cerebellar nucleus. On the midline, completely contained within the vermis, is the median zone; its cells project to the fastigial nucleus. The lateral edge of the vermis and a narrow strip of adjacent hemisphere represent the paramedian zone, which projects to the interpositus nucleus. Finally, the remainder of the hemisphere is the lateral zone, directly connected to the underlying dentate nucleus.

The cerebellum can also be classified by the organization of its af-

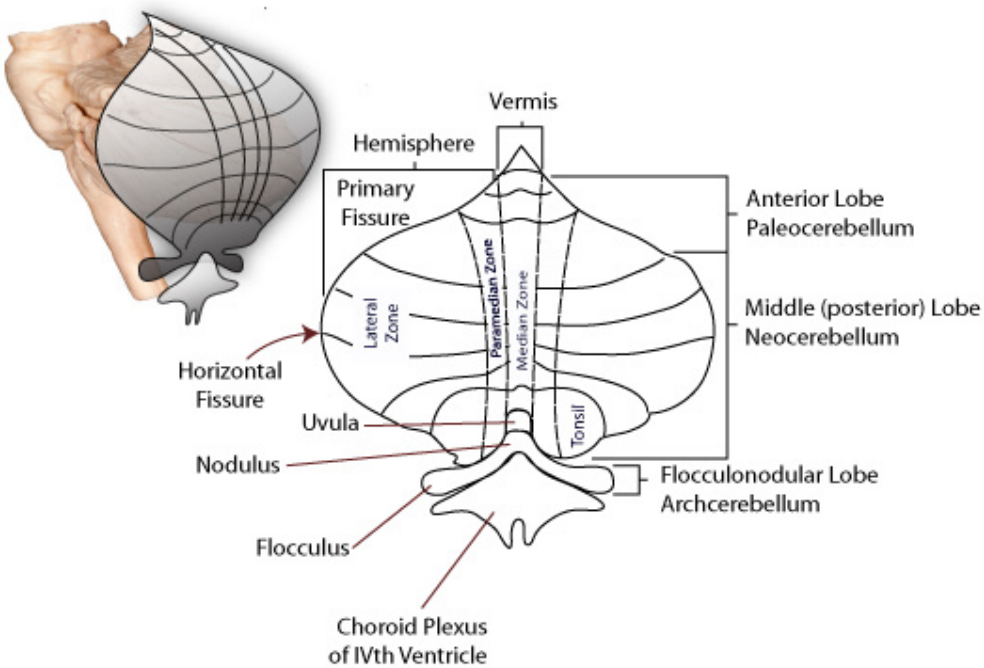


Figure 6-1. Diagram of the cerebellum demonstrates its various nomenclatures. (Noback CR, Demarest RJ. The human nervous system: basic principles of neurobiology. 3rd. ed. New York: McGraw-Hill, 1981:323)

ferent fibers. The flocculonodular lobe receives a significant projection from the vestibular system and is called the vestibulocerebellum. Afferent fibers from the spinal cord (spinocerebellar tracts) terminate in the anterior lobe and in portions of the vermis; these regions are therefore called the spinocerebellum. Lateral portions of the posterior lobe receive a significant projection of fibers from the neocortex through the pontine nuclei; this area is called the pontocerebellum.

From an evolutionary perspective, the flocculonodular lobe represents the oldest part; it is therefore known as the archicerebellum. The anterior lobe and associated portions of the vermis represent the "not-so-old" cerebellum, or paleocerebellum. Finally, the enlarged hemispheres of the posterior lobe represent the phylogenetically newest part, or neocerebellum (Figure 6-1).

Cerebellar Regions

Vestibulocerebellum

The vestibulocerebellum receives primary afferent fibers from the ipsilateral vestibular apparatus. These projections are directed mainly to the nodulus, whereas the flocculus receives input from visuomotor nuclei located along the medial longitudinal fasciculus. Efferent fibers from the vestibulocerebellum send projections directly to the ipsilateral vestibular nuclei (Figure 6-2 and Figure 6-5). In turn, the vestibular nuclei influence axial musculature through the vestibulospinal tracts and extraocular eye muscles through the medial longitudinal fasciculus (Figure 6-5). The vestibulocerebellum uses information from the otolithic organ (gravity) to control posture, balance, and eye movements.

Spinocerebellum

The spinocerebellum consists of the median and intermediate zones. Geographically, these comprise most of the vermis and anterior lobe. Inputs to the median zone arise in the neck and trunk musculature and in the vestibular, auditory, and visual systems. Its output is directed to the fastigial nucleus, which then projects axons to the sources of the vestibulospinal and reticulospinal tracts. Through these connections, the median zone of the cerebellum coordinates muscle activity in the medial motor system, which regulates axial and proximal limb musculature.

The intermediate zone receives input from the spinocerebellar tracts carrying proprioceptive information from the limb musculature. Its output is directed through the interpositus nuclei (emboliformis and globose) to the red nucleus and ventrolateral thalamic nucleus. This output influences muscle coordination in the lateral motor system through the rubrospinal and corticospinal tracts (Figure 6-2 and Figure 6-5). The lateral motor system functions to control the distal limb musculature.

Pontocerebellum

The lateral hemispheres of the posterior lobe consist of most of the pontocerebellum (Figure 6-2). Their major afferent connections arise in the contralateral pontine nuclei. These nuclei are innervated by neurons in the ipsilateral cerebral cortex. It is through this cortico-ponto-cerebellar pathway that the cerebral cortex and cerebellum plan patterns for coordinated muscle activities in the distal portion of the extremities. Efferent fibers, which carry these motor patterns from the pontocerebellum, are relayed through the dentate nucleus to contralateral thalamus and subsequently, to motor cortex.

The dentate nucleus also participates in a complex feedback circuit involving the red nucleus of the midbrain and the inferior olivary nucleus of the medulla. In this pathway, efferent projections from the dentate nucleus innervate the contralateral red nucleus, rubro-olivary axons course over the central tegmental tract of the brainstem to reach the inferior olive, and olivocerebellar fibers in the medulla cross the midline to join the inferior cerebellar peduncle and innervate the cerebellar cortex. These olivocerebellar axons form climbing fibers in the cortex. Each climbing fiber innervates the dendritic arbor of one Purkinje cell. This rubro-olivary feedback loop to the cerebellum is involved in learning new motor skills (Sanes et al., 1990).

CLINICAL DISCUSSION: The most common pathologies of the cerebellum usually involve exposure to toxic substances (e.g., alcohol), a tumor, or an infarction. It is possible to catalog some of the clinical cerebellar syndromes with respect to specific anatomic regions (Brown, 1982; Gilman, 1986; Biller and Brazis, 1996). The cerebellum is composed of three zones: median, paramedian, and lateral, based on their connections. In the simplest schema of clinical cerebellar presentations, two general regional syndromes are recognized. The median cerebellar syndrome involves damage to the midline structures in the sagittal plane. The presentation can feature abnormalities in equilibrium, posture, gait, eye movements, and head position (titibutions) as well as truncal ataxia and vestibular nystagmus. The lateral cerebellar syndrome involves damage to the lateral zone and can present with signs of limb ataxia: hypotonia, dysmetria, decomposition of movement, past-pointing, and impaired check. Since isolated lesions to the paramedian zone have not been reported, the clinical presentation of this zone has been linked to those of the lateral zone (Gilman, 1986).

A further classification breaks the midline syndrome into anterior and posterior components. The anterior lobe or rostral vermis syndrome features disturbed gait and postural reflexes such as those seen in chronic alcoholic degeneration (a process that attacks the anterior lobe). The posterior lobe or caudal vermis syndrome (also called basal or flocculonodular syndrome) results from damage to the flocculonodular lobe and the posterior portion of the median zone. It can present with disturbances of equilibrium, truncal ataxia, and vestibular nystagmus. Each of these syndromes will be discussed further.

Cerebellar Syndromes

Anterior Cerebellar or Rostral Vermis Syndrome

Lesions of the anterior spinocerebellum present as gait disturbances without changes in reflexes (Brown, 1982). Outwardly, this is characterized by a wide-based stance and reeling gait in the patient. There can be little indication of ataxia in the limbs upon isolated heel-to-shin or finger-to-nose testing. Although infrequent, hypotonia, nystagmus, or dysarthria can be expressed as well. This presentation is called the anterior cerebellar or rostral vermis syndrome and can indicate a tumor in the anterior lobe or alcohol-induced cerebellar degeneration.

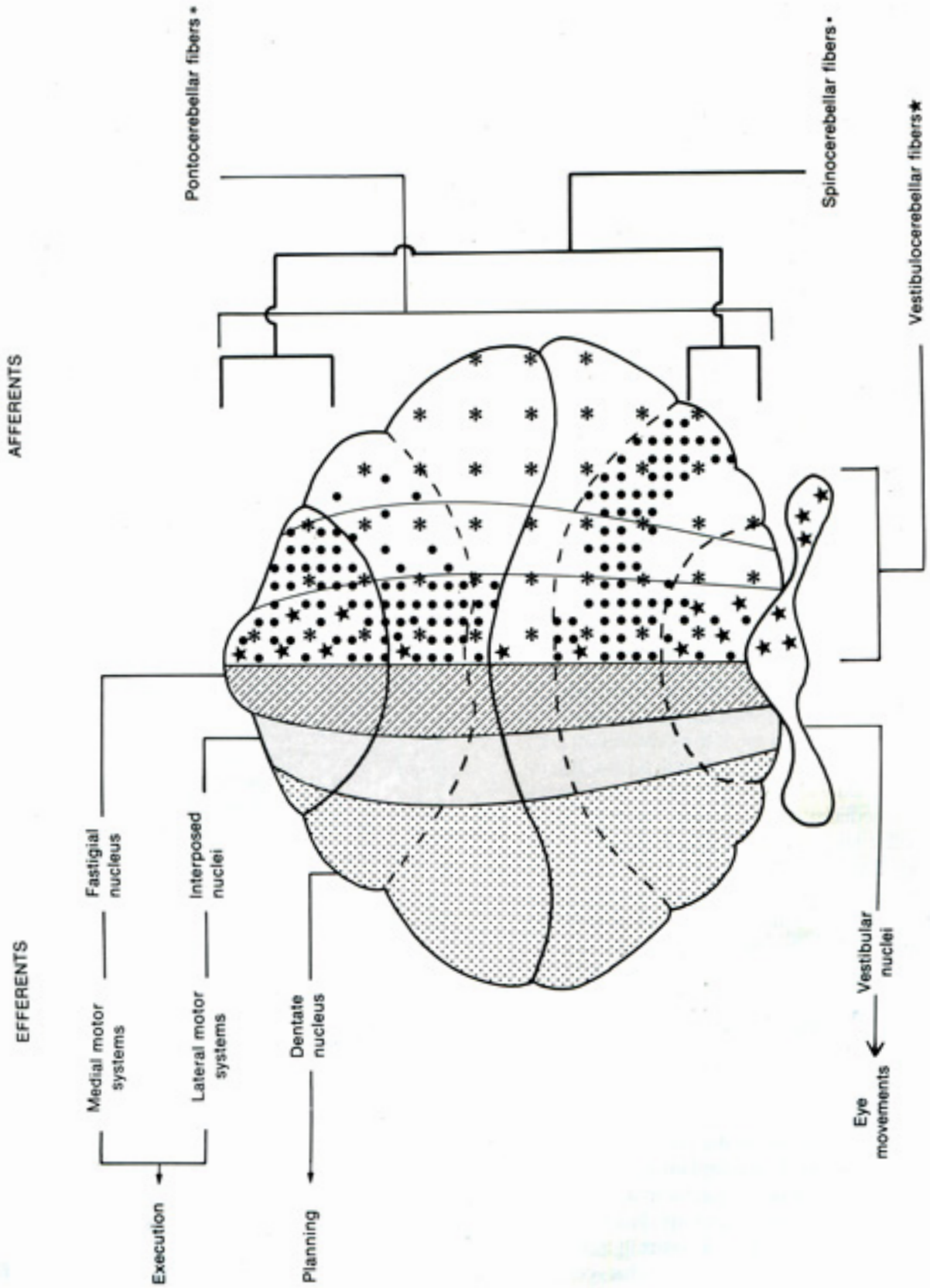


Figure 6-2. A diagram of the cerebellum indicates its input and output zones. These zones are positioned on the gross anatomic divisions of this structure.

Basal Cerebellar or Caudal Vermis Syndrome

Damage to the vestibulocerebellum and lower portion of the posterior (spinocerebellum) lobe can result in the basal or caudal vermis cerebellar syndrome (truncal ataxia). The three signs are: (1) gait disturbance and axial disequilibrium characterized by difficulty maintaining balance while walking (this is not considered limb ataxia) or while sitting, (2) head rotation or titibutions and, (3) nystagmus. Signs of limb ataxia such as past-pointing and dysmetria are usually not present. Because of its small size, pure lesions of the flocculonodular lobe are rare; damage to this structure usually occurs in concert with damage to other portions of the cerebellum or brain stem.

Lateral Cerebellar Syndrome

The complex neurologic sequelae following lateral cerebellar hemisphere damage have various names: lateral cerebellar syndrome, neocerebellar syndrome, limb ataxia, or hemisphere syndrome. This syndrome can feature defective postural fixation of the limbs as well as errors in rate, range, direction, timing, and force of skilled movements. All movements of the affected limb are slow. Past-pointing, dysmetria, and movement (intention) tremor can be present. The affected limb is on the side of the cerebellar lesion. Horizontal nystagmus, in the direction of gaze, can present with hemisphere lesions (Brown, 1982;Biller and Brazis, 1996).

Cerebellar Peduncles

Inferior Cerebellar Peduncle (ICP)

The spinocerebellar and olivocerebellar fibers enter the cerebellum through the inferior cerebellar peduncle (ICP or restiform body). The medial border of this peduncle also contains projections from the vestibulo-cerebellum to the vestibular nuclei. The inferior cerebellar peduncle is first recognizable in the caudal medulla (see Plate 8) where it forms from the union of the dorsal spinocerebellar tract and the olivocerebellar fibers. It rises dorsally into the cerebellum at the pontomedullary border (see Plates 13 and 14). Olivocerebellar fibers are distributed throughout the cerebellar cortex, whereas the spinocerebellar fibers are targeted on the anterior lobe and on portions of the median and intermediate zones.

CLINICAL DISCUSSION: Lesions of the inferior cerebellar peduncle can result in ataxia similar to that resulting from lesions of the spinocerebellum. The lateral medullary syndrome (see Chapter 4) can present with ataxia due to involvement of this peduncle (or in caudal medullary infarcts, the spinocerebellar tracts). Since lesions of the inferior cerebellar peduncle leave the cerebellum functioning, but devoid of proper sensory information, the resulting deficit is termed "sensory ataxia" to distinguish it from the ataxia resulting from direct cerebellar damage.

Middle Cerebellar Peduncle (MCP)

The middle cerebellar peduncle is the largest of the fiber tracts entering the cerebellum. It arises in the pontine nuclei (see Plates 14 to 19). The axons from pontine neurons, representing the transverse pontine fibers, cross the midline and coalesce along the lateral aspect of the brain stem to become the massive middle cerebellar peduncle. These fibers terminate in the cortex of the cerebellum. The pontine cells receive input from the corticopontine fibers, thus establishing a cortico-ponto-cerebellar pathway.

CLINICAL DISCUSSION: Lesions of the middle cerebellar peduncle can result in ipsilateral ataxia, often combined with signs of cranial nerve damage, such as that seen in the lateral pontine syndrome. Lesions involving the pontine nuclei (the source of the middle cerebellar peduncle) and adjacent corticospinal tract can result in complex presentations such as ataxic hemiparesis (Fisher, 1978). Lesions of the middle cerebellar peduncle are also discussed in Chapter 5.

Superior Cerebellar Peduncle (SCP)

The efferent pathway of the cerebellum is the superior cerebellar peduncle. Arising in the deep nuclei (Figure 6-4), this peduncle passes rostrally along the lateral walls of the fourth ventricle (see Plates 13 and 14). At the pontomesencephalic junction, it slips from under the rostromedial edge of the middle cerebellar peduncle (Plate 15) and enters the tegmentum of the brain stem (see Plates 16 and 17). Deep in the midbrain tegmentum, the superior cerebellar peduncle decussates (see Plates 18 and 19) and passes around the red nucleus (see Plates 20 and 21). Rostral to the red nucleus the fibers in the superior cerebellar peduncle are referred to as the cerebellothalamic tract (CThT, Plates 20 and 21). After entering the caudal thalamus, these fibers pass through the thalamic fasciculus (ThFas, Plate 22) to end in its ventrolateral nucleus (see Plates 22 and 23).

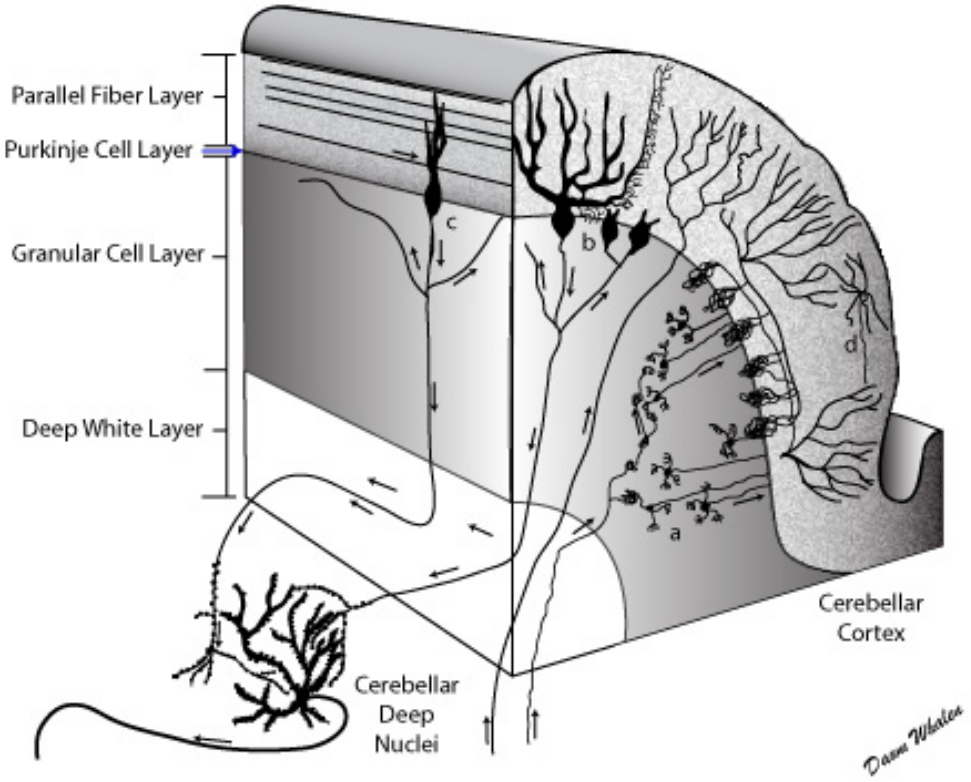
Although most of the fibers in the superior cerebellar peduncle are leaving the cerebellum, a small component of these axons is entering. The ventral spinocerebellar tract, which arises in the dorsal horn of the spinal cord, joins the ventral border of the superior cerebellar peduncle in the rostral pons (see Plate 15). After entering the cerebellum, the ventral spinocerebellar tract leaves the peduncle and proceeds into the anterior lobe (see Chapter 3).

CLINICAL DISCUSSION: Lesions of the superior cerebellar peduncle can result in ataxia similar to lesions of the middle cerebellar peduncle and cerebellar hemispheres. If the lesion is caudal to the decussation of the superior cerebellar peduncle in the midbrain, the ataxia is expressed on the ipsilateral side. However, lesions rostral to the decussation are expressed contralaterally. Signs of midbrain dysfunction can accompany lesions involving the superior cerebellar peduncle (see Chapter 7).

Microstructure of the Cerebellum

The cerebellum can be divided into two general regions based on cytology. The outermost, or cortex, contains several layers of cells, one of which is a monolayer of large Purkinje cell bodies. The innermost region is a massive zone of white matter. Embedded in the base of the white matter are the deep cerebellar nuclei. Afferent fibers to the cerebellum travel through its peduncles. They pass around the deep nuclei (often with collateral branches to these nuclei) and ascend through the white matter to the cortex, where they make connections with Purkinje cells or closely related interneurons. The axons of the Purkinje cells represent the efferent fibers of the cerebellar cortex. They descend through the white matter to terminate in the deep cerebellar nuclei. Finally, the deep nuclei give rise to fibers that enter the superior cerebellar peduncle, the major

Figure 6-3. Cytoarchitecture of the cerebellar cortex.(a) Granule cell, (b) Purkinje cell, (c) Basket cell, (d) Stellate cell, (e) Golgi cell, (f) Mossy fiber, (g) Climbing fiber, (h) Catecholamine fiber. (Barr ML, Kiernan JA. The human nervous system: anatomical viewpoint. 5th ed. Philadelphia: JB Lippincott, 1988,165)



efferent pathway of the cerebellum.

Cerebellar Cortex

A prominent feature of the cerebellar cortex is the monolayer of Purkinje cells. These cells are the largest neurons of the cortex; their dendrites extend outward in elaborate arbors through the molecular or outermost layer. Their axons enter the white matter, eventually reaching the deep nuclei. The dendritic tree of the Purkinje cell is flattened in the transverse plane (Figure 6-3). Passing through its dendrites are axons from granule cells. These axons are oriented parallel to the folia of the cerebellum. Their arrangement with the Purkinje cell dendrites is somewhat reminiscent of telephone wires and poles; they are referred to as parallel fibers, a term reflecting their common orientation.

Also synapsing on Purkinje cell dendrites are climbing fibers that arise in the contralateral inferior olivary nuclei (see Plates 8 to 12). Each climbing fiber closely invests a Purkinje cell dendritic arbor. Thus, neurons in the inferior olive can have a profound effect on Purkinje cell activity.

The granule cells are located in a layer deep to the Purkinje cell bodies (Granule cell layer, Figure 6-3). Granule cell dendrites receive afferent fibers from the vestibular system, spinal cord, and pontine nuclei. Granule cell axons pass by the Purkinje cell body to enter the molecular layer, where they bifurcate to form parallel fibers. These fibers are strung through the Purkinje cell dendrites. Afferent stimuli activate the granule cell/parallel fiber system, which in turn activates Purkinje cells.

Numerous stellate, basket, and Golgi cells are also found in the cerebellar cortex. Activated by mossy fibers' afferent stimuli similar to granule cells, these other interneurons have an inhibitory effect on Purkinje cells. Thus, the Purkinje cells integrate excitatory and inhibitory input from several different sources, and their output influences the activity of cells in the deep nuclei.

Deep or Intracerebellar Nuclei

Embedded in the base of the white matter are the deep cerebellar nuclei. These structures represent the main source of efferent projections from the cerebellum. From medial to lateral, they are fastigial, interpositus (globose and emboliform), and dentate (Figure 6-4). Purkinje cell axons are a major source of input and have an inhibitory influence on these nuclei. Each nucleus receives its afferent fibers from a specific region of the cerebellar cortex and in turn, forms efferent projections to specific targets in the brain stem. Fig-

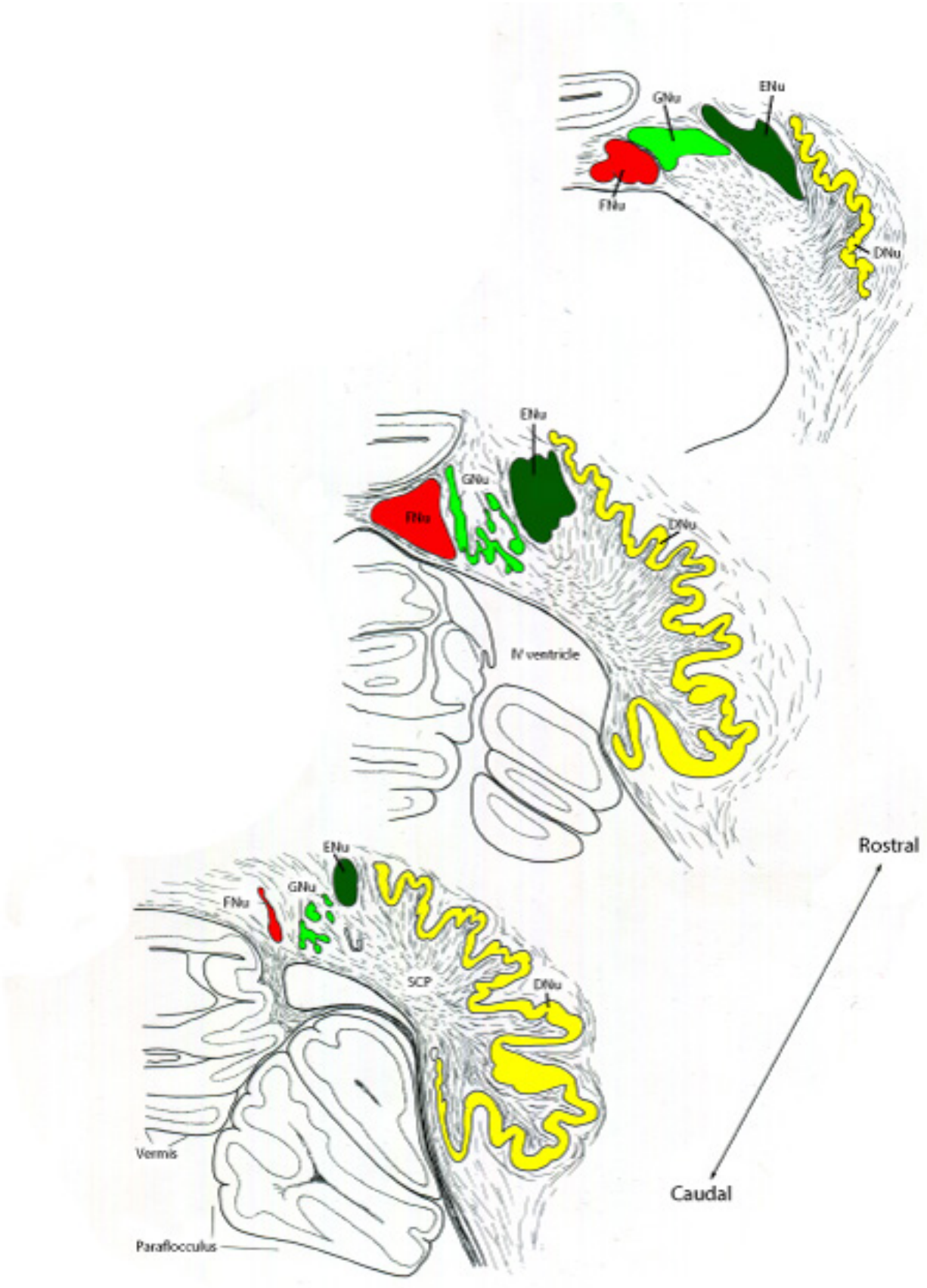


Figure 6-4. The deep or intracerebellar nuclei. This figure contains three sections throughout the deep cerebellar nuclei, illustrating their position and surrounding tracts.

ure 6-5 illustrates the relationship between cerebellar cortex, deep nuclei, and specific cerebellar efferent projections.

Fastigial Nucleus (FNU)

Afferent fibers from Purkinje cells in the median zone (spinocerebellum) innervate the fastigial nucleus (FNu). The efferent connections of this nucleus are complex (Figure 6-5). Axons of neurons in the fastigial nucleus innervate the ipsilateral medial and lateral vestibular nuclei (source of the medial and lateral vestibulospinal tracts) as well as the pontine and medullary reticular formation (source of the pontine and medullary reticulospinal tracts). A small component of the fastigial nucleus projects to the accessory optic nuclei in the midbrain, and the intralaminar and ventrolateral nucleus of the thalamus. (These latter projections are not shown in Figure 6-5.) The fastigial nucleus is concerned with maintaining truncal posture and head and neck position, as well as influencing eye movements. These represent functions of the medial motor system.

lnterpositus Nuclei

The intermediate zone of cerebellar cortex is the source of afferent fibers to the two interpositus nuclei: globose (GNu) and emboliform (ENu). Axons from these nuclei innervate the ipsilateral red nucleus of the midbrain and the contralateral ventrolateral nucleus of the thalamus (which then communicates with motor cortex; Figure 6-5). Through these connections, the intermediate zone of the cerebellum influences the rubrospinal and corticospinal tracts, coordinating movement of the musculature in the limbs. Thus, the intermediate zone regulates the lateral motor system.

Dentate Nucleus (DNU)

The prominent dentate nucleus (DNu) appears very similar to the inferior olive in appearance (Figure 6-4 and Plates 8 to 12). It receives Purkinje cell axons from the lateral zone, including the pontocerebellum. Its efferent fibers cross the midline in the decussation of the superior cerebellar peduncle and reach two major targets, the red nucleus (see Plates 20 and 21) and the ventrolateral nucleus of the thalamus (see Plates 22 to 24; Figure 6-5). In the red nucleus, dentate axons influence rubral neurons projecting to the inferior olive. The dento-rubro-olivo-cerebellar circuit is a complex feedback loop for the cerebellum and is involved in learning motor skills (Sanes et al., 1990; Thach et al., 1992). The dentothalamic axons form a portion of the dento-thalamo-cortical circuit, which is involved in the planning of and preparation for skilled movements by the distal limb musculature.

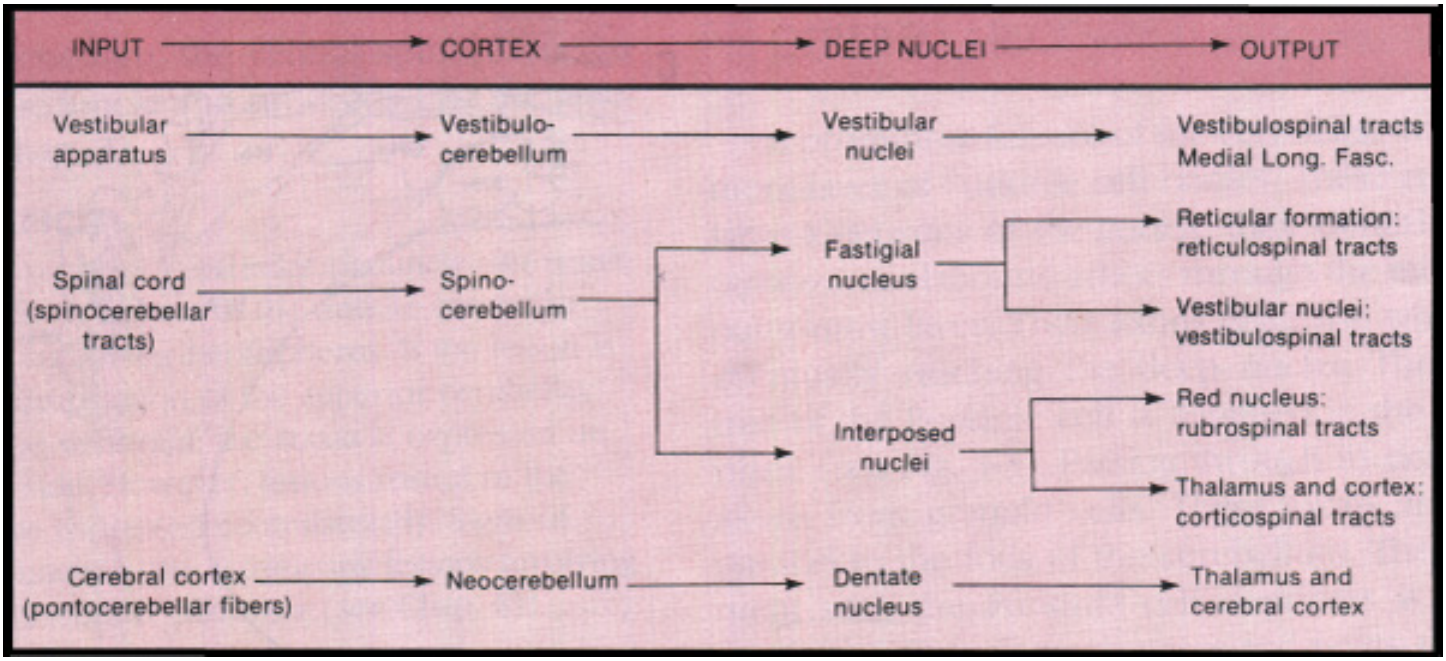


Figure 6-5. A diagram of the deep cerebellar nuclei and their connections

Case Study 6-3

Chief Complaint

A 49-year-old man was admitted to the hospital after experiencing the rapid onset of acute gait imbalance 3 days ago.

History of Chief Complaint

He had spent Sunday doing light work in the yard and that evening suddenly developed a severe headache. It was his impression that the difficulty walking also developed approximately at that time. Over the next 3 days the headaches gradually remitted somewhat, but the gait imbalance persisted unchanged. He noted that he tended to lean to the left on standing or walking. He currently was experiencing a mild headache, but denied any vertigo. He denied any history of neck trauma. Vomiting occurred once or twice late Sunday night, but had not reoccurred since that time.

Family History

He was married, with two children, both of whom were in college. His mother was alive and in good health; his father had died from a myocardial infarct at the age of 60.

Past Medical History

He had had diabetes since childhood; control was maintained daily with insulin. He had recently experienced visual loss, and numbness in his toes. He had a history of mild hypertension that had been controlled with pharmaceuticals for the past 3 years.

General Physical Examination

He was an awake, oriented, and afebrile male, appearing his stated age and of appropriate weight. He was well nourished; his skin had good color, texture, and temperature. He had several small bruises on his left foot. Optic discs had numerous microaneurysms, with several surrounding deep hemorrhages and scattered hard exudates. A bruit was noted over the left carotid artery. Chest was clear to auscultation and percussion; abdomen was soft with no masses or lumps. Blood pressure, pulse, temperature, and respirations were normal on the date of admission.

Neurologic Examination

Mental Status. He was awake and oriented to time and place. Memory and knowledge were appropriate. He was mildly dysarthric.

Cranial Nerves. Eye movements were full, with a left-beating nystagmus on gaze to the left, more marked in the left than in the right eye. The left pupil was smaller than the right; both pupils reacted normally to light. The right palpebral fissure was greater than the left. Normal hearing to finger rub was present in both ears, and he denied tinnitus. He had diminished sensation to pinprick on the right side of his face, with slightly diminished corneal reflex on the right. Pinprick sensation and corneal reflex on the left were intact. His gag and jaw-jerk reflexes were intact. He had a mild paralysis of the facial muscles around the corner of his mouth on the right. His palate elevated on the midline and his tongue protruded on the midline.

Motor Exam. Limb strength and reflexes were physiologic in all extremities. Past-pointing was present on finger-to-nose testing in the left upper extremity and on heel-to-shin testing in the lower extremity. He demonstrated a mild endpoint intention tremor on purposeful movements in the left upper extremity. On attempted synchronous rapid alternating movements of the hands, the left hand moved more slowly. Left pronator drift was evident, and he deviated to the left on walking.

Sensory Exam. Vibratory, two-point discrimination, and proprioceptive senses were intact throughout the body. Pinprick sensation was intact on the left side of his body but diminished in the upper and lower extremities on the right.

Follow-up

Follow-up examination at six months after discharge finds the patient slightly clumsy with movements involving the left extremity. He complains of occasional stumbling movements involving the left leg and has some difficulty picking up delicate objects with his left hand. Motor exam finds a slight suggestion of past-pointing with both heel-to-shin and finger-to-nose testing; otherwise coordination and strength are normal. The right-sided hemianalgesia has greatly diminished, however a very slight asymmetry is still detectable. Eye movements are full and symmetrical and facial symmetry is equal. He has sensation to pinprick throughout his face and his corneal reflexes are present bilaterally. He complains of a vague, but slightly different feeling on the right side of his face when compared to the

left side.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

Cerebellar Vasculature

The cerebellum is supplied by three major vessels: the superior cerebellar artery, the anterior inferior cerebellar artery, and the posterior inferior cerebellar artery (Figure 6-6). The distribution of these three arterial systems is not restricted to any specific geographic region of the cerebellum; consequently, the following vasculature syndromes are not identical to the specific regional syndromes presented earlier in the chapter.

Occlusion or infarction of the distal branches of any one of the cerebellar vessels will damage the hemispheres and peduncles of this structure (Amarenco, 1991). The resulting presentation usually involves ataxia, dizziness, vertigo, nausea and vomiting, and nystagmus (Marshall, 1989;Sypert and Alvord, 1975). However, the stems of these vessels also supply significant portions of the brain stem; consequently, cranial nerve and long tract signs often accompany stem infarctions of these arteries. The specific cranial nerves or long tracts involved differ with each arterial system. Therefore, these signs represent significant differentiating factors for distinguishing infarctions in each of the three cerebellar arterial territories.

Superior Cerebellar Artery (SCA)

The superior cerebellar artery (SCA) arises from the basilar artery near its point of bifurcation into the two posterior cerebral arteries (Figure 6-6). The superior cerebellar artery and the posterior cerebral artery sandwich the oculomotor nerve. The superior cerebellar artery passes caudal to the trochlear nerve and rostral to the trigeminal nerve as it winds around the cerebral peduncle to reach the superior surface of the cerebellum. (See the description of arteries in Chapter 7.) The penetrating branches of the superior cerebellar artery supply the dorsolateral quadrant of the caudal midbrain (see Plates 15 to 19), middle and superior cerebellar peduncles, deep cerebellar nuclei, and cerebellar white matter. Cortical branches supply the anterior vermis, anterior hemispheres, and lateral margins of the cerebellum.

CLINICAL DISCUSSION: The major signs of infarction restricted to the cerebellar territory of the superior cerebellar artery are limb and gait ataxia (Kase et al., 1985), abnormal saccades (Ranalli and Sharpe, 1986) and several forms of nystagmus.

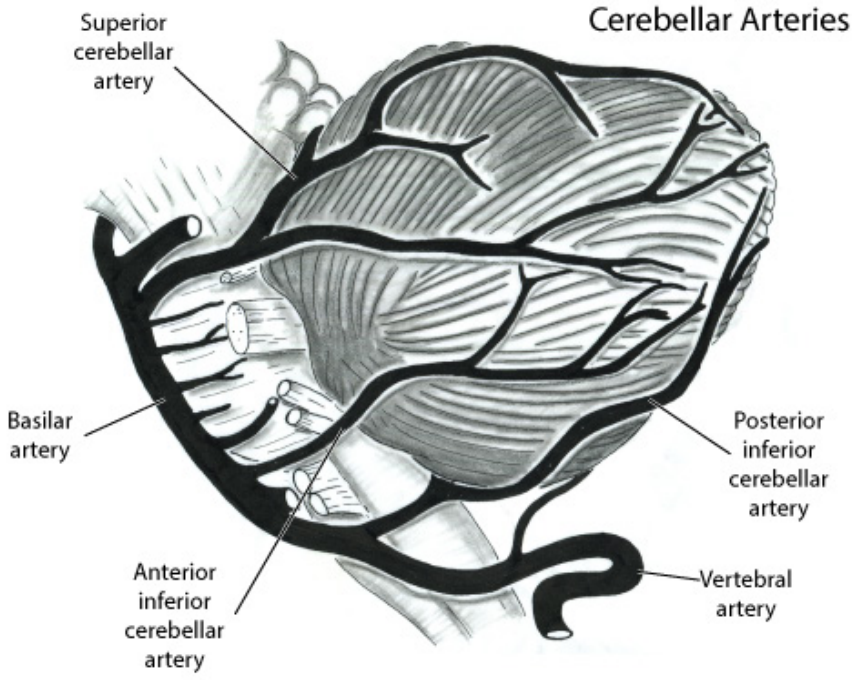


Figure 6-6. This lateral view of the cerebellum illustrates the distribution of its three major arteries. (Modified with permission from Melloni JL, Doxi I, Melloni HP, Melloni BJ. Melloni's illustrated review of human anatomy. Philadelphia: JB Lippincott, 1988:7)

Brain stem signs of superior cerebellar artery pathology include transient chorea (Kase et al., 1985), loss of pain and temperature sensation from the contralateral face and body, ipsilateral Horner's syndrome, and contralateral supranuclear facial palsy (Marshall, 1989).

Anterior Inferior Cerebellar Artery (AICA)

The anterior inferior cerebellar artery (AICA) arises from the basilar at the level of the caudal pons (Figure 6-6). It sweeps laterally, in close relationship to the facial and acousticovestibular cranial nerves. After passing through the cerebellopontine angle, the artery reaches the inferior surface of the cerebellum. Its penetrating branches supply the dorsolateral quadrant of the rostral medulla and caudal pons (see Plates 10 to 14), inferior portion of the middle cerebellar peduncle, and inferior cerebellar peduncle. Its cortical branches supply flocculus, part of vermis, and inferior portions of cerebellar cortex.

CLINICAL DISCUSSION: Lesions restricted to the cerebellar distribution of the anterior inferior cerebellar artery are not well documented in the literature. Textbooks often include ataxia and dysmetria; however, these signs could also reflect involvement of the middle cerebellar peduncle. Lesions involving the entire territory of this artery result in limb and gait ataxia caused by involvement of the middle cerebellar peduncle. Infarction in the brain stem territory of the anterior inferior cerebellar artery can present with hemifacial paralysis (nuclear or nerve lesion), Horner's syndrome, and lateral gaze palsy on the ipsilateral side, alternating analgesia involving the ipsilateral face and contralateral body, as well as deafness, tinnitus, vertigo, nausea, vomiting, and nystagmus (Toole, 1984;Amarenco and Hauw, 1990).

Posterior Inferior Cerebellar Artery (PICA)

The posterior inferior cerebellar artery (PICA) arises from the vertebral artery at approximately the cervicomedullary junction (Figure 6-6). It is in close relationship with cranial nerves IX through XII as it winds its way around the brain stem to reach the posterior margin of the cerebellum. It supplies the dorsolateral quadrant of the medulla (see Plates 7 to 10), inferior and posterior vermis, tonsils, and inferolateral surface of the cerebellum. Its penetrating branches supply part of the dentate nucleus.

CLINICAL DISCUSSION: The major signs of infarction restricted to the cerebellar territory of the posterior inferior cerebellar artery are rotatory dizziness that is intensified by motion, nausea, vomiting, imbalance, and nystagmus (Duncan et al., 1975). The nystagmus is often horizontal in both directions of gaze (Bogousslavsky and Meienberg, 1987).

The neurologic signs resulting from infarction of the medullary distribution of this artery can represent the lateral medullary syndrome (see Chap. 4): dysphagia, dysphonia, hiccup, ipsilateral Horner's syndrome, paralysis of the soft palate and larynx, and alternating analgesia involving ipsilateral face and contralateral body (Marshall, 1989). Ipsilateral ataxia and dysmetria can result from damage to the inferior cerebellar peduncle in the brain stem.

References

Amarenco P (1991) The spectrum of cerebellar infarctions. Neurol 41: 973-979.

Amarenco P, Hauw JJ (1990) Cerebellar infarctions in the territory of the anterior and inferior cerebellar artery. Brain 113: 139-155.

Biller J, Brazis PW (1996) The localization of lesions affecting the cerebellum. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 365-380. Boston: Little, Brown and Company.

Bogousslavsky J, Meienberg O (1987) Eye-movement disorders in brain-stem and cerebellar stroke. Arch Neurol 44: 141-148.

Brown JR (1982) Diseases of the cerebellum. In: Clinical Neurology (Joynt RJ, ed), pp 1-43. Philadelphia: J.B. Lippincott.

Duncan GW, Parker SW, Fisher CM (1975) Acute cerebellar infarction in the PICA territory. Arch Neurol 32(6): 364-368.

Fisher CM (1978) Ataxic hemiparesis. Arch Neurol 35: 126-128.

Gilman S (1986) Cerebellum and motor dysfunction. In: Diseases of the Nervous System (Asbury AK, McKhann GM, McDonald WI, eds), pp 401-422. Philadelphia: W.B. Saunders Comp.

Kase CS, White JL, Joslyn JN, Williams JP, Moher JP (1985) Cerebellar infarction in the superior cerebellar artery distribution. Neurol 35(5): 705-711.

Marshall J (1989) Cerebellar vascular syndromes. Hdbk Clin Neurol 11(55): 89-94.

Ranalli PJ, Sharpe JA (1986) Contrapulsion of saccades and ipsilateral ataxia: a unilateral disorder of the rostral cerebellum. Ann Neurol 20: 311-316.

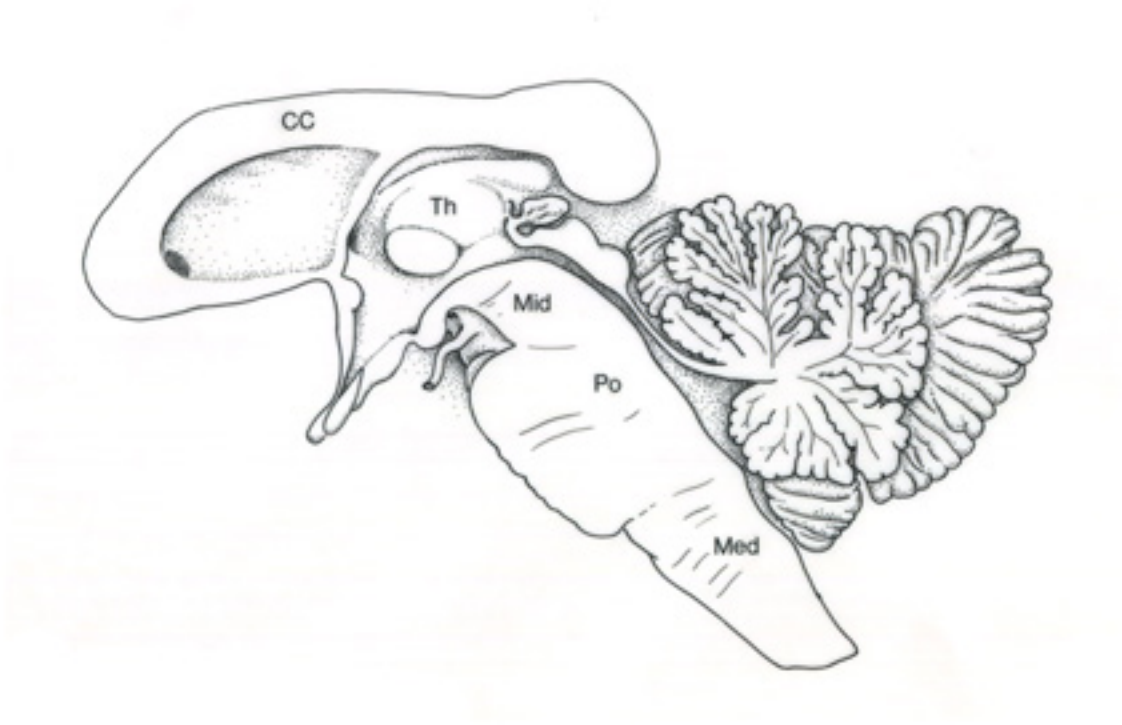
Sanes JN, Dimitrov B, Hallett M (1990) Motor learning in patients with cerebellar dysfunction. Brain 113: 103-120.

Sypert GW, Alvord EC (1975) Cerebellar infarction. Arch Neurol 32(6): 357-363.

Thach WT, Goodkin HP, Keating JG (1992) The cerebellum and adaptive coordination of movement. Ann Rev Neurosci 15: 403-442.

Toole JF (1984) Cerebrovascular Disorders 3ed. New York: Raven Press.

Chapter 7
Midbrain



INTRODUCTION

The midbrain, the narrowest portion of the brain stem, lies between the supra- and infratentorial compartments, surrounded by the incisure of the tentorium cerebelli. This portion of the brain stem is characterized by the massive cerebral peduncles (legs) located ventrally and by the superior and inferior colliculi (little hills) dorsally. The neural circuits intrinsic to this region involve coordination of body and eye movements with respect to external stimuli and maintain consciousness by influencing the level of neural activity in the cerebral cortex. The midbrain contains the nuclei and radiations of oculomotor, trochlear, and portions of trigeminal cranial nerves. It receives its blood supply from penetrating branches of the basilar and posterior cerebral arteries.

In this chapter the nuclei and tracts of the midbrain will be examined. The vascular supply to the midbrain will be studied and several clinicopathologic cases will be presented.

GENERAL OBJECTIVES

1. To learn the location and function of the major tracts and cranial nuclei in the midbrain
2. To learn the presenting signs and symptoms consequent to lesions involving these tracts and nuclei
3. To apply the preceding knowledge to an understanding of the clinical manifestations of the major midbrain vascular lesions

INSTRUCTION

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human brain stem and brain stem model
2. A human brain stem with intact blood supply
3. A medical dictionary

Chapter Seven Topics:

Case Study 7-1

Chief Complaint

This 57-year-old, right-handed woman is presenting with a marked weakness of her right eyelid and double vision when her eye is forced open.

History of Chief Complaint

She had experienced two episodes of blurred vision and headache on the day prior to admission. That evening she went to bed early. She awoke with an inability to open the right eyelid. When she held the eyelid open with her finger, she noted marked double vision.

Medical History

This patient had had moderate hypertension for 30 years. The hypertension was managed using beta-blockers.

Family History

The patient has been married for 35 years and has three children in college. Both parents are living; her father has had a long history of hypertension. She has a 25-pack-year history of smoking and claims to consume a moderate amount of alcohol each week.

Physical Examination

On examination she was stable, awake, oriented, and of anxious demeanor. The patient was well nourished, well hydrated, obese, and in poor physical condition; she appeared slightly older than her stated age. Optic discs had sharp edges. Her chest was clear to auscultation and percussion. Her blood pressure was 160/100; pulse, temperature, and respirations were physiologic. Abdomen was difficult to palpate because of her obesity; however, no tenderness was observed. Peripheral pulses were difficult to access; mild edema was present at the ankles but not at the wrists.

Neurologic Examination

Mental Status. The patient was alert and oriented to time and place. Speech was articulate and content was meaningful. Memory and knowledge were appropriate for her background. She could follow two- and three-step commands and was an adequate historian.

Cranial Nerves. Visual fields were full to confrontation. If asked to open her eyes, the right eyelid did not elevate beyond 2 mm; the left opened 10 to 12 mm. When the right eyelid was elevated by an external force, the right eye was deviated to the right and down; she could effect no volitional medial or upward movement of the right eye. The right eye did not respond to caloric testing, nor did it respond during attempted convergence. A full range of motion was present with the left eye. Pupillary responses were intact bilaterally. Although it did not move, the right eye would constrict with the left eye on attempted convergence. Hearing was normal in both ears. A minor weakness was noted in the left corner of her mouth when she attempted to grimace. Her palate elevated symmetrically, and corneal, jaw-jerk, and gag reflexes were intact. Her tongue protruded on the midline and her shoulder shrug was symmetric and of physiologic strength.

Motor Exam. Strength was intact in all limbs. Deep tendon reflexes were physiologic and symmetric in the upper extremities and slightly increased in the left lower extremity compared to the right. There was a left Babinski response.

Sensory Exam. Pinprick, two-point discrimination, vibratory sense, and proprioception were present throughout face and body.

Follow up

Follow up at four months post discharge reveals a persistent ophthalmoplegia involving the right eye and paralysis of the right eyelid. Tendon reflexes are bilaterally symmetrical in all four limbs and there is no residual Babinski response on either side.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

Mesencephalic Structures

The major ascending and descending tracts of the spinal cord pass through the midbrain. In addition, there are numerous intrinsic nuclei related to the cranial nerves and reticular formation with which you should become familiar. These items are listed on the following plates. The abbreviation following each structure corresponds to that used on the atlas plate. The first time you encounter a given structure its description will be provided, along with comments on function and any clinical deficit consequent to its destruction. For subsequent sections, the structure will be mentioned by name only unless significant changes have occurred in its location or composition.

Atlas Plate 16

Go to the Atlas

Atlas Plate 17

Go to the Atlas

The dorsal portions of these sections pass through the caudal midbrain; the ventral portions are located in the pons. A prominent feature of Plate 16 is the peripheral location of the massive superior cerebellar peduncle containing dentothalamic fibers from the cerebellum. The prominent feature of Plate 17 is the appearance of the inferior colliculus on the dorsal surface of the midbrain tegmentum and the inward movement of the superior cerebellar peduncle. The pontine structures on this plate were presented in Chapter 5.

SUPERIOR CEREBELLAR PEDUNCLE (SCP)

The superior cerebellar peduncle (SCP) has a ventral tail that curves in a medial direction (more prominent on Plate 17), giving this fiber bundle a calycine profile. To the inside of the calyx lies the central tegmental tract; to the outside are the three sensory lemnisci: medial lemniscus, antero-lateral tract (or spinal lemniscus), and lateral lemniscus. The composition of the superior cerebellar peduncle and the clinical deficits resulting from its destruction were discussed in Chapters 5 and 6.

RADIATION OF THE TROCHLEAR NERVE (TroNr)

The trochlear nucleus lies slightly rostral to Plate 17 in the midbrain; however, the radiations of its nerve (TroNr) can be seen as small fiber bundles in the lateral aspect of the central gray (see Plate 17). These fascicles leave the nucleus and pass dorsally around the central gray to reach the tectum. They emerge from the brain stem and cross the midline posterior to the inferior colliculus (Figure 6-1). After leaving the dorsal aspect of the midbrain, the trochlear nerve crosses the subarachnoid space to reach the inferior surface of the tentorium cerebelli. This nerve innervates the contralateral superior oblique muscle which, if contracted, causes the globe to deflect downward from the adducted position, and to rotate inward from the abducted position.

LATERAL LEMNISCUS AND ITS NUCLEI (LL, LLNu)

The lateral lemniscus (LL) has extended dorsally to enter the base of the inferior colliculus. This prominent fiber tract is carrying ascending axons from the cochlear nuclei and superior olive to the inferior colliculus. The nuclei of the lateral lemniscus (LLNu) can be seen embedded in the fibers of the lemniscus at its rostral end.

CLINICAL DISCUSSION: Section of the lateral lemniscus will produce diminished hearing functions in the contralateral ear. Symmetric, bilateral lesions of the lateral lemniscus and inferior colliculus by contusion on the tentorial incisura in an automobile accident has produced complete bilateral deafness (Howe and Miller, 1975). Damage to the area around the base of the inferior colliculus and the tegmentum near the lateral lemniscus can produce "acoustic hallucinations" (Cascino and Adams, 1986).

INFERIOR COLLICULUS (IC)

The two bilateral masses of the inferior colliculus (IC) in the posterior tectum are major relay centers for the auditory pathways. The inferior colliculus receives afferent projections from the contralat-

eral cochlear nucleus and bilateral projections from the superior olivary nuclei and the nuclei of the lateral lemniscus. The combining of these projections within the inferior colliculus generates a map of acoustic space. The inferior colliculus uses this map in the process of sound localization data (Jenkins and Masterton, 1982) and in generating reflex responses to unexpected stimuli. Ascending projections from the inferior colliculus are directed through its brachium to the ipsilateral medial geniculate nuclei of the thalamus; descending projections travel through the lateral lemniscus to reach the superior olives and cochlear nucleus.

CLINICAL DISCUSSION: Lesions of the inferior colliculus diminish hearing functions from the contralateral ear. Consequently, compression of the inferior colliculi by pineal tumors can result in loss of hearing. Distortions of acoustic perception can result from lesions around the margins of this structure. Damage to the ventromedial aspect of the inferior colliculus and the superior medullary vellum has resulted in bilateral hyperacusis in a patient (Sand et al., 1986).

MIDBRAIN RETICULAR FORMATION (MRetF)

Numerous groups of cells, serving differing functions, are present in the midbrain reticular formation (MRetF). Along the dorsal midline are those nuclei involved in control of conjugate eye movement: rostral interstitial nucleus of the medial longitudinal fasciculus, nucleus of Darkschewitschi, and interstitial nucleus of Cajal. Collectively, these nuclei are referred to as the preoculomotor system since many of their efferent fibers have a direct influence on the motor nuclei of the extraocular eye muscles. They are found embedded in the central gray of the midbrain, closely associated

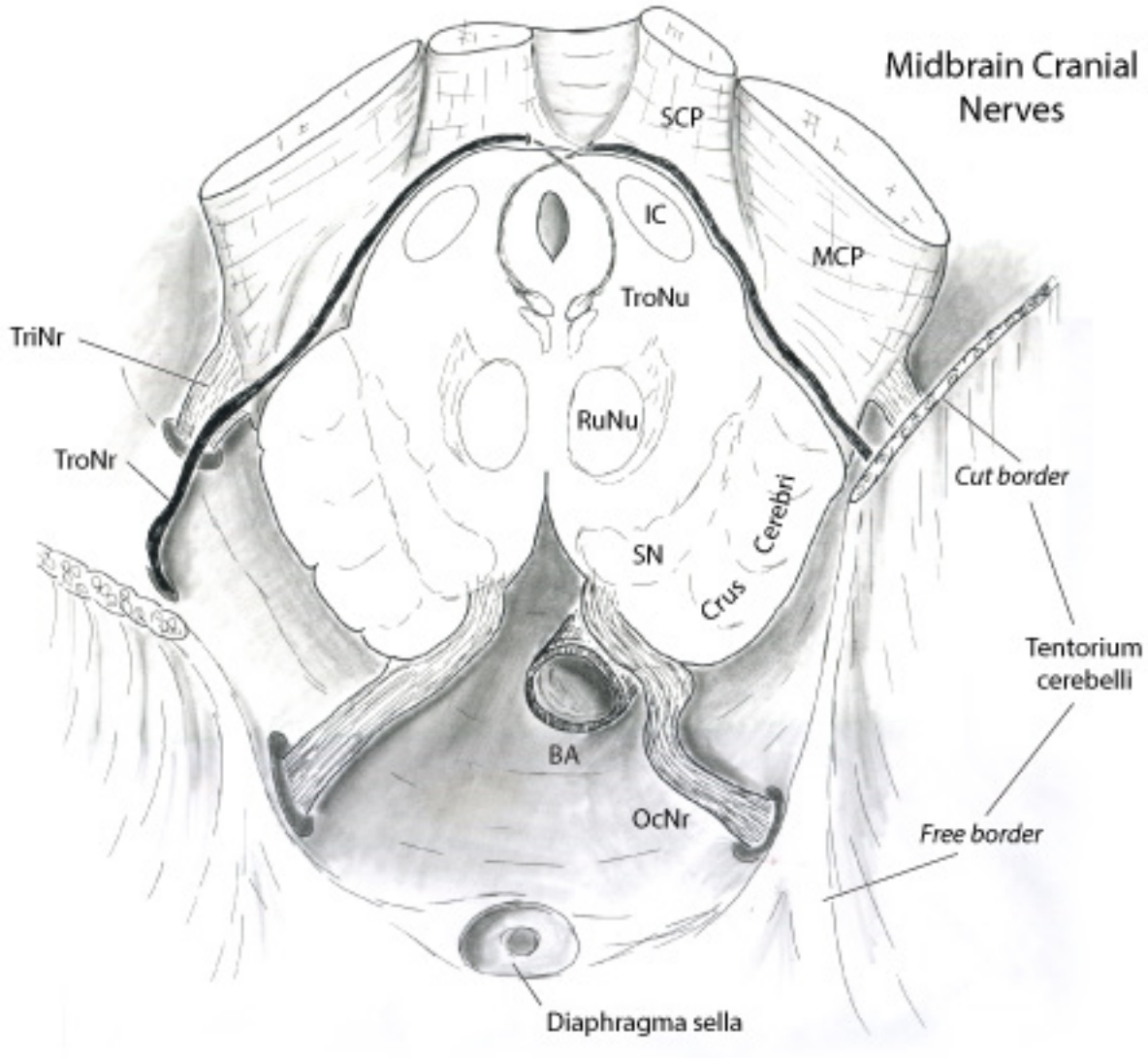


Figure 7-1. A drawing of the midbrain and its relationship to the tentorium cerebelli. The tentorium has been cut and the cerebellum removed to reveal the brain stem, which has been transected at the midbrain-thalamic border. The trochlear nerve is seen leaving the dorsal surface of the midbrain and penetrating the inferior surface of the tentorium. The oculomotor nerve is seen leaving the ventral surface of the midbrain and penetrating the dura.

with the rostral end of the medial longitudinal fasciculus. Afferent projections to the preoculomotor nuclei originate in the paramedian pontine reticular formation (horizontal gaze center) as well as in the contralateral frontal cortex (eye fields, area 8), superior colliculus, pretectum, and vestibular nuclei. Efferent fibers from the preoculomotor nuclei innervate the oculomotor, trochlear, and vestibular nuclei. The preoculomotor system and the paramedian pontine reticular formation are involved in controlling vertical and horizontal eye movements (Bender, 1980).

The midbrain reticular formation also gives rise to a diffuse projection of axons running into the intralaminar nuclei of the thalamus for eventual relay into the cerebral cortex. These axons are part of the ascending reticular activating system. The cell bodies of origin for these projections are found in a portion of the reticular formation extending from the rostral pons through the midbrain. This diffuse system of fibers is involved in modulating the level of neural activity in the cerebral cortex.

Passing through the lateral midbrain reticular formation are the corticonuclear fibers that are involved with control of horizontal gaze. These fibers leave the internal capsule, descend through the posterior thalamus and midbrain, and cross the midline to eventually innervate the paramedian pontine reticular formation.

CLINICAL DISCUSSION: Damage to the ascending reticular activating system by lesions of the midbrain reticular formation can result in coma (Plum and Posner, 1982). Unilateral damage to this system can diminish the input to one cerebral hemisphere, resulting in a profound, contralateral "neglect syndrome" (Watson et al., 1974).

Laterally placed lesions of the midbrain reticular formation can interrupt the descending corticonuclear fibers to the paramedian pontine reticular formation, resulting in loss of horizontal gaze. Since these fibers have not decussated at this point, the deficit is expressed on the contralateral side, and the patient is unable to gaze volitionally into the visual hemisphere opposite the lesion. However, the eyes can be deflected into this hemisphere using the oculocephalic reflex or caloric stimuli.

Ventrally positioned lesions of the midbrain or pons that leave the preoculomotor nuclei and the ascending reticular activating system intact, but interrupting the descending corticospinal and corticonuclear fibers bilaterally can create a "locked-in" syndrome. Patients are conscious in their surroundings, but because of the loss of the descending motor control systems they cannot respond except through the initiation of vertical eye movements (Plum and Posner, 1982). Lesions resulting in locked-in syndrome can be vascular in origin, but can also arise from transtentorial herniation secondary to trauma (Keane and Itabashi, 1985;Keane, 1986).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Central gray (CeGy)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Ventral trigeminothalamic tract (VTTr)
- Central tegmental tract (CTT)
- Rubrospinal tract (RuSp)
- Midbrain reticular formation (MRetF)
- Raphe complex (Central superior) (RaNu)

Atlas Plate 18

The dorsal portion of this section passes through the inferior colliculus, crossing the extreme caudal border of the superior colliculus. The ventral portion is located in the pons. The pontine structures contained on this section are discussed in Chapter 5.

SUPERIOR COLLICULUS (SC)

The superior colliculi (SC) form two mounds in the tectum at the rostral border of the midbrain. (They are best observed in Plate 19.) The cells and fibers of the superior colliculi are arranged in a series of horizontal layers. These layers receive input from the visual, auditory, and somatic sensory systems, as well as projections from frontal and parietal cortex. The deeper layers of the superior colliculus contain the efferent neurons of the tectobulbar and tectospinal tracts.

Projections from the superior colliculus are directed to numerous sites. The tectobulbar tract projects to the accessory optic nuclei of the midbrain and the reticular formation. The tectospinal tract reaches the cervical spinal cord, and the tectocortical fibers project to the extrastriate visual cortex.

Using its visual, auditory, and somatic sensory inputs, the superior colliculus forms a map of the body and of external space. It uses this map to guide head, eye, and upper limb movements in tracking and responding to unexpected stimuli (Sparks, 1986). The superior colliculus is involved particularly in generating visually guided saccades.

The superior colliculus participates in the parallel processing of visual information. The retino-tecto-cortical fibers form a pathway to the visual cortex that runs parallel to the retino-geniculo-cortical projections passing through the thalamus. In humans this parallel pathway can still process visual stimuli when there is damage

in the thalamic route. If forced to use the tectal pathway alone, the patient does not see recognizable images but can detect flashing light and moving targets (Barbur et al., 1980).

CLINICAL DISCUSSION Isolated lesions of the superior colliculus in monkeys interfere with the animal's ability to attend to novel stimuli, especially when they are unexpected. Collicular lesions in humans cause increased saccade latencies and a defect in saccade execution (hypometria), so that they fall short of the target.

DECUSSATION OF THE SUPERIOR CEREBELLAR PEDUNCLE (dSCP)

The superior cerebellar peduncle contains fibers from the dentate nucleus of the cerebellum that will terminate in the contralateral red nucleus of the midbrain (see Plates 20 and 21) and ventrolateral thalamic nucleus (see Plate 21). The decussation of this large fiber tract in the midbrain marks the point where its axons cross the midline.

CLINICAL DISCUSSION: Lesions that damage the central portion of the midbrain, including the decussation of the superior cerebellar peduncle, often produce coma (Ropper and Miller, 1985), thus masking any motor deficits. However, cases have been reported of small vascular lesions in the caudal tectal plate and midbrain tegmentum that produce unsteady gait and ataxia in all four limbs (Sand et al., 1986), as well as truncal ataxia (Durward et al., 1982). These symptoms are presumably due to the involvement of the superior cerebellar peduncle.

TROCHLEAR NUCLEUS (TroNu)

The trochlear nucleus (TroNu) is located in the ventral portion of the central gray, indented into the dorsal border of the medial longitudinal fasciculus. Its axons form the radiations of the trochlear nerve that arch dorsally along the border of the central gray and cross the midline on the dorsal surface of the tectum before exiting the brain stem (Figure 7-1). This nucleus provides motor innervation to the superior oblique muscle.

CLINICAL DISCUSSION: An isolated lesion of the trochlear nucleus or nerve can result in paralysis of the superior oblique muscle; in such a case the affected eye may move slightly upward and outward (extorsion). Diplopia may occur on forward gaze and worsen on attempted downward and inward vision. The patient's head is tipped to the opposite side in an effort to bring the visual fields of both eyes into alignment and reduce the diplopia.

Head trauma is the most common cause of trochlear nerve palsy (Rush and Younge, 1981). Extracerebral damage to the nerve distal to the decussation results in paralysis of the ipsilateral superior oblique muscle. The trochlear nerve can be damaged by compression as it enters the incisure of the tentorium cerebelli (Figure 7-1). In addition, traumatic head injuries that induce bleeding into the superior cerebellar cistern are a source of trochlear palsy. In bleeding accidents, the onset of the palsy can be hours after the injury (Lavin and Troost, 1984).

Trochlear palsy due to an intracranial lesion is very rare but has been reported. Causal factors of such lesions are aneurysms and vascular malformations, usually positioned posterior to the inferior colliculus or in the superior medullary velum (Gonyea, 1990).

CUNEIFORM NUCLEUS (CunNu)

The cuneiform nucleus (CunNu) is a small, wedge-shaped nucleus closely associated with the central gray of the midbrain. The nucleus is thought to be involved with the pathways processing pain (Bernard et al., 1989). It receives afferent fibers from the spinal cord and projects axons to the raphe nuclei of the medulla. The medullary raphe nucleus is the source of axons to the dorsal horn that modulate input from the nociceptive, primary afferent fibers.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Inferior colliculus (IC)
- Lateral lemniscus (LL)
- Central gray (CeGy)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Ventral trigeminothalamic tract (VTTr)
- Central tegmental tract (CTT)
- Rubrospinal tract (RuSp)
- Midbrain reticular formation (MRetF)
- Raphe complex (central superior) (RaNu)
- Dorsal longitudinal fasciculus (DLF)
- Medial longitudinal fasciculus (MLF)

Atlas Plate 19

Go to the Atlas

The dorsal portion of this section passes through the superior colliculus; the ventral portion transects the pontomesencephalic junction. Characteristic of this section is the merger of the cerebral peduncle into the basilar pons. The pontine structures present on this section have been discussed in Chapter 45

Highlight Point

The clinical manifestions of damage to the oculomotor nucleus, radiations or nerve can include:

Ipsilateral eye positioned
down and out

Pupil fixed and dilated,
unresponsive to light

OCULOMOTOR NUCLEUS (OcNu)

The oculomotor nucleus is positioned along the midline, under the cerebral aqueduct (Figure 7-2). It contains general somatic motoneurons that innervate four of the extraocular eye muscles: the medial, inferior, and superior rectus muscles and the inferior oblique muscle. These muscles function to move the globe on the vertical axis. With the eye in full abduction, the superior and inferior recti move the globe up and down on the vertical axis, respectively. With the eye in full adduction, the inferior and superior oblique muscles move the globe up and down on the vertical axis, respectively (Masdeu and Brazis, 1996). The oculomotor nucleus also innervates the levator palpebrae muscle, which elevates the eyelid.

The oculomotor nucleus is situated at the rostral end of the medial longitudinal fasciculus and receives projections from the vestibular nuclei, abducens nucleus, prepositus hypoglossal nucleus, and the paramedian pontine reticular formation or horizontal gaze center. Afferent projections to this nucleus also arise from a cluster of small nuclei surrounding the rostral end of the median longitudinal fasciculus. Two nuclei in this region, the rostral interstitial nucleus of the medial longitudinal fasciculus and the interstitial nucleus of Cajal, as well as their surrounding neurons, are referred to as the vertical gaze center. Collectively, the nuclei at the rostral end of the median longitudinal fasciculus, which project axons into the oculomotor nucleus, are referred to as the preoculomotor nuclei.

On the rostrodorsal border of the oculomotor nucleus is the nucleus of Edinger-Westphal, which contains general visceral efferent (preganglionic), parasympathetic neurons. These cells innervate the ciliary ganglion and control pupillary constriction.

CLINICAL DISCUSSION: In total paralysis of the oculomotor nucleus or nerve, ptosis is present in the ipsilateral eye because of loss

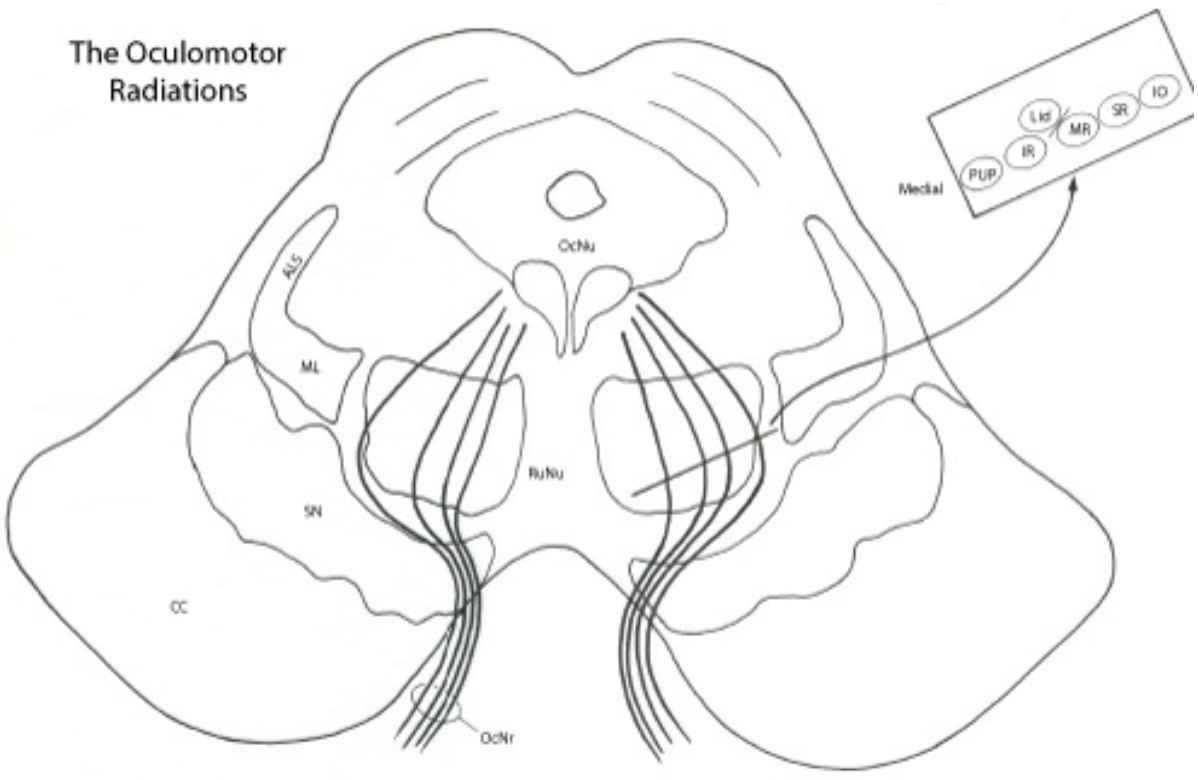


Figure 6-2. The course of the oculomotor nerve in the midbrain demonstrates the topography of fiber fascicles within the radiations of the oculomotor nerve. The inset is taken from the main section and illustrates the position of the fascicles of the oculomotor nerve. Each oval represents a fascicle associated with a specific muscle (IO, inferior oblique; IR, inferior rectus; Lid, levator palpebrae; MR, medial rectus; PUP, pupillary fibers; SR, superior rectus). (Modified from Castro O, Johnson LN, Mamourian AC. Isolated inferior oblique paresis from brain-stem infarction. Arch Neurol 1990;47:235)

of the levator palpebrae muscle. When the lid is elevated forcefully, the globe is found fully abducted with little or no vertical movement and only slight medial movement due to relaxation of the lateral rectus muscle. The pupil is dilated and unresponsive to light. Partial paralysis, involving selected muscles in the oculomotor system, can occur.

BRACHIUM OF THE INFERIOR COLLICULUS (BrIC)

The brachium or arm of the inferior colliculus (BrIC) contains axons from the inferior colliculus in the midbrain to the ipsilateral medial geniculate of the thalamus. This tract is the major auditory projection from the midbrain to the thalamus.

CLINICAL DISCUSSION: Lesion of the brachium of the inferior colliculus in cats results in deficits similar to those associated with lesions of the inferior colliculus (Jenkins and Masterton, 1982) i.e., contralateral diminution of hearing functions.

INTERPEDUNCULAR NUCLEUS (IPNu)

The interpeduncular nucleus (IPNu) is a small cluster of neurons on the ventral surface of the midbrain, nestled between the two massive cerebral peduncles. This nucleus is a relay station in the flow of information from the limbic forebrain to the brainstem serotonergic systems. It receives afferent fibers from the septal area of the forebrain through the habenulointerpeduncular tract (see Chapter 8. Efferent fibers from the interpeduncular nucleus establish connections with the raphe nuclei and central gray (Groenewegen et al., 1986).

SUBSTANTIA NIGRA (SN)

The substantia nigra (SN) is embedded in the dorsomedial surface of the cerebral peduncles. It receives a projection from the corpus striatum (caudate nucleus and putamen) called the striatonigral tract. The substantia nigra includes cell types producing dopamine. These axons form the nigrostriatal tract, which projects to the caudate nucleus and putamen. The substantia nigra plays a role in control of the motor system. The integration of this nucleus with the basal ganglia is further discussed in Chapter 11.

CLINICAL DISCUSSION: Vascular lesions in the vicinity of the substantia nigra usually involve the cerebral peduncles as well; the paralysis resulting from the loss of the corticospinal fibers tends to mask any signs generated by the loss of the substantia nigra. Neurodegeneration of the dopamine-containing neurons in the substantia nigra results, through a complicated pathway (Chapter 11), in a deregulation of the internal segment of the globus pallidus (Alexander and Crutcher, 1990), which can then increase its inhibition of the ventral lateral thalamic nucleus. The result is a diminished output from thalamus to motor cortex. The patient experiences hypokinesia or decreased ability to initiate motion and bradykinesia, a decreased speed of motion (DeLong, 1990). These two motor deficits are part of the Parkinson's syndrome.

Small vascular lesions of the substantia nigra are usually clinically silent since it requires destruction of in excess of 80% of the nucleus before clinical presentation occurs. If 80-90% of the nucleus is destroyed in a vascular accident, then a good portion of the cerebral peduncle is most likely damaged as well. The resulting spastic paralysis will mask any clinical presentation of a movement disorder from the substantia nigra.

VENTRAL TEGMENTAL AREA (VTA)

The ventral tegmental area (VTA) is a loose collection of dopaminergic cells located medial to the substantia nigra and continuous rostrally with the lateral hypothalamic area. Its ascending projections reach many of the limbic forebrain structures (Moore, 1982).

CLINICAL DISCUSSION: Dopaminergic neurons in the ventral tegmental area are depleted in Parkinson's disease. Just how much this contributes to the syndrome is unclear at this writing. Being connected to the limbic forebrain, it is conceivable that diminution in the function of these neurons plays a role in the personality changes seen in the parkinsonian patient. Excessive production of dopamine by these cells has been found in the postmortem brains of schizophrenic patients (Bird et al., 1979).

CEREBRAL PEDUNCLE OR CRUS CEREBRI (CC)

The massive cerebral peduncles or crus cerebri are present in the ventrolateral quadrant of the midbrain. Rostrally, this fiber bundle represents a derivative of the internal capsule; caudally, it is continuous with the corticospinal tract in the pons and pyramidal tract in the medulla. A topographic distribution of axons is present in the cerebral peduncles. The frontopontine fibers are located most ventrally; the corticonuclear, corticospinal, temporopontine, occipito-pontine, and parietopontine fibers follow in order, progressing dorsally (Figure 7-2).

The fibers of the crus cerebri arise in large part from the cerebral cortex and pass through the internal capsule. Damage to either structure can result in degeneration of a portion of the crus and is expressed as hemiplegia in the patient. This reduction in mass of the crus is detectable by imaging and is proportional to the extent of the causal lesion in the forebrain (Warabi et al., 1987). In addition, the reduction in area of the crus is inversely proportional to the probability of recovery of function (Warabi et al., 1990).

CLINICAL DISCUSSION: Vascular accidents involving the peduncles usually present with contralateral paresis of the limbs (involving the distal extremities more than the proximal), which is assumed to be due to the loss of the corticospinal fibers. In addition, contralateral facial paralysis in the lower quadrant of the face from the loss of the supranuclear innervation of these cranial motor nuclei and contralateral dystaxia from loss of the corticopontine fibers are present (Fisher and Curry, 1965;Helweg-Larsen et al., 1988).

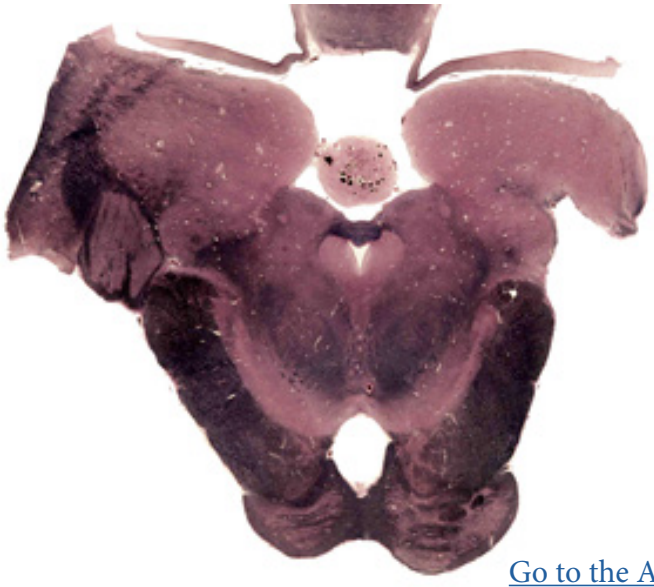
The effects of small lesions in the cerebral peduncles are controversial. Surgical lesions, placed in the corticospinal portion of the human cerebral peduncles, produced only slight hypokinesia and very mild loss of function (Bucy and Keplinger, 1961). Based on these studies, it is proposed that section of the corticospinal portion of the peduncle alone will not result in spasticity. It is certainly possible that the vascular accidents observed clinically have damaged more than the corticospinal fibers, such as the corticonuclear fibers to the reticular formation, accounting for the spastic paralysis that presents in these patients.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Superior colliculus (SC)
- Central gray (CeGy)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Ventral trigeminothalamic tract (VTTr)
- Central tegmental tract (CTT)
- Rubrospinal tract (RuSP)
- Midbrain reticular formation (MidRetF)
- Medial longitudinal fasciculus (MLF)
- Dorsal longitudinal fasciculus (DLF)

Atlas Plate 20



Go to the Atlas

The dorsal portion of this section passes through the caudal thalamus; the ventral portion passes through the midbrain and an extreme rostral edge of the pons. The pontine and thalamic structures of these sections are discussed in Chapters 5 and 8, respectively. A salient feature of this section is the massive cerebral peduncles that cradle the midbrain and thalamus.

PRETECTAL NUCLEI (PrTecNu)

The pretectal nuclei (PrTecNu) are positioned between the superior colliculi caudally and the thalamus rostrally (Figure 7-1). They receive information bilaterally, from the retina, thereby representing the contralateral visual hemisphere. Pretectal axons project directly to the ipsilateral Edinger-Westphal nuclei of the oculomotor complex as well as through the posterior commissure to the contralateral Edinger-Westphal nucleus. From the Edinger-Westphal nucleus, parasympathetic fibers travel with the oculomotor nerve to reach the ipsilateral ciliary ganglion in the eye. Short ciliary or postganglionic fibers from the ciliary ganglion innervate the pupillary sphincter muscles of the iris and the ciliary body (Figure 7-3). The pretectal system is involved in the pupillary light reflex and the accommodation-constriction response (Barr and Kiernan, 1993). Light shined in one eye will, acting through the bilateral projections from the pretectum, constrict both pupils (Masdeu and Brazis, 1996).

CLINICAL DISCUSSION: Bilateral damage to the pretectal area causes the loss of convergence movements and pupillary light reflex that occur in Parinaud's syndrome or the syndrome of the dorsal midbrain (Waga et al., 1979). Partial damage to the retina or to the retinopretectal fibers in the optic nerve or contralateral optic tract, although not eliminating the light reflex, can weaken that side's ability to maintain pupillary constriction. When light is shone into the eye contralateral to the damage, a consensual response rapidly constricts both pupils. However, when it is quickly moved over to the ipsilateral eye, the pupils dilate because of the weakened constrictor tone from the damaged pretectum. This phenomenon of paradoxical dilation is called the Marcus Gunn pupil and is a sign of damage to the pretectal afferent fibers (Patten, 1996 page 8). The Marcus Gunn pupil test is typically used to demonstrate demyelination of the optic nerve in patients with presumptive multiple sclerosis.

ROSTRAL INTERSTITIAL NUCLEUS OF THE MEDIAL LONGITUDINAL FASCICULUS (RINMLF)

The rostral interstitial nucleus of the medial longitudinal fasciculus (RINMLF) is located in the central gray at the rostral end of the medial longitudinal fasciculus. It controls vertical gaze (Büttner-Ennever et al., 1982) and pursuit movements (Ranalli et al., 1988) through a complex set of efferent projections. Fibers influencing downward vertical saccades project caudally along the medial longitudinal fasciculus to reach the ipsilateral oculomotor and trochlear nuclei. Those influencing upward vertical saccades project superiorly to cross the midline in the posterior commissure and then descend in the medial longitudinal fasciculus to reach the contralateral oculomotor and trochlear nuclei.

CLINICAL DISCUSSION: Lesions involving the area around the medial longitudinal fasciculus, rostral to the oculomotor or trochlear nuclei, can affect vertical conjugate gaze (Christoff, 1974). Dorsally positioned, small infarctive lesions affecting the rostral interstitial nucleus or its efferent fibers in the posterior commissure can produce Parinaud's syndrome or loss of upward conjugate gaze (Pierrot-Deseilligny et al., 1982), whereas more ventrally placed lesions that spare the posterior commissure can produce a downward conjugate gaze palsy (Jacobs et al., 1973). Larger lesions in this region result in complete vertical gaze palsy (Pierrot-Deseilligny et al., 1982). Because of the interaction between sides, even unilateral lesions involving the rostral interstitial nucleus can result in a bidirectional (vertical) gaze paresis (Ranalli et al., 1988).

POSTERIOR COMMISSURE (PoCom)

Fibers from the pretectal nuclei and the accessory optic nuclei decussate through the posterior commissure (PoCom) of the thalamus. These include fibers from those portions of the pretectal nuclei involved in the pupillary light reflex that are crossing to innervate the contralateral Edinger-Westphal nucleus.

CLINICAL DISCUSSION: Damage to the posterior commissure and its surrounding nuclei can interrupt conjugate vertical gaze, particularly upward gaze (Christoff, 1974).

RADIATIONS OF THE OCULOMOTOR NERVE (OcNr)

Axons of the oculomotor neurons (OcNr) leave the nucleus in a series of fascicles fanning out in an inferolateral direction and passing through the red nucleus, forming the radiations of the oculomotor nerve. These fibers coalesce into a unified bundle on the edge of the interpeduncular fossa and leave the brain stem along the medial aspect of the cerebral peduncle (Figure 7-2). The axons in each fascicle innervate a specific muscle in the orbit. An orderly arrangement of fascicles for each of the extraocular eye muscles (Castro et al., 1990) has been reported (Figure 7-2). From medial to lateral the representation is as follows: inferior rectus, medial rectus, superior rectus, and inferior oblique. The fascicle for the levator palpebrae is located in close association with that for the medial rectus, whereas the axons of general visceral efferent neurons form a separate fascicle that courses on the extreme medial border of the oculomotor radiations.

CLINICAL DISCUSSION: Complete section of the oculomotor radiations is similar to destruction of the nucleus; the globe is abducted and slightly depressed, and the pupil is dilated and nonreactive to light. Small infarctions in the ventral midbrain can damage a limited number of third-nerve radiations. A specific lesion of the fascicles to the inferior oblique muscle, the lateralmost fascicle, has been reported (Castro et al., 1990). Axons for the visceral motor component run separated from, and medial to, the general somatic component. Thus, they can be spared in small lesions of the midbrain tegmentum, producing a paresis of the globe in the presence of a reactive pupil. In such cases, the patient presents with a third nerve palsy, but with functioning pupils (Keane, 1988).

RED NUCLEUS (RuNu)

A large spherical mass of cells in the ventral midbrain forms the red nucleus (RuNu). Afferent fibers to this structure arrive from the cerebral cortex and dentate nucleus of the cerebellum. Two major projections arise from the red nucleus. The rubrospinal tract innervates the ventral and intermediate horns of the contralateral spinal cord. This pathway and the corticospinal tract form the descending output of the lateral motor system. The rubro-olivary tract connects the red nucleus with the inferior olive of the medul-

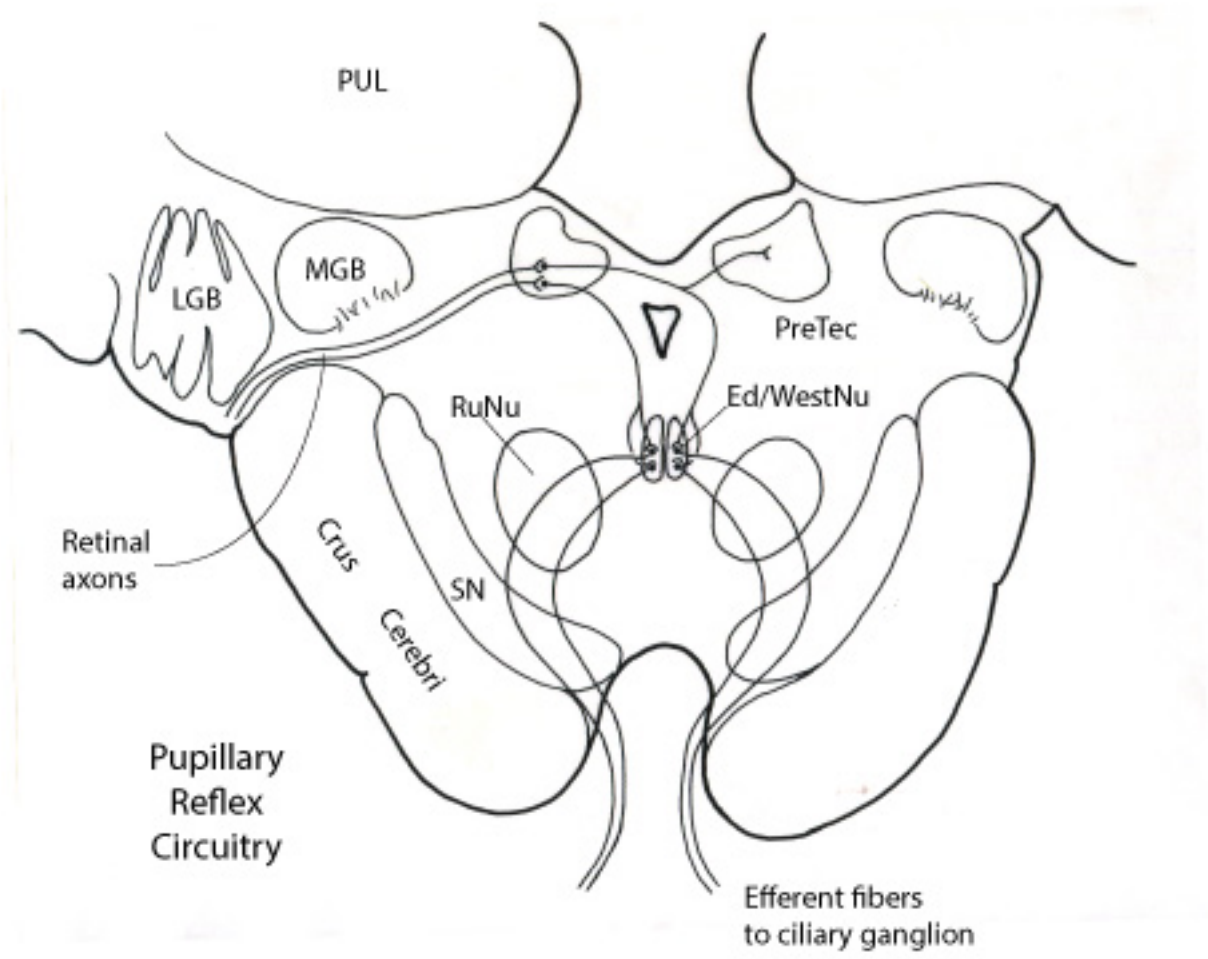


Figure 7-3. This diagram of the pretectal nuclei illustrates their role in the pupillary light reflex.

la. This tract is part of a feedback circuit passing from the cerebellum to red nucleus, inferior olive, and back to the cerebellum. The integrity of this circuit, although unnecessary for executing established motor patterns, is necessary for learning new motor patterns (Thach et al., 1992).

The red nucleus lies in a dense nest of fiber tracts entering the thalamus. Laterally, it is closely surrounded by the dentothalamic tract (superior cerebellar peduncle) as it passes from the decussation of the SCP to the thalamus. Rostrally, the border of the red nucleus is in close juxtaposition with the pallidothalamic tract extending from the globus pallidus to the thalamus. Lesions in the vicinity of the red nucleus can infringe on these tracts, both of which are related to the function of the motor system.

The influence of the red nucleus on motor behavior in humans has long been questioned. Recently, it has been postulated that this nucleus and its tract (rubrospinal) are activated when automated movements are being executed, whereas the corticospinal tract is involved with nonautomated movements (Kennedy, 1990).

CLINICAL DISCUSSION: The clinical significance of damage to the red nucleus in humans is questionable. Most likely, the rubral deficits are masked by the other component of the lateral motor system, the corticospinal tract. Lesions in the area of the red nucleus can present with limb tremor, hypokinesia, and ataxia. However, these clinical signs are most likely due to damage to the surrounding dentothalamic tract and pallidothalamic fibers rather than an expression of rubral dysfunction (see Chaps. 6 and 11).

DENTOTHALAMIC TRACT OR CEREBELLOTHALAMIC TRACTS (CThT)

After its decussation, the superior cerebellar peduncle, containing the dentothalamic tract, passes laterally around the red nucleus and ascends into the thalamus. Between the decussation and the thalamus, these axons are also referred to as the cerebellothalamic tract (CThT). Fibers from the dentate nucleus terminate in the contralateral ventrolateral thalamic nucleus. As the tract approaches the thalamus, it joins other fibers to form the thalamic fasciculus (ThFas, Plate 22).

CLINICAL DISCUSSION: Section of the superior cerebellar peduncle presents with limb tremor, hypokinesia, and ataxia (see Chapter 6). The clinical signs, resulting from section of the dentothalamic fibers superior to their decussation in the midbrain, present on the contralateral side.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

- Brachium of the inferior colliculus (IC, Br)
- Substantia nigra (SN)
- Ventral tegmental area (VTA)
- Central gray (CeGy)
- Medial lemniscus (ML)
- Anterolateral system (ALS)
- Ventral trigeminothalamic tract (VTTr)
- Dorsal trigeminothalamic tract (DTTR)
- Dorsal longitudinal fasciculus (DLF)
- Medial longitudinal fasciculus (MLF)
- Central tegmental tract (CIT)
- Midbrain reticular formation (MidRetF)
- Crus cerebri (CC)
- Rostral interstitial nucleus of the medial longitudinal fasciculus (RINMLF)

Case Study 7-2

Chief Complaint

A 79-year-old, right-handed, retired business executive was brought to his general practitioner's office by his son after suffering a momentary loss of consciousness followed by the onset of double vision and a tremor in his left arm.

History of Chief Complaint

He complained of frequent dizzy periods over the last 5 days.

Past Medical History

He had been married for 40 years; his wife had died 5 years earlier. He had been an executive for a large firm. After retirement he had been active socially and played sports. His past medical history was positive for rheumatic fever at age 6. For the past 5 months he had been experiencing periods of dizziness and fatigue. He had a 30-pack-year history of smoking but quit completely 3 years prior. He drank 2 to 3 ounces of alcohol socially per week.

General Physical Examination

He was alert and oriented, well nourished, and of average weight; he appeared his stated age. The patient frequently had to cover his right eye with his hand in order to move about the room. Optic discs were clear with sharp borders. External auditory canals were patent. His neck was supple and there were no bruits over the carotid arteries. His larynx and pharynx were non-reddened. His chest was clear to auscultation and percussion; abdomen was soft without rigidity, tenderness, or organomegaly. Heart rate was irregularly irregular. Peripheral pulses were intact; a pulse deficit was present, with the auscultated apical rate exceeding the radial pulse rate. Blood pressure was 135/93, temperature was 37°C, and respirations were 16/min. No cervical, axillary, or inguinal lymphadenopathy was present.

Neurologic Examination

Mental Status. The patient was alert and oriented to time and place with memory and knowledge appropriate for his age. He was articulate in speech and had good comprehension of spoken and written language. He gave a comprehensive history.

Cranial Nerves. On forward gaze, with the lid forcibly elevated, the right eye had an external strabismus; on attempted left lateral gaze, the right eye drifted toward the midline. The right pupil was larger than the left. The right pupil was unresponsive to light shined in either eye; the left pupil was responsive to direct and consensual light. The right eyelid elevated 4 mm, whereas the left elevated 13 mm on forward gaze. With the right eyelid forcibly elevated, its visual field was full to confrontation. The visual field in the left eye was also full. The patient noted diplopia on attempted forward gaze. The diplopia was absent with the right eye covered and exacerbated when the right eyelid was fully elevated. Hearing was normal in both ears. He had a full range of facial expressions. Jaw-jerk and corneal reflexes were normal; the palate was elevated on the midline; gag reflex was normal, and tongue protruded on the midline.

Motor Exam. Strength was slightly diminished in the left limbs; deep tendon reflexes were +2/4 on the right and +3/4 on the left. Babinski response was equivocal on the left and not present on the right. A tremor of intent was present in the left arm. Finger-to-nose testing was normal on the right, but he was slightly off target when using the left upper limb. The left arm and hand displayed an occasional jerky movement that the patient could not suppress.

Sensory Exam. Pinprick and temperature sensation were normal throughout body and face; position sense and vibratory sensation on the left side of his body was diminished. This sensory loss was more noticeable in the upper than in the lower extremity.

Follow up

Upon examination 3 months following hospital discharge, the patient had normal gross motor strength with +2/4 deep tendon reflexes about the elbow, wrist, knee and ankle bilaterally. Movements of the left extremities were smooth and steady with no indication of past-pointing remaining. Position and vibratory senses were normal in all extremities on the right and the lower extremity on the left. He continued to experience a diminution of position and vibratory senses in the left upper extremity. He could move his right eye into all four quadrants but complained of a mild diplopia and demonstrated a slight external strabismus at rest.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions, what is the origin of this patient's pathology?

9. If the origin is vascular, what arterial supply is involved with the lesion in this patient?

▶ DISCUSSION II

Midbrain Vasculature

The vasculature of the midbrain is relatively complex (Figure 7-4). The basilar artery and its two terminal branches, the posterior cerebral arteries, contribute many penetrating and circumferential branches. In addition, the midbrain is the only portion of the brain stem distal to the thalamus to receive arteries from the anterior circulation; the anterior choroidal arteries accomplish this task.

Posterior Circulation

The basilar artery divides at its rostral end to form the two posterior cerebral arteries; this occurs in the cisternal space ventral to the midbrain. Short, anteromedial branches from the top of the basilar artery and from the proximal segment of the two posterior cerebral arteries supply the median zone to the midbrain. This tuft of vessels, which can arise from a common stem, extends rostrally, giving rise to the thalamic paramedian arteries supplying the medial nuclei of the thalamus, subthalamus, and hypothalamus. If considered all together, the arterial branches at the top of the basilar and proximal posterior cerebral arteries supply a central zone in the midbrain and thalamus (see Plates 19 to 25) and are responsible for the paramedian syndrome of the mesencephalic-thalamic border (Castaigne et al., 1981). Specific midbrain areas serviced by the paramedian branches are the interpeduncular nucleus, red nucleus, decussation of the superior cerebellar peduncle, oculomotor nucleus and its associated structures, and the ventral portion of the central gray.

Two groups of long, circumferential branches from the basilar artery wrap around the brain stem to reach the colliculi (Figure 7-4). The caudal group contains the superior cerebellar arteries (SCA in Figure 7-4), which give off only a few branches to the midbrain until reaching the colliculi. The rostral group contains the collicular arteries (CA in Figure 7-4). Penetrating branches from the collicular arteries service the cerebral peduncles, substantia nigra, medial lemniscus, and dentothalamic tract. The distal twigs of the collicular arteries reach around the lateral and posterior aspect of the brain stem to end in the superior and inferior colliculi.

The posteromedial choroidal arteries (PMChA in Figure 7-4) branch off the proximal segment of the posterior cerebral artery, turn posteriorly, and extend around the cerebral peduncles, running in an arc, parallel but rostral to the collicular arteries. Penetrating branches from posteromedial choroidal arteries perfuse the cerebral peduncles, substantia nigra, medial lemniscus, and dentothalamic tract. The distal twigs of these arteries reach around the posterior aspect of the brain stem to end in the superior and inferior colliculi.

Anterior Circulation

The anterior choroidal artery (AChA in Figure 7-4) branches off the proximal segment of the anterior cerebral artery and passes caudally around the cerebral peduncle, giving off penetrating twigs as it travels. The anterior choroidal artery courses in an arc parallel to the posteromedial choroidal and collicular arteries. Its penetrating branches supply a ventrolateral arc around the brain stem, including cerebral peduncles, substantia nigra, medial lemniscus, and dentothalamic tract.

Table 7-1

NEUROLOGIC SIGN	ANATOMIC SOURCE
Paramedian Syndrome	
Oculomotor palsy	Oculomotor nucleus or its radiations
Vertical gaze palsy	Preoculomotor nuclei
Limb ataxia	Dentothalamic fibers
Memory loss	Median thalamus
Dementia	Median thalamus
Sleep dysfunction	Median thalamus
Weber's syndrome	
Oculomotor palsy	Oculomotor nucleus or its radiations
Spastic paresis	Cerebral peduncle
Akinesia or tremor	Pallidothalamic fibers, substantia nigra or its tracts
Dystaxia or ataxia	Dentothalamic fibers
Benedict's Syndrome	
Oculomotor palsy	Oculomotor nucleus or its radiations
Dskinesia	Pallidothalamic fibers, substantia nigra or its tracts
Parinaud's Syndrome	
Upgaze palsy	Preoculomotor system
"Top of the Basilar" Syndrome	
Oculomotor palsy	Oculomotor nucleus or its radiations
Vertical gaze palsy	Preoculomotor system
Visual field defects	Optic radiations or visual (occipital) cortex
Behavioral dysfunctions	Medial aspect of temporal lobe

Midbrain Lesion Syndromes

Perfusion of the midbrain can be divided into several zones (Duvernoy, 1978): anterior, lateral, and posterior (see Plates 19 and 20). Each zone consists of numerous penetrating vessels derived from a group of circumferential arteries. The anterior zone is further partitioned into anteromedial (or medial paramedian) and anterolateral (or lateral paramedian) regions.

Several arterial syndromes can be defined in the midbrain. These syndromes represent vascular territory damaged by perfusion failure. A pattern exists in their distribution. The paramedian syndrome can occur when the anteromedial penetrating arteries in the anterior zone are compromised; Weber's syndrome can occur when the anterolateral penetrating branches in the anterior zone are damaged; Benedict's syndrome can result when arteries in the lateral zone of penetrating branches are damaged; and Parinaud's

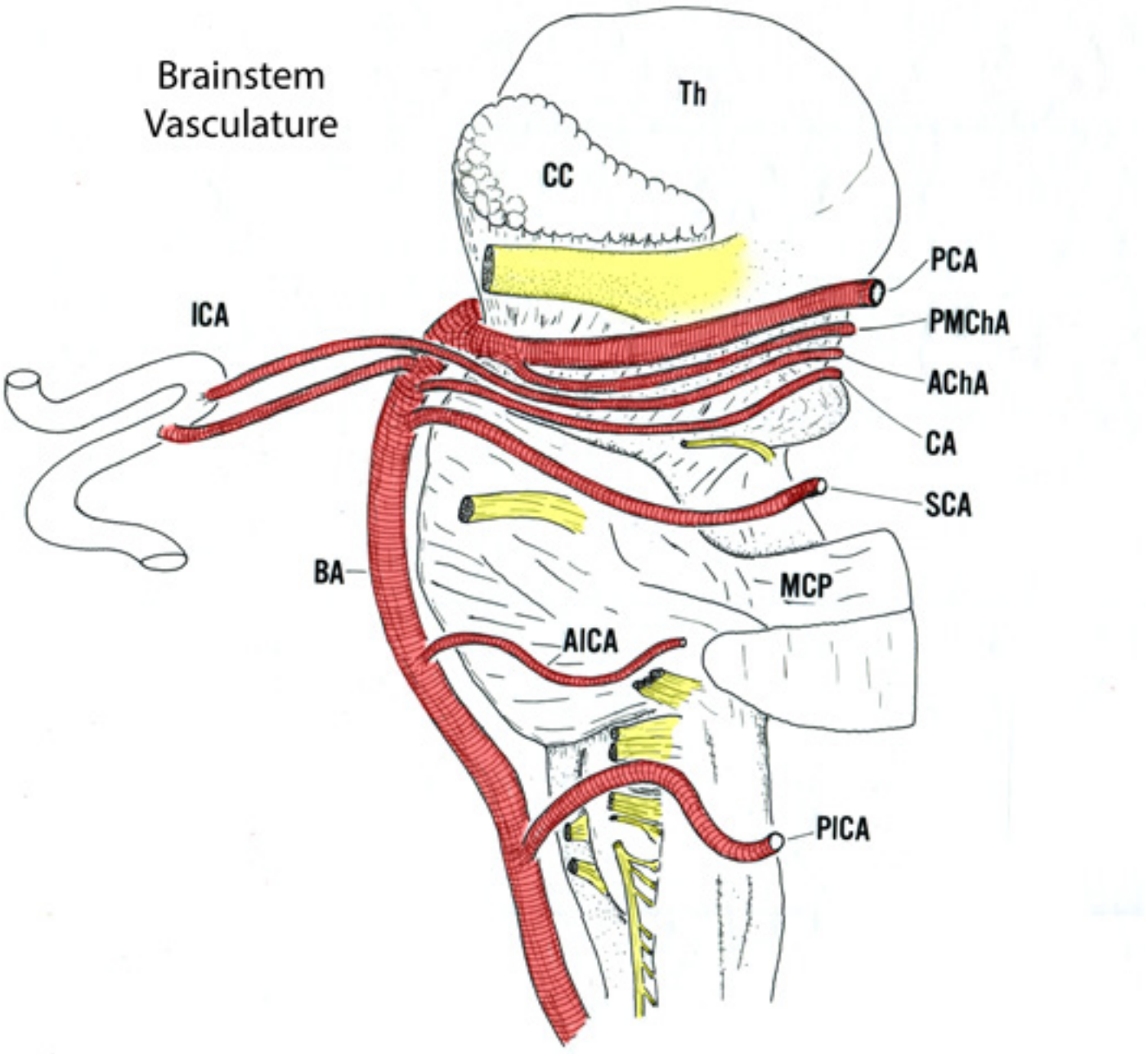


Figure 7-4. Diagram illustrating blood supply to midbrain (Modified from Mettler FA. Neuroanatomy. 2nd ed. St. Louis: CV Mosby, 1942:160)

syndrome arises from either the penetrating branches of the posterior zone or tumors of the pineal gland.

Paramedian Syndrome

Oculomotor palsy and/or vertical gaze palsy, bilateral limb ataxia, and dysmetria are the presenting signs of the paramedian syndrome. It can occur due to occlusion of the anteromedial branches of the basilar or proximal posterior cerebral arteries. In this syndrome damage is done to the oculomotor nerve, oculomotor nucleus, rostral interstitial nucleus (vertical gaze center), and decussation of the superior cerebellar peduncle (Table 7-1). Extension of the ischemic zone can occur into the midline thalamus, resulting in dementia as well as sleep and memory disturbances (See Chapter 8).

Weber's Syndrome

Oculomotor palsy and contralateral spastic paralysis are the cardinal signs of Weber's syndromes (Brazis, 1996). Akinesia and tremor can also be associated, as well as supranuclear palsy of the facial nerve. Conversely, all sensory systems can be intact in this syndrome. Damage is done to the roots of the oculomotor nerve, substantia nigra, and cerebral peduncles (Table 7-1). Anterolateral branches of the basilar, posterior cerebral, collicular, or anterior choroidal arteries can be involved in the genesis of this syndrome.

Benedict's Syndrome

Ipsilateral oculomotor palsy and contralateral motor dysfunction (hyperkinesia or akinesia) are the cardinal signs of Benedict's syndrome (Brazis, 1996). Damage is done to the root of the oculomotor nerve, red nucleus, dentothalamic fibers, and substantia nigra (Table 7-1). Distal tips of the lateral paramedian branches of the basilar, posterior cerebral, collicular, posteromedial choroidal, or anterior arteries can also be causal factors.

Parinaud's Syndrome

Upgaze palsy is the characteristic sign of Parinaud's or dorsal midbrain syndrome (Brazis, 1996). Damage is done to the superior colliculus and to the area at the rostral end of the medial longitudinal fasciculus. These structures are components of what is termed the preoculomotor systems (Table 7-1). The type of eye movement dysfunctions (upgaze palsy) suggests interruption of supranuclear control on the oculomotor nucleus (Baloh et al., 1985). Causative factors include the following: occlusion of the collicular or posterior choroidal arteries supplying the tectum, expansion of a pineal tumor applying pressure to the tectum and underlying tissue, or giant aneurysm in the posterior cranial fossa (Coppeto and Lessell, 1983).

"Top of the Basilar" Syndrome

The basilar artery is larger in diameter than its two sources, the vertebral arteries. Emboli that survive the trip upward through the vertebrals target the top of the basilar, where they can lodge in and around its bifurcation. Occlusion of the distal (rostral) end of the basilar artery can infarct the midbrain, portions of the thalamus, and medial temporal lobe of the cerebrum (Caplan, 1980). A complex constellation of neurologic signs and symptoms arises, as is illustrated in Table 7-1. The major neurologic presentations resulting from midbrain damage in the "top of the basilar" syndrome are disturbances in alertness, behavior, visual fields, and eye movements, such as oculomotor palsy and vertical gaze palsy, and the presentation of amnesia (Caplan, 1989). The deficits due to thalamic and cerebral damage will be considered in Chapters 8 and 9.

References

Alexander GF, Crutcher MD (1990) Functional architecture of basal ganglia circuits: neural substrates of parallel processing. Trends Neurosci 13: 266-271.

Baloh RW, Furman JM, Yee RD (1985) Dorsal midbrain syndrome: clinical and oculographic findings. Neurol 35: 54-60.

Barbur JL, Ruddock KH, Waterfield VA (1980) Human visual responses in the absence of the geniculo-calcarine projection. Brain 103: 905-928.

Barr ML, Kiernan JA (1993) The Human Nervous System: An Anatomical Viewpoint. Philadelphia: J.B. Lippincott.

Bender MB (1980) Brain control of conjugate horizontal and vertical eye movements. A survay of the structural and function correlates. Brain 103: 23-69.

Bernard JF, Peschanski M, Besson J-M (1989) Afferents and efferents of the rat cuneiformis nucleus: an anatomical study with reference to pain transmission. Brain Res 490: 181-185.

Bird ED, Spokes EGS, Iverson LL (1979) Increased dopamine concentration in limbic areas of the brain from patients dying with schizophrenia. Brain 102: 347-360.

Brazis PW (1996) The localization of lesions affecting the brainstem. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 343-364. Boston: Little, Brown and Company.

Bucy PC, Keplinger JE (1961) Section of the cerebral peduncles. Arch Neurol 5: 132-139.

Büttner-Ennever JA, Buttner U, Cohen B, Baumgartner G (1982) Vertical gaze paralysis and the rostral interstitial nucleus of the medial longitudinal fasciculus. Brain 105: 125-149.

Caplan LR (1980) "Top of the basilar" syndrome. Neurol 30: 72-79.

Caplan LR (1989) Vertebrobasilar system syndromes. Hdbk Clin Neurol 53(9): 371-408.

Cascino GD, Adams RD (1986) Brainstem auditory hallucinosis. Neurol 36: 1042-1047.

Castaigne P, Lhermitte F, Buge A, Escourolle R, Hauw JJ, Lyon-Caen O (1981) Paramedian thalamic and midbrain infarcts: clinical and neuropathological study. Ann Neurol 10: 127-148.

Castro O, Johnson LN, Mamourian AC (1990) Isolated inferior oblique paresis from brain-stem infarction. Arch Neurol 47: 235-237.

Christoff N (1974) A clinicopathologic study of vertical eye movements. Arch Neurol 31: 1-8.

Coppeto JR, Lessell S (1983) Dorsal midbrain syndrome from giant aneurysm of the posterior fossa: report of two cases. Neurol 33: 732-736.

DeLong MR (1990) Primate models of movement disorders of basal ganglia origin. Trends Neurosci 13: 281-285.

Durward QJ, Barnett HJM, Barr HWK (1982) Presentation and management of mesencephalic hematoma. J Neurosurg 56: 123-127.

Duvernoy HM (1978) Human Brainstem Vessels. Berlin: Springer-Verlag.

Fisher CM, Curry HB (1965) Pure motor hemipeligia of vascular origin. Arch Neurol 13: 30-44.

Gonyea EF (1990) Superior oblique palsy due to a midbrain vascular malformation. Neurol 40: 554-555.

Groenewegen HJ, Ahlenius S, Haber SN, Kowall NW, Nauta WJH (1986) Cytoarchitecture, fiber connections, and some histochemical aspects of the interpeduncular nucleus in the rat. J Comp Neurol 249: 65-102.

Helweg-Larsen S, Larsson H, Henriksen O, Sorensen PS (1988) Ataxic hemiparesis: three different locations of lesions studied by MRI. Neurol 38: 1322-1324.
Howe JR, Miller CA (1975) Midbrain deafness following head injury. Neurol 25: 286-289.

Jacobs L, Anderson PJ, Bender MB (1973) The lesions producing paralysis of downward but not upward gaze. Arch Neurol 28: 319-323.

Jenkins WM, Masterton RB (1982) Sound localization: effects of unilateral lesions in central auditory system. J Neurophysiol 47: 987-1016.

Keane JR (1986) Locked-in syndrome after head and neck trauma. Neurol 36: 80-82.

Keane JR (1988) Isolated brain-stem third nerve palsy. Arch Neurol 45: 813-814.

Keane JR, Itabashi MH (1985) Locked-in syndrome due to tentorial herniation. Neurol 35: 1647-1649.

Kennedy PR (1990) Corticospinal, rubrospinal, and rubro-olivary projections: a unifying hypothesis. Trends Neurosci 13: 474-479.

Lavin PM, Troost BT (1984) Traumatic fourth nerve palsy. Arch Neurol 41: 679-680.

Masdeu JC, Brazis PW (1996) The localization of lesions in the ocular motor system. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 155-250. Boston: Little, Brown and Company.

Moore RY (1982) Catecholamine neuron systems in the brain. Ann Neurol 12: 321-327.

Patten J (1996) Neurological differential diagnosis. London: Springer.

Pierrot-Deseilligny CH, Chain F, Gray F, Serdaru M, Escourolle R, Lhermitte F (1982) Parinaud's syndrome: Electro-oculographic and anatomical analysis of six vascular cases with deductions about vertical gaze organization in the premotor structures. Brain 105: 667-696.

Plum F, Posner JB (1982) The Diagnosis of Stupor and Coma. Philadelphia: F.A. Davis Company.

Ranalli PJ, Sharpe JA, Fletcher WA (1988) Palsy of upward and downward saccadic, pursuit, and vestibular movements with unilateral midbrain lesion: pathophysiological correlations. Neurol 38: 114-122.

Ropper AH, Miller DC (1985) Acute traumatic midbrain hemorrhage. Ann Neurol 18(1): 80-86.

Rush JA, Younge BR (1981) Paralysis of cranial nerves III, IV, and VI: Cause and prognosis in 1,000 cases. Archives of Opthalmology 99: 76-79.

Sand JJ, Biller J, Corbett J, Adams HP, Dunn V (1986) Partial dorsal mesencephalic hemorrhages: report of three cases. Neurol 36(4): 529-533.

Sparks DL (1986) Translation of sensory signals into commands for control of saccadic eye movements: role of primate superior colliculus. Physiol Rev 66: 118-171.

Thach WT, Goodkin HP, Keating JG (1992) The cerebellum and adaptive coordination of movement. Ann Rev Neurosci 15: 403-442.

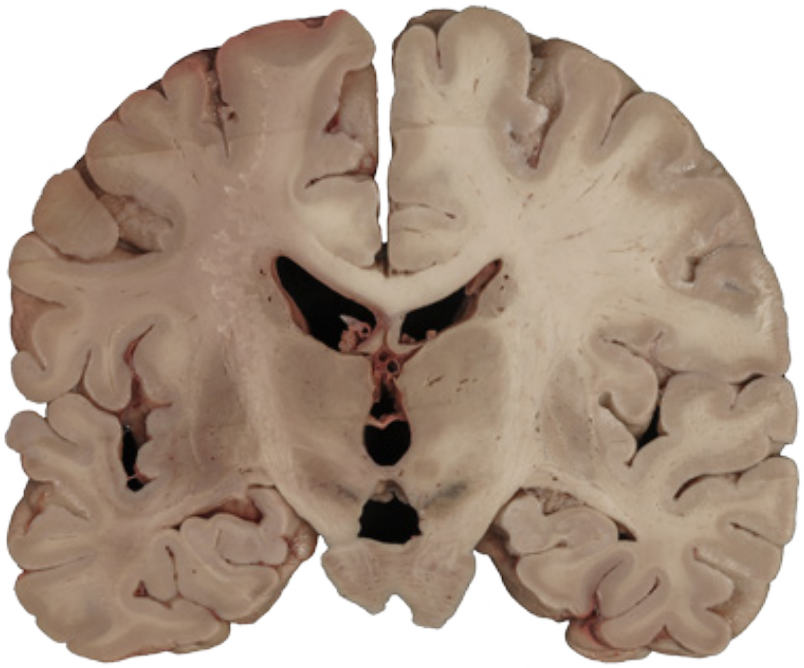
Waga S, Okada M, Ymanoto Y (1979) Reversibility of Parinaud syndrome in thalamic hemorrhage. Neurol 29(3): 407-409.

Warabi T, Inoue K, Noda H, Murakami S (1990) Recovery of voluntary movement in hemiplegic patients. Brain 113: 177-189.

Warabi T, Miyasaka K, Inoue K, Nakamura N (1987) Computed tomographic studies of the basis pedunculi in chronic hemiplegic patients: topographic correlation between cerebral lesion and midbrain shrinkage. Neuroradiology 29: 409-415.

Watson RT, Heilman KM, Miller BD, King FA (1974) Neglect after mesencephalic reticular formation lesions. Neurol 24: 294-298.

Chapter 8
Thalamus



INTRODUCTION

The diencephalon represents the rostral end of the brainstem and is surrounded by the internal capsule laterally, and the lateral ventricle and corpus callosum superiorly (Figure 8-1). It is divided into two elongated or egg-shaped hemispheres, which are separated by the narrow third ventricle. In Figure 8-1 we are looking down on the thalamus after removing the upper portion of the cerebrum. The internal capsule can be seen passing lateral to the thalamus, and the basal ganglia (caudate and putamen) are seen wrapped around the rostral end of the internal capsule.

Each thalamic hemisphere is partitioned into dorsal and ventral portions by the hypothalamic sulcus (Figure 7-2). The dorsal thalamus is composed of the thalamus proper (usually called the thalamus) and epithalamus; the ventral portion is composed of the hypothalamus and subthalamus. The epithalamus forms the roof of the thalamus and contains two structures: the pineal body and a fiber tract, the stria medullaris which courses along the superomedial border of the thalamus. The nuclei of the thalamus proper form reciprocal connections with the ipsilateral cerebral cortex, whereas those of the hypothalamus are involved in regulating endocrine and autonomic nervous systems. The diencephalon receives its blood supply from penetrating arteries derived from the Circle of Willis or its immediate branches.

GENERAL OBJECTIVES

1. To identify the location of major thalamic nuclei and learn their relationship to the cerebral cortex

2. To identify the major hypothalamic regions and learn their relationships with the endocrine and autonomic nervous systems

3. To learn the presenting signs and symptoms consequent to lesions involving major nuclei and tracts in the thalamus, where they are known

4. To apply this knowledge to understanding the clinical manifestations of major thalamic vascular lesions

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using a knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before you attempt to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and answer the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A human brain sectioned on the midsagittal plane
2. A brain stem model with thalamus
3. A medical dictionary

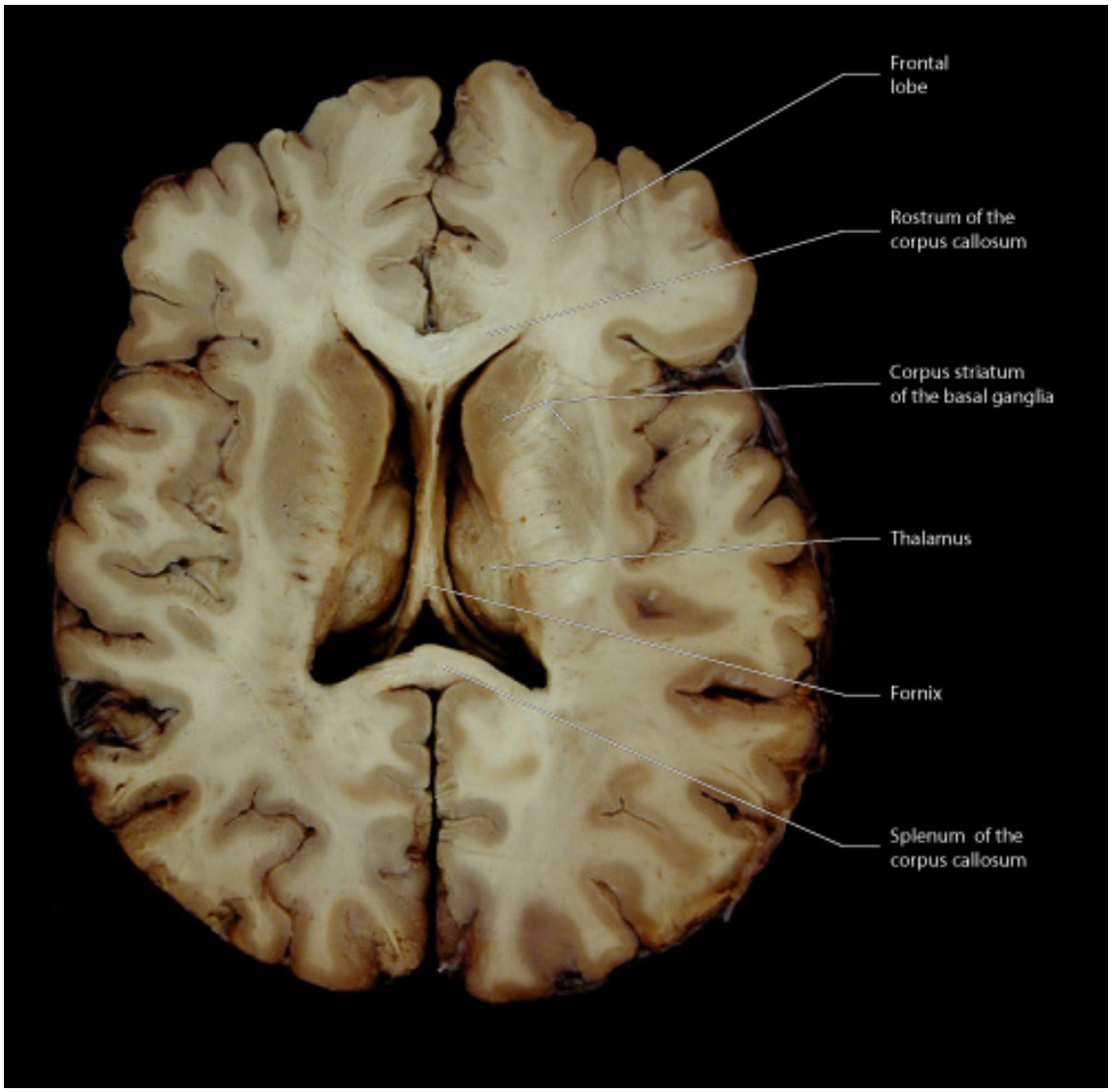


Figure 8-1. A horizontal section taken through the thalamus. The cerebral hemisphere is characterized by a gray ribbon of cells on the outside, an underlying mass of white matter (axons) and a set of deep nuclei, the thalamus and basal (cerebral) ganglia. The two hemispheres are interconnected by a massive fiber bundle, the corpus callosum, which is seen twice in this section due to its curved nature. Of the two deep nuclei, the thalamus is closest to the midline and in several places crosses the midline. A well circumscribed bundle of fibers, the fornix, passes over the thalamus on its way from the temporal lobe to the hypothalamus.

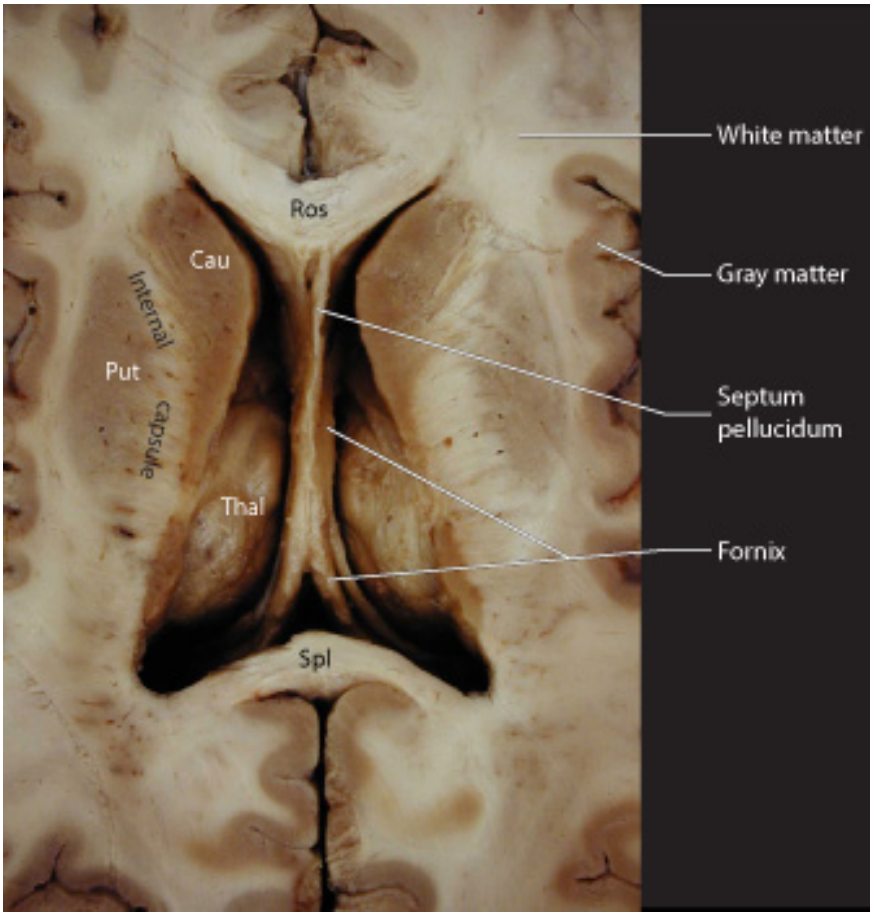


Figure 8-2. This is a magnified view of the deep nuclei in Figure 8-1. The open space is the two lateral ventricles. The basal ganglia are seen to be composed of two nuclear masses, the caudate and the putamen. These two nuclei are separated by the internal capsule. The caudate protrudes into the anterior portion of the lateral ventricle creating an anterior horn (Figure 8-3). The thalamus is a nuclear mass that protrudes deep into the ventricular system posteriorly. The corpus callosum is seen on either end of the ventricular system. The rostrum (Ros) of the corpus callosum is positioned anteriorly whilst the splenium (Spl) of the corpus callosum is positioned posteriorly. The fornix passes from posterior to anterior, wrapping over the thalamic hemispheres. Anteriorly, the fornix is attached to the rostrum of the corpus callosum by the septum pellucidum.

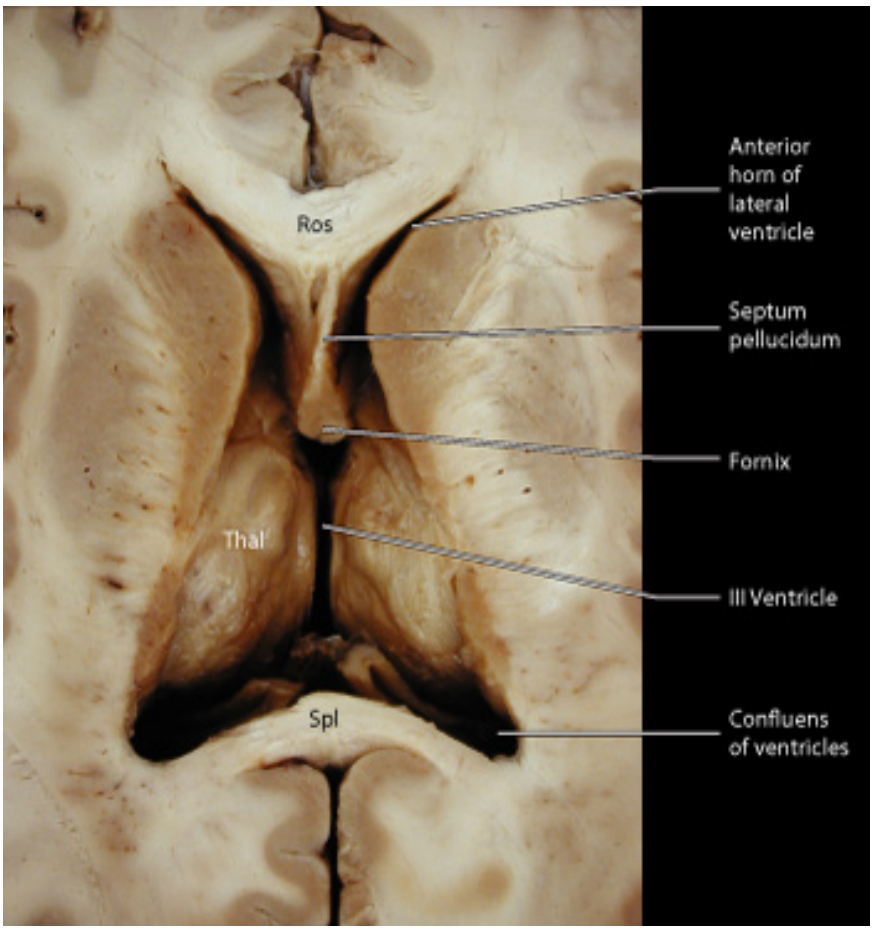


Figure 8-3 This is the same view as above following the sectioning and removing the fornix to demonstrate the two thalamic hemispheres.

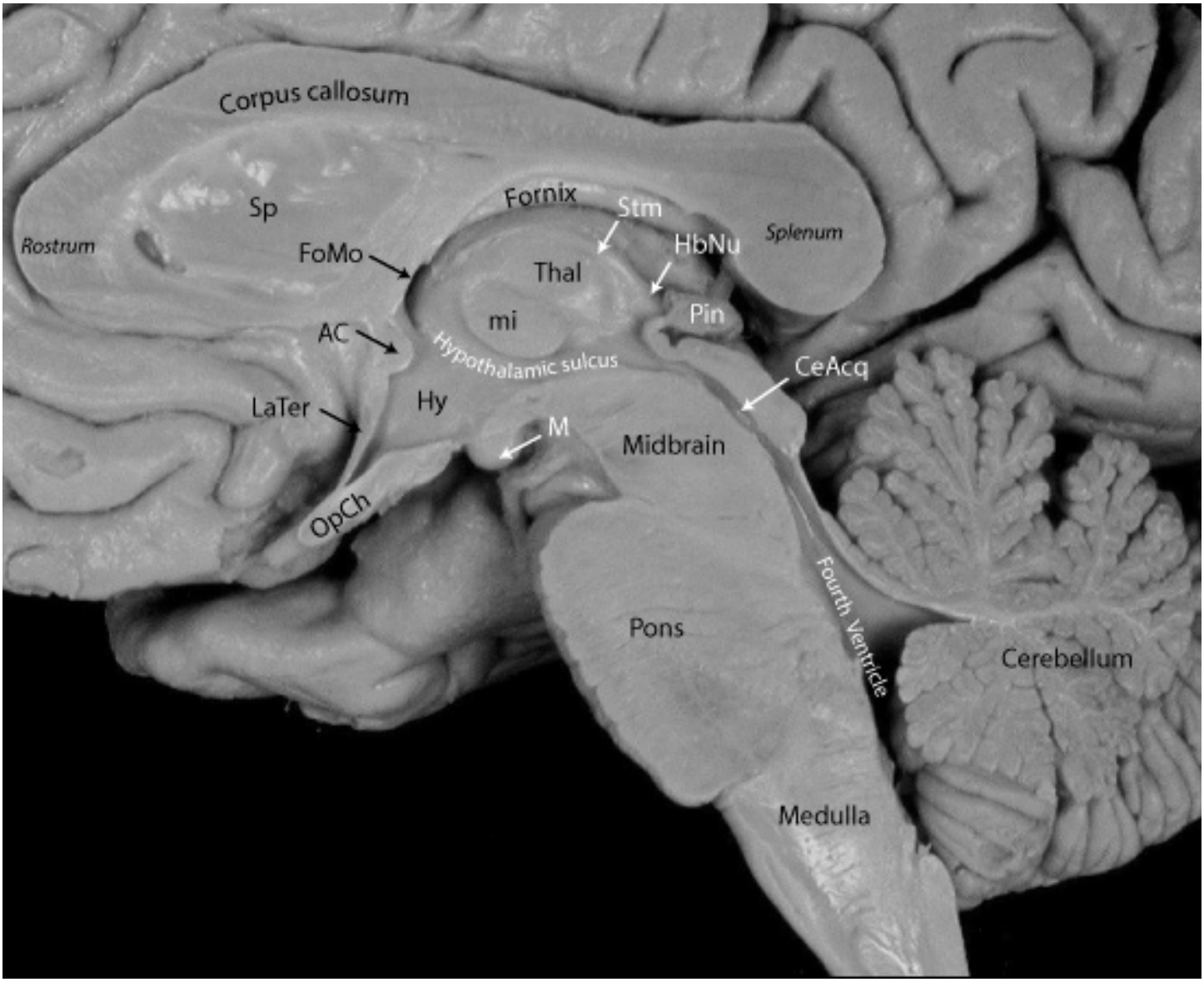


Figure 8-4. This is a sagittal view of the brainstem. The diencephalon is seen as a mass of cells and fibers positioned superior to the midbrain. The fornix and corpus callosum appear to cap over the diencephalon, which itself is divided into four parts, the largest is the hemispherical thalamus (dorsal thalamus), which is separated from the hypothalamus (ventral thalamus) by the hypothalamic sulcus. A thin stria medullaris (arising in the habenular nucleus) marks the epithalamus. Lastly the subthalamus lies on the border of the midbrain and is not visible in this section. The massa intermedia (mi) or thalamic adhesion represents a midline fusion of the thalamic nuclei, it is prsent in about 80% of individuals. The hypothalamus presents a triangular appearance in the sagittal plane with the anterior commissure (AC), mammillary nuclei (M), and optic chiasm (OpCh) as its borders. The walls of the third ventricle are represented by the visible surface of the thalamus and hypothalamus. The hypothalamic sulcus begins at the foramen of Monro (FoMo) and passes through the third ventricle to enter the cerebral aqueduct. This latter structure connects the third ventricle with the fourth ventricle underlying the cerebellum.

Chapter topic organization:

Case Study 8-1

Case Study 8-2

DISCUSSION I

Thalamic Structures
Gross Anatomic Organization
Internal Structure

Atlas Plate 20

- PINEAL
- PULVINAR NUCLEUS (PulNu)
- LATERAL GENICULATE NUCLEUS (LGNU)
- OPTIC RADIATIONS (OpRad)
- MEDIAL GENICULATE NUCLEUS (MGNu)

Atlas Plate 21

- STRIA MEDULLARIS (StMed)
- HABENULAR NUCLEUS (Hab)
- HABENULOPEDUNCULAR TRACT (HPTr)
- VENTROPOSTERIOR NUCLEI (VPL and VPM)
- MEDIAL LEMNISCUS (ML)
- CENTROMEDIAN NUCLEUS (CM)
- DORSOMEDIAL NUCLEUS (DMNu)
- LATEROPOSTERIOR NUCLEUS (LP)
- INTERNAL MEDULLARY LAMINA (IML)
- EXTERNAL MEDULLARY LAMINA (EML)
- THALAMIC RETICULAR NUCLEUS (ThRetNu)
- SUBTHALAMIC NUCLEUS (SThNu)
- CEREBELLOTHALAMIC TRACT (CThT)
- BODY OF THE FORNIX

Atlas Plate 22

- VENTROLATERAL NUCLEUS (VL)
- THALAMIC FASCICULUS (ThFas)
- ZONA INCERTA (Zi)
- LENTICULAR FASCICULUS (LenFas)
- MAMILLARY BODY (MB)
- MAMMILLOTHALAMIC TRACT (MTTr)
- POSTERIOR HYPOTHALAMUS (PHyTh)

Atlas Plate 23

- MASSA INTERMEDIA (MI)
- ANSA LENTICULARIS (AnLen)
- LATERAL HYPOTHALAMIC AREA (LHyTh)
- MEDIAL HYPOTHALAMUS (MHyTh)
- OPTIC TRACT (OpTr)

Atlas Plate 24

- ANTERIOR HYPOTHALAMUS (AHyTh)
- INFERIOR THALAMIC PEDUNCLE (InThP)

Atlas Plate 25

- ANTERIOR THALAMIC NUCLEUS (AN)
- VENTROANTERIOR THALAMIC NUCLEUS (VA)

Case Study 8-3

Case Study 8-4

DISCUSSION II

- Thalamic Vascular Supply
- Paramedian Group
- Anterolateral Group
- Posterolateral Group
- Lateral Group
- Thalamic Vascular Syndromes
- Midline Territory Syndrome
- Anterolateral Territory Syndrome
- Posterolateral Territory Syndrome
- Lateral Thalamic/Internal Capsule Zone Syndrome

Reference List

Case Study 8-1

Chief Complaint
A 65-year-old man presented with right-sided hemiparesis, homonymous hemianopsia, dysarthria, and confusion.

History of Chief Complaint
This 65-year-old, right-handed man was brought to the emergency room early in the morning by his family. They complained that he was unable to move his right hand, his speech was slurred, and that he appeared to be confused. He had been that way since shortly after he awoke that morning.

Medical History
He was in good health until 7 years prior, when he was diagnosed as having hypertension. One year later, he was admitted to the community hospital a day after experiencing a brief episode of quadriparesis, blurred vision, and nausea. At that time Doppler studies of the carotids were normal, as were lumbar puncture, electroencephalogram, and a computed tomographic (CT) scan. Diabetes was detected and he was consequently given a regimen of insulin and discharged. During the next 4 years, no known transient ischemic episodes occurred. The day prior to his most current admission, he had complained of intermittent weakness in his right hand.

Family History
At the time of admission he was married, retired from military service, and had two children, both of whom were married. His father had had hypertension and died at 55 of coronary artery disease; his mother was still living.

General Physical Examination
He was a stable, well-hydrated, well-nourished man in no acute distress who appeared his stated age. Funduscopic examination revealed arterial-venous nicking without hemorrhage or papilledema. His heartbeat was regular without murmurs or gallops. Blood pressure was 180/100. Respiration and pulse were normal. Lungs were clear to auscultation. Abdomen was soft without masses. Skin was of good texture and temperature. Several small areas of active keratosis on the right posterior scalp were evident.

Neurologic Examination
Mental Status. He was awake and alert, but disoriented with respect to time, place, and personal information, relying on his family members to supply much of the history. He had impaired recent memory and fund of knowledge. (He said Kennedy was the current US President.) He confused the left and right sides of his body. His speech was poorly articulated and perseverative; he used word substitutions and mispronounced words frequently; however, he had normal repetition of speech.

Cranial Nerves. He had a full range of eye movements. There was a right homonymous hemianopsia present. Pupils were symmetric and bilaterally responsive to light, both direct and consensual. Hearing was normal in both ears. Corneal, jaw-jerk, and gag reflexes were intact. His face was asymmetric on spontaneous emotional expression (e.g., smiling) but not on voluntary movement (right "emotional" facial paralysis). Discriminative touch was intact across his face, bilaterally. The uvula was elevated on the midline; the tongue protruded on the midline. Shoulder shrug was symmetric.

Motor Systems. Strength in the limbs was +5/5 in the left arm and leg, +3/5 in the right arm, and +4/5 in the right leg. Deep tendon reflexes were elevated in the right arm more than the right leg; they were physiologic on the left. A Babinski sign was noted on the right.

Sensation. Pain, light touch, and vibration sense were normal, but discriminative touch and proprioception were impaired in the right hand.

Follow-up
Reexamination at two months after his initial presentation found an alert but very confused gentleman with poor orientation for person, place and time. He had to be continually reminded of why he was being examined. His language remained poorly articulated and perseverative; however, there was some improvement in meaning since his last visit. He could smile on command and also smiled with emotional stimuli. The weakness in his right arm and leg had partially resolved; however, the deep tendon reflexes in these extremities remained elevated.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

Case Study 8-2

Chief Complaint

A 47-year-old, left-handed man status post MI was admitted to the hospital with a primary complaint of chest pain and shortness of breath of 3 weeks duration. He also complained of a progressive narrowing of his visual fields.

History of Chief Complaint

His chest pain, which had been relieved after his documented MI 6 months ago, had begun to return. It was accompanied by dyspnea that worsened on exertion.

Medical History

Since childhood he had consumed at least a gallon of water a day and had had thirst, polyuria, and nocturia. Having grown up with these symptoms, he had considered them normal. He had a long history of behavioral dysfunction that included rage and anger inappropriate for the situation. He had a recent history of angina on exertion, and electrocardiographic analysis 6 months ago documented an acute myocardial infarct.

Family History

At the time of admission he was not married, lived alone, and admitted to having very little libido throughout his life. His mother, father, and two siblings were alive and in good health. No one else in his family had exhibited his chief complaints.

General Physical Examination

He appeared to be a well-hydrated, well-nourished man, alert but with an anxious demeanor. He appeared his stated age. He weighed 240 pounds and his height was 66 inches. His head was normocephalic. Fundoscopic examination revealed a normal cup-to-disc ratio; soft cotton wool patches were noted two disc spaces from the disc in the superior temporal retina bilaterally; no aneurysms, hemorrhages, or papilledema was evident. His heartbeat was regular without

gallops or thrills; an S2 systolic murmur was noted at the left sternal border. The apical beat was displaced to the left. Abdominojugular reflux was noted on application of abdominal pressure. Respiration was labored, breath sounds were decreased; crackles and wheezes were heard at the bases of the lungs on auscultation. The abdomen was soft, without masses or tenderness. Temperature was elevated at 37.5°C and oscillated between 37.3°C and 37.9°C over a 24-hour period. Skin was moist with good texture and turgor. Pretibial edema (+2) was present in the lower extremity.

Neurologic Examination

Mental Status. The patient was awake and oriented for time and place; memory and knowledge were appropriate for his education. His speech was articulate and meaningful. Although he was cooperative most of the time, he experienced bouts of rage, where he yelled at the attending staff and physician.

Cranial Nerves. He had a full range of eye movements. Visual acuity was normal in the center of his fields but diminished rapidly to the sides; vision in the temporal fields was absent altogether. Corneal, jaw-jerk, and gag reflexes were intact. His face was symmetric, with normal expression of emotion. Hearing was diminished in the right ear more than in the left. Uvula and palate were symmetric and elevated on the midline; the tongue protruded on the midline. Shoulder shrug was symmetric.

Motor Systems. Gross motor strength was equal in upper and lower extremities; deep tendon reflexes were 2/4 and equal in upper and lower extremities. Babinski response was physiologic, with no muscular atrophy or hypertrophy. No drift or involuntary motion was detected.

Sensation. There was no loss of vibration or proprioceptive sense, and no loss of pain or thermal sense was evident.

Follow-up

During his hospital admission, marked thirst and daily intake of 4000 to 17,000 mL of fluid were noted. Urine outputs of 3500 to 18,000 mL daily were recorded. The specific gravity of his urine was always below 1.005. One month after admission, the patient died of congestive heart failure.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

Thalamic Structures

The medulla, pons, and midbrain are derived embryologically from the alar and basal plates of the neural tube. This pattern changes in the diencephalon. The dorsal thalamus (or thalamus proper) arises from the alar plate; the basal plate plays a much smaller role, giving rise to portions of the ventral thalamus only. The dorsal thalamus has extensive connections with the overlying mantle of neocortex, whereas the ventral thalamus is related through its connections with the older portions of the cerebral cortex, such as the allocortex, as well as with the brain stem and spinal cord. The alteration in embryogeny along with the changes in connectivity contributes to a substantially different organizational pattern for the diencephalon than that present throughout the more caudal portions of the brain stem. Finally, the dorsal thalamus is deeply involved in our neosensory, motor and cognitive processes, whilst the ventral thalamus or hypothalamus is involved in our emotional and motive-driven behavior.

Gross Anatomic Organization

If all telencephalic structures of the forebrain were removed, the diencephalon would appear as two large, egg-shaped masses at the rostral end of the brain stem. A horizontal section passing through the lateral ventricles superior to the diencephalon illustrates its position between the fiber bundles of the internal capsule (Figure 8-1). The anterior limb of the internal capsule separates caudate from putamen (portions of the basal ganglia; see Chap. 11); the posterior limb of the internal capsule separates the putamen laterally from the diencephalon medially. A strand of choroid plexus lies along the dorsal surface of the diencephalon. The narrow third ventricle separates the two diencephalic hemispheres.

The diencephalon is divided into two major regions by the hypothalamic sulcus (Figure 8-4), each with separate functions. Its dorsal portion is intimately related through reciprocal connections to neocortex, modulating both the information traveling to, and the levels of neuronal activity in, the cerebral cortex. The ventral portion of the thalamus integrates sensory information from external and internal environments and regulates visceral and emotional behaviors through control over the autonomic nervous system via the brain stem and spinal cord, as well as its control over the endocrine system via the pituitary gland.

Most of the connections between the dorsal thalamus and the cerebral cortex pass through the internal capsule. In general these connections are reciprocal, that is, the thalamic nuclei project axons to specific cerebral cortical areas and, in turn, the cortical areas project axons down through the internal capsule to specific thalamic nuclei. The connections of the hypothalamus are organized in a very different pattern. Axonal connections between the cerebral cortex and the hypothalamus mainly pass through an older fiber tract termed the median forebrain bundle. As such, these connections lack the specificity seen in the thalamocortical projections arising in the dorsal thalmus. The hypothalamus also has a significant output ventrally into the pituitary controlling much of the endocrine system of the body. This pathway involves the median eminence on the floor of the third ventricle, the hypothalamic stalk and the pituitary gland (Figure 8-5).

Internal Structure

The dorsal thalamus can be divided into two regions: epithalamus and thalamus proper (usually called thalamus). The epithalamus contains a nuclear group, the habenular nuclei, and a fiber tract, the stria medullaris (Figure 8-6), which courses along the medial border of the thalamus. The epithalamic structures have major connections to the limbic system (see Chap. 10).

The thalamus proper is divided into several groups of nuclei separated by thin bands of fibers and cells called medullary laminae. Four major groups of thalamic nuclei are recognized: anterior, medial, ventral, and lateral-posterior (Figure 8-6). These groups are separated from each other by the internal medullary lamina. An external medullary lamina surrounds the entire mass, to the outside of which lies the thalamic reticular nucleus (see Plates 21 to 25). Within each of the major groups several individual nuclei exist, each nucleus being mapped to a specific region of the ipsilateral neocortex (Table 8-1) through reciprocal connections.

The ventral thalamus is also divided into two regions: subthalamus and hypothalamus. The subthalamus forms the border between the diencephalon and midbrain, located very close to the substantia nigra. It is involved in regulating motor activity and is connected to the basal ganglia while the hypothalamus is positioned directly under the thalamus and is a major controlling region for the autonomic nervous system.

The hypothalamus is separated from the thalamus proper by the hypothalamic sulcus; this appears as a narrow, curved groove passing ventrally around the massa intermedia (mi) on Figure 8-4). The rostral border of the hypothalamus is the lamina terminalis, which stretches between the optic chiasm (OpCh in Figure 8-4) and a large fiber bundle called the anterior commissure (AC in Figure 8-4). The lateral borders of the hypothalamus are formed by the optic tract and cerebral peduncle; caudally, the hypothalamus ends with the mammillary bodies (M in Figure 8-4). The ventral surface of the hypothalamus is raised into a ventrally directed dome called the median eminence. At the center of this eminence is the infundibulum, or stalk, of the pituitary.

Within the hypothalamus are several diffuse nuclei whose connections pass through three large fiber bundles: the mammillothalamic fasciculus, the fornix, and the median forebrain bundle. The hypothalamus receives projections from the spinal cord, brain stem, and the older portions of forebrain: the hippocampus and amygdala. Through its projections to the autonomic nuclei of the brain stem and spinal cord and its connections to the pituitary via

the median eminence and infundibulum, the hypothalamus exerts control over visceral and emotional behavior.

The nuclei and tracts of the thalamus and hypothalamus are packed closely together. This presents two major problems when studying the deficits consequent to thalamic infarctions: (1) Even small lesions can damage multiple thalamic structures, presenting with a varied mixture of clinical signs and symptoms, many of which are similar to those seen in much larger lesions of the cerebral cortex. (2) In addition, the thalamocortical and corticothalamic fibers pass across the medial to lateral axis of the thalamus going to or from the internal capsule; small lesions in the lateral portions of thalamus can damage lateral nuclei as well as the axons of more medially placed nuclei. Again, the resulting clinical presentation can be quite complex. This is further emphasized by studies of cerebral metabolism consequent to thalamic lesions (Szelies et al., 1991). Even small lesions in specific areas of thalamus are capable of significantly decreasing cortical metabolism, as observed by using positron emission tomography to image the uptake of a labeled isotope of glucose. Thus it is difficult to ascertain whether the patient's presenting signs are due to the small thalamic lesion or to a more global shutdown of cerebral cortex.

Table 8-1

Thalamic nuclei	Cortical target
Anterior nuclei	Cingulate gyrus
Medial nuclei	Prefrontal lobe
Ventral nuclei	Parietal and frontal gyri
Lateral nuclei	Parietal, occipital & temporal gyri
Lateral geniculate nucleus	Occipital gyri
Medial geniculate nucleus	Temporal gyri

Bearing these caveats in mind as well as the warnings concerning the use of the lesion method in human neuroanatomy (Damasio and Damasio, 1989), it is possible to glean information on thalamic structure and function from the clinical literature on intracerebral

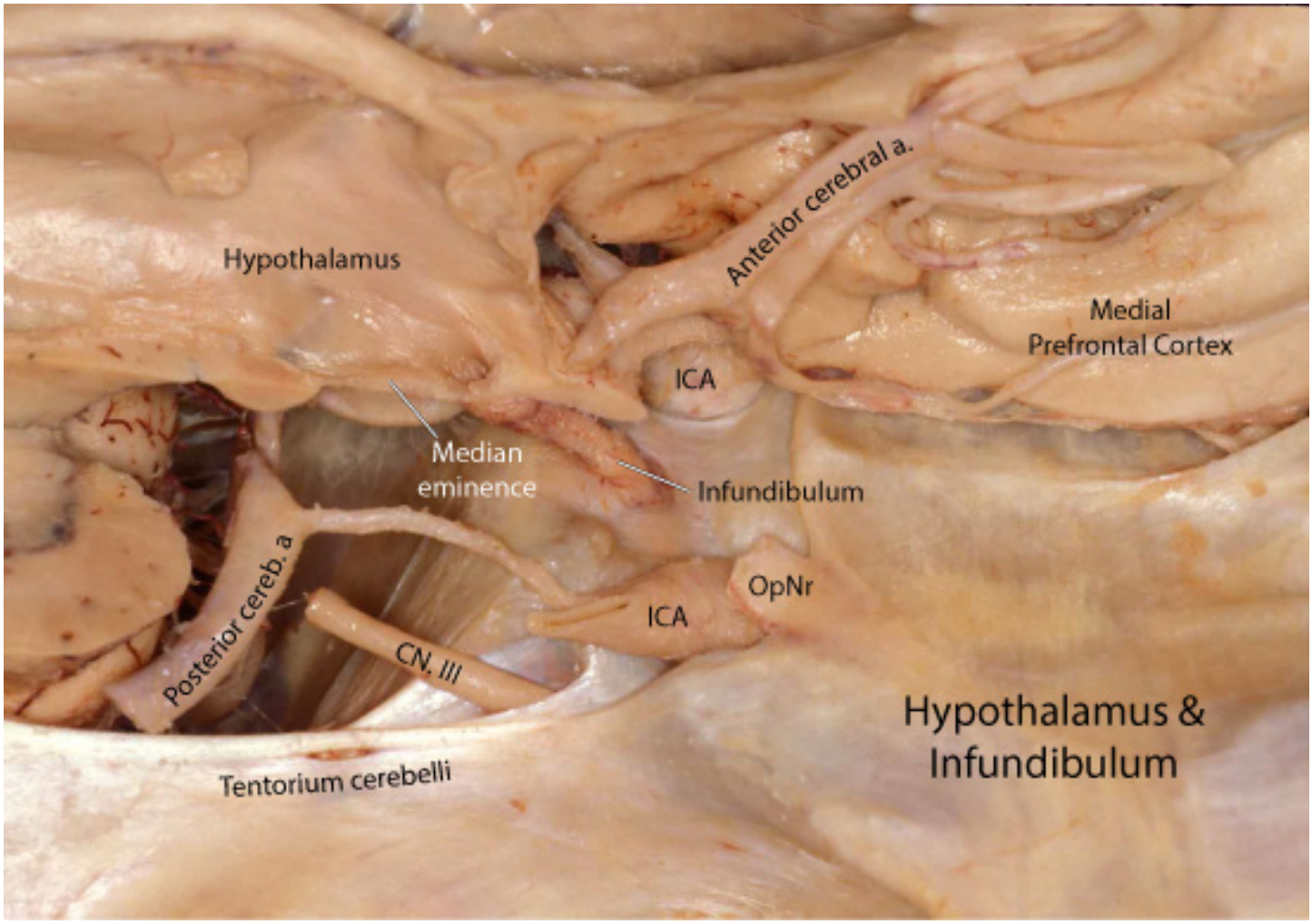
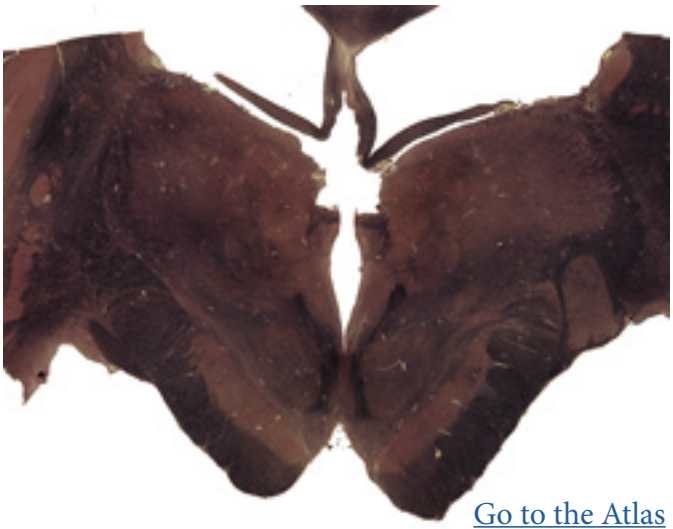


Figure 8.5: A lateral oblique view of the hypothalamus and infundibular stalk. The brain was sectioned on the midline while still in the cranium and the right cerebral hemisphere has been removed to expose the hypothalamus and infundibular stalk. The median eminence is the thickening in the hypothalamus on the floor of the third ventricle.

infarctions. Recent studies employing magnetic resonance imaging (MRI) and CT scanning have attempted to identify complexes of neurologic signs and symptoms that occur with damage to specific vessels supplying the diencephalon (Bogousslavsky et al., 1988;Kawahara et al., 1986;Graff-Radford et al., 1984;Castaigne et al., 1981;Walshe et al., 1977). Although there are signs and symptoms that can be associated with specific vascular territories, only a few can be associated with specific thalamic nuclei or fiber tracts. Where they are known, an attempt will be made to include relevant comments on deficits of each thalamic nucleus or structure. A summary of vascular territories and the neurologic sequelae associated with damage in these territories will be included with the section on blood supply.

Atlas Plate 20



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The dorsal portion of this section passes through the caudal thalamus; the ventral portion passes through the midbrain and an extreme rostral edge of the pons. The pontine and midbrain structures were discussed in Chapters 4 and 6, respectively. Characteristic of sections through the caudal thalamus is the large, pillowlike profile of the dorsally positioned pulvinar, a thalamic nucleus.

PINEAL

The pineal gland lies in a matrix of arachnoid tissue, straddling the caudal end of the third ventricle between the two masses of the pulvinar. It is also directly anteroinferior to the great vein of Galen. Rostrally, it is attached to the habenular nucleus of the thalamus by two peduncles, or stalks; caudally, the body of the pineal overlies the superior colliculus. The gland is composed of pinealocytes supported by a meshwork of neuroglia and is involved in the production of melatonin.

Although the pineal gland is not directly connected to the central nervous system by fiber tracts, it does receive sympathetic autonomic innervation from the hypothalamus via thoracic spinal cord and superior cervical ganglion. The portion of the hypothalamus involved in this circuit receives projections from the retina. The pineal nerves, which hitchhike on the internal carotid and its branches, are called the nervi conarii (Erlich and Apuzzo, 1985), in reference to the original name for the pineal, konareion ("cone-shaped"). Through this innervation the pineal receives a signal indicating the presence or absence of light. Sympathetic output is stimulated by darkness and increases the production and release of melatonin from the gland. This mechanism allows the pineal, through its periodic release of melatonin, to act as a circadian clock (Erlich and Apuzzo, 1985).

Melatonin has been demonstrated to have an antigonadotrophic effect. In humans, circulating levels of melatonin fall with puberty. This hormone is also suspected of influencing the activity of the thyroid and adrenal glands, but the mechanism appears quite complex (Erlich and Apuzzo, 1985). A link between pineal dysfunction, abnormal secretion of corticotropin, and major depressive disorders has also been proposed (Wetterberg, 1983).

CLINICAL DISCUSSION: Removal of the pineal gland is compatible with human life; however, its removal in prepubescent males can result in precocious puberty. The major neurologic significance of the pineal arises when tumors cause expansion of the gland and compression of the tectal plate and underlying midbrain tegmentum. This presents as loss of conjugate vision and vertical gaze paresis (Parinaud syndrome; see Chap. 7). Low levels of melatonin, measured nocturnally, were found in patients suffering from Cushing disease and from major depressive disorders. In manic-depressive patients who were supersensitive to light, higher than normal amounts of melatonin have been reported to be present (Wetterberg, 1983). These observations point to a relationship between melatonin and the release of corticotrophin-releasing factor that can significantly influence endocrinologic and neuropsychological activity.

PULVINAR NUCLEUS (PulNu)

The pulvinar nucleus (PulNu) is the largest of the thalamic nuclei. It is associated with the lateral posterior nucleus in the caudal portion of the thalamus and has reciprocal connections with areas of cerebral cortex located around the parieto-occipito-temporal junction, called the posterior parietal association cortex. It also has well-developed connections with portions of the occipital cortex.

The pulvinar contains representations of the contralateral visual hemispheres; thus, the nucleus is considered part of the extrageniculate visual system in the thalamus, even though it does not receive direct projections from the retina (Ohye, 1990). It has been suggested that the pulvinar is involved in providing the appropriate amount of cortical attention for language-related tasks on the dominant side and for mechanicospatial tasks on the nondominant side of the brain (Masdeu and Brazis, 1996).

CLINICAL DISCUSSION: Deficits expressed following lesions in the vicinity of the lateroposterior/pulvinar complex show a strong preference for laterality. Small hemorrhagic lesions on the nondominant side present with disturbances of topographic memory, constructional apraxia (Kawahara et al., 1986;Masdeu and Brazis, 1996), and visual neglect (Masdeu and Brazis, 1996). Lesions on the dominant side present with a speech deficit called thalamic aphasia; it is similar in composition to a mixed transcortical aphasia (Kawahara et al., 1986;Masdeu and Brazis, 1996).

LATERAL GENICULATE NUCLEUS (LGNU)

The thalamic relay for the visual system is the lateral geniculate nucleus (LGNu). It consists of multiple layers of cells and fibers wrapped in a dense capsule of efferent axons called the optic radiations. The major afferent projections to the lateral geniculate arise from retinal ganglion cells via the optic nerve and tract. In addition, the nucleus receives projections from the occipital (visual) cortex via the internal capsule. Since the lateral geniculate is distal to the optic chiasm in the ascending visual pathway, it contains a representation of contralateral visual space (Barr and Kiernan, 1993). The superior portion of the retina is represented in the superomedial part of the geniculate; the inferior portion of the retina is represented in the inferolateral part of the nucleus.

CLINICAL DISCUSSION: Destruction of the lateral geniculate, optic tract, or optic radiations results in the loss of the contralateral visual hemisphere, called hemianopsia. Complete destruction of the nucleus results in dense hemianopsia without the macular sparing that is seen even in large lesions of visual cortex (Barr and Kiernan, 1993).

The anterior choroidal artery supplies portions of the lateral geniculate nucleus. Occlusion of this artery can result in contralateral loss of the superior and inferior visual fields with sparing of a narrow, horizontal, central stripe (Masdeu, 1996a). The reduction of the visual field into a horizontal visual stripe is pathognomonic for lesions of the lateral geniculate.

OPTIC RADIATIONS (OpRad)

The thalamocortical axons from the lateral geniculate form a dense capsule of fibers as they leave the nucleus. Once in the posterior limb of the internal capsule they pass first superiorly and then posteriorly around the inferior horn of the lateral ventricle en route to the occipital (visual) cortex.

The curved pathway of the optic radiations (OpRad) is referred to as Meyer's loop. The fibers representing the superior visual fields pass into the temporal lobe, whereas those representing the inferior visual fields pass deep to the parietal lobe.

CLINICAL DISCUSSION: After leaving the area of the nucleus, the optic radiations fan out to sweep around the border of the temporal and parietal lobes. Here it is possible to achieve partial lesions of the tract. Such lesions present as quadrantanopsia, or "visual field cuts," in the contralateral visual hemisphere (Barr and Kiernan, 1993). Loss in the superior visual field therefore suggests damage to the temporal lobe or inferior lip of calcarine cortex; loss in the inferior visual field suggests damage to the parietal lobe (Masdeu, 1996a). Complete section of the optic radiations should be similar to a lesion of the lateral geniculate: loss of vision from the contralateral hemisphere, or hemianopsia.

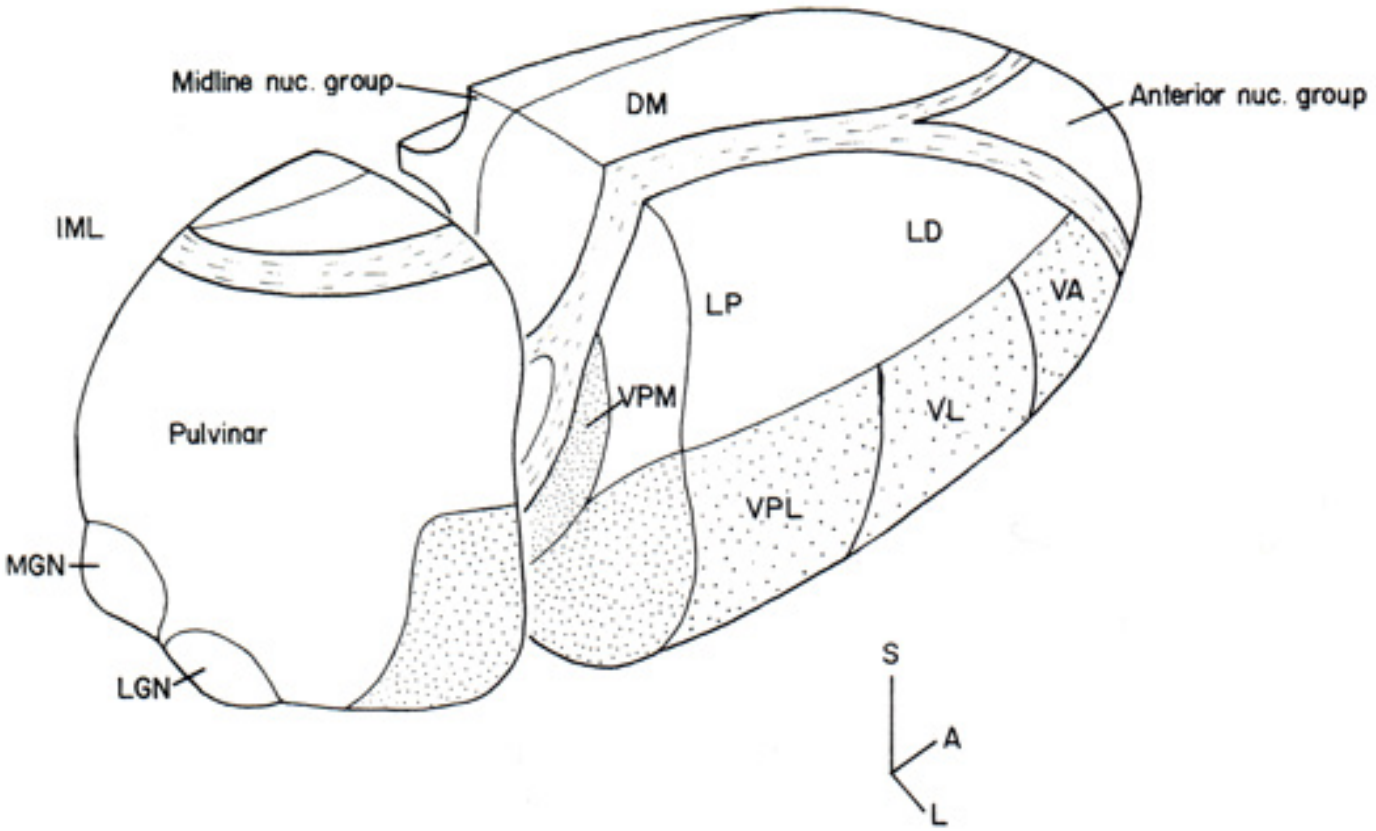


Figure 8-6. View of the thalamus partitioned into its nuclear groups. The internal medullary lamina forms the boundary separating the ventral and posterior groups from the medial, lateral, and anterior groups. (DM, dorsomedial nucleus; IML, intramedullary lamina; LD, lateral dorsal nucleus; LP, lateral posterior nucleus; MGN, medial geniculate nucleus; LGN, lateral geniculate nucleus; VPM ventroposteromedial nucleus; VPL, ventroposterolateral nucleus; VA, ventroanterior nucleus; VLS, ventrolateral superior; L, lateral; A, anterior)

The posterior cerebral artery (PCA) supplies the portion of the temporal lobe containing Meyer's loop, thus PCA infarctions can result in a superior quadrantanopia. Conversely, the middle cerebral artery (MCA) supplies that portion of Meyer's loop passing through the parietal lobe. Thus, infarctions of MCA can result in an inferior quadrantanopia.

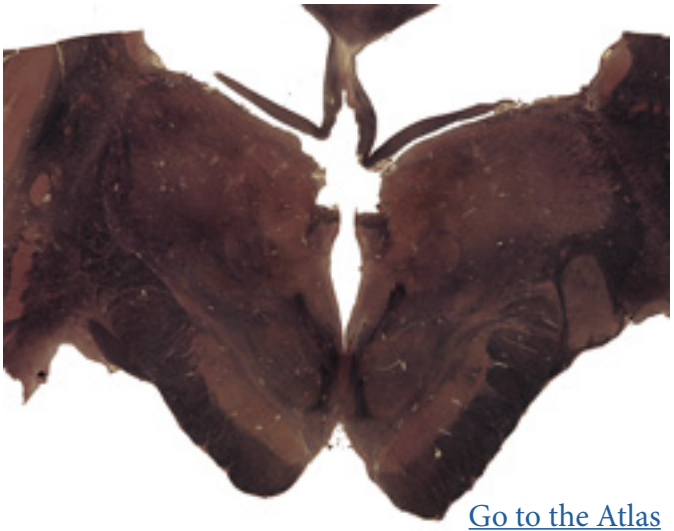
MEDIAL GENICULATE NUCLEUS (MGNu)

The medial geniculate nucleus (MGNu) is a complex cluster of cells on the caudal border of the thalamus, positioned medial to the lateral geniculate (Winer, 1984). The ascending auditory pathways from the inferior colliculus relay through the medial geniculate nucleus en route to the ipsilateral cerebral cortex. This nucleus is located in a fiber capsule on the caudal end of the thalamus, lateral to the superior colliculus and ventral to the pulvinar. The fiber capsule is composed of ascending afferent fibers from the brachium of the inferior colliculus and efferent fibers forming the auditory radiations to temporal (auditory) cortex.

The auditory cortex is not an exclusive target of the medial geniculate nucleus; it also has projections to limbic system structures such as the amygdala. These limbic connections of the thalamic auditory nuclei have been implicated in the reflex pathways relating acoustic stimuli to specific autonomic functions such as heart rate (Jarrell et al., 1986).

CLINICAL DISCUSSION: Very little is written concerning lesions of the medial geniculate nucleus in humans. Since the auditory system has bilateral representation above the trapezoid body, the loss in hearing after unilateral lesions will not be as profound as that of visual losses following thalamic lesions. Bilateral lesions of the human thalamus, which did not appear to involve the cortex, resulted in an auditory agnosia for nonverbal sounds (Motomura et al., 1986). However, this defect may result more from cortical hypofunction resulting from loss of thalamic input than from thalamic damage. Lesions of the medial geniculate nucleus or its afferent or efferent fiber systems in cats result in diminished hearing functions in the contralateral auditory hemisphere (Jenkins and Masterton, 1982).

Atlas Plate 21



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The dorsal portion of this section passes through the caudal thalamus, above the level of the hypothalamus; the ventral portion of the section passes through the rostral midbrain. The midbrain structures on this section have been presented in Chapter 6. A characteristic feature of this section is the encapsulated lateral geniculate nucleus.

STRIA MEDULLARIS (StMed)

The stria medullaris (StMed) courses from septal nuclei to habenular nuclei, forming a prominent landmark positioned along the dorsomedial border of the thalamus (see Plates 21 to 25). It is part of the pathway for limbic system information moving from the septal area to the brain stem and spinal cord (see Chap. 9).

HABENULAR NUCLEUS (Hab)

The habenular nucleus (Hab) is located on the dorsomedial boundary of the caudal thalamus. It receives afferent projections from the septal nuclei via the stria medullaris and projects to the interpeduncular nuclei over a descending pathway termed the fasciculus retroflexus or the habenulointerpeduncular tract. Thus, the habenula forms a relay station in the flow of limbic system information from the septal area to the brain stem and spinal cord (see Chap. 9).

HABENULOPEDUNCULAR TRACT (HPTr)

Projections from the habenular nucleus reach the interpeduncular nucleus of the midbrain by passing over the habenulopeduncular tract (HPTr). This tract is also known as the fasciculus retroflexus. The pathway involving the stria medullaris, habenular nuclei, habenulointerpeduncular tract, and interpeduncular nuclei represents a route over which olfactory information from the limbic forebrain can gain access to the nuclei of the brain stem.

VENTROPOSTERIOR NUCLEI (VPL and VPM)

The ventroposterior nuclei (VPL and VPM) are the major somatic sensory nuclei in the thalamus. They represent an elongated structure which is tipped onto a diagonal line coursing from superolateral to inferomedial, and is divided into lateral and medial nuclei (Figure 7-3). The lateral nucleus of this complex receives fibers from the medial lemniscus (contralateral body representation; Figure 7-4), whereas the medial portion receives fibers from the trigeminothalamic tracts (contralateral head representation). The edges of the nuclei receive fibers from the anterolateral system.

The ventroposterior nuclei project to the ipsilateral somatic sensory cortex of the postcentral gyrus in a topographic manner. The ventroposterior lateral nucleus (body representation) projects medially; the ventroposterior medial (face representation) projects laterally, thus establishing the homunculus in somatic sensory cortex. These two nuclei form an important link in the transfer of somatic sensory information from spinal cord and brain stem to the cerebral cortex.

CLINICAL DISCUSSION: Small lesions, restricted to the ventroposterior nuclear group, can present with a pure somatic sensory loss from portions of the contralateral face and body (Fisher, 1978;Caplan, 1988). Larger lesions can present with a feeling of numbness across the contralateral extremities and down the torso, maintaining a sharp demarcation at the midline (Masdeu and Brazis, 1996). This vertical border of sensory loss along the midline

is characteristic of lesions in the somatic sensory portion of thalamus.

Lesions in the area of the ventroposterior nuclei and pulvinar complex can also present as dysesthesia (Graff-Radford et al., 1984). Numbness and tingling are perceptions commonly encountered with lesions of the area of the ventroposterior nuclei (Bogousslavsky et al., 1988;Caplan, 1988). In cases where large lesions destroy the ventroanterior and ventrolateral nuclei as well, the dysesthesia can take the form of severe, burning pain, the Dejerine-Roussy syndrome of thalamic pain (Caplan, 1988). The medial and lateral nuclei of the ventroposterior complex have different blood supplies. The medial nucleus (face representation) lies in the midline vascular territory, while the lateral nucleus (body representation) lies in the posterolateral territory. Consequently, infarctions restricted to a specific vascular territory can result in sensory dissociation between the face and body.

MEDIAL LEMNISCUS (ML)

The medial lemniscus (ML) arises in the contralateral dorsal column nuclei (see Chap. 4). Its fibers represent the sensory modalities of discriminative touch, vibratory sense, and proprioception. Axons from the medial lemniscus terminate in the ventroposterior lateral nucleus (Figure 8-7). As it enters the nucleus, the homunculus (fiber topography) is arranged with its feet positioned laterally and its arms positioned medially.

CLINICAL DISCUSSION: Damage to the medial lemniscus will produce hemisensory loss on the contralateral side of the body. The modalities lost are proprioception, two-point discriminative touch, and vibratory sense.

CENTROMEDIAN NUCLEUS (CM)

The centromedian nucleus (CM)—a large, spherical mass—is located in the posterior portion of the thalamus and is surrounded by a capsule of fibers called the internal medullary lamina (Figure 8-6). The centromedian nucleus receives connections from the forebrain, globus pallidus, ventrolateral thalamic nucleus, and mesencephalic reticular formation. Its axons project to prefrontal cortex, ventrolateral nucleus, putamen, and caudate. Most of these

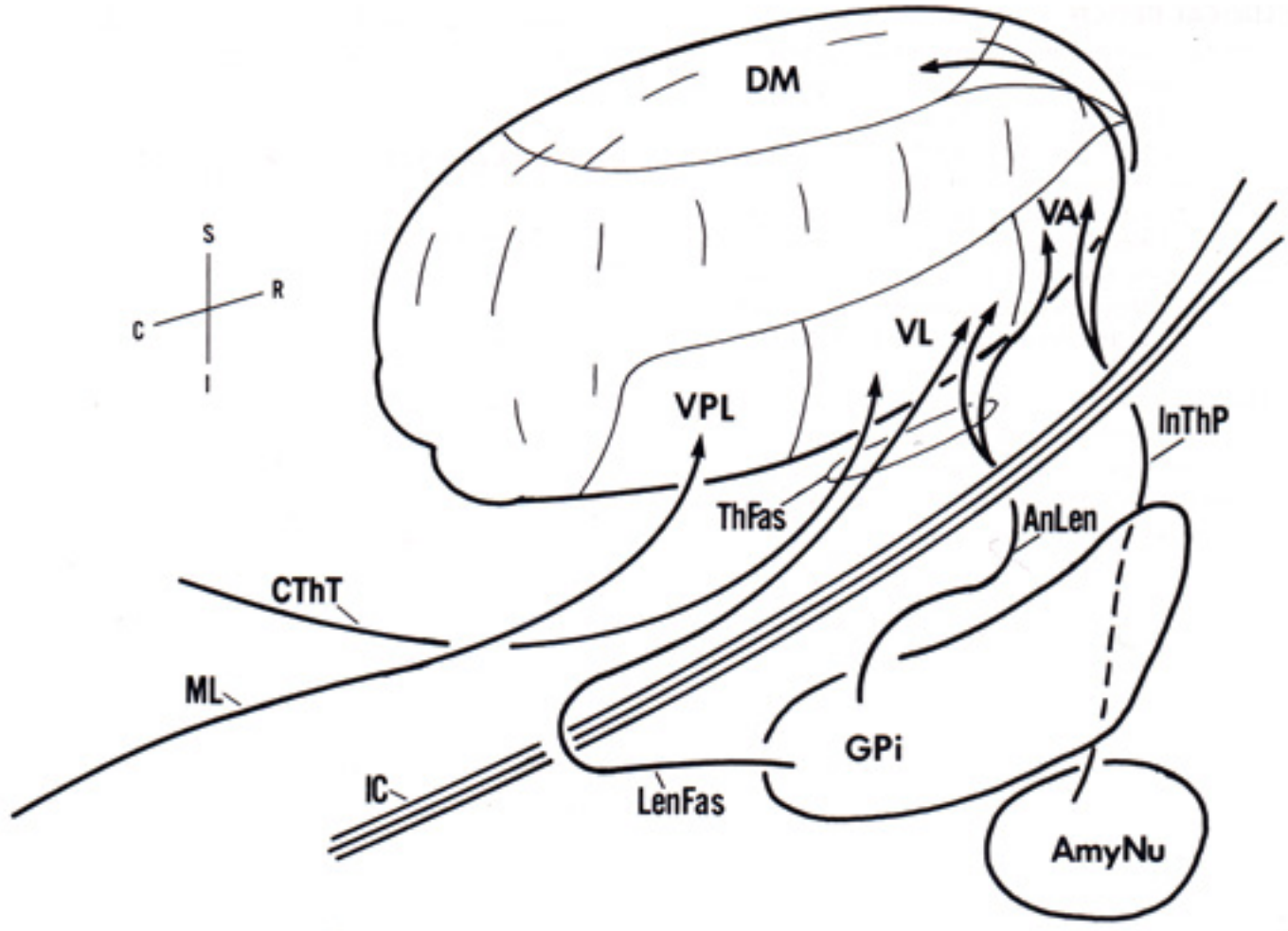


Figure 8-7. Diagram illustrating the major inputs to the ventral group of thalamic nuclei. The thalamic mass is depicted in the same profile as that seen in Figure 8-3. The major input pathways are illustrated with lines and arrows. (AmyNu, amygdaloid nucleus; AnLen, ansa lenticularis; C, caudal; CThT, cerebellothalamic tract; DM, dorsomedial nucleus; GPi, internal segment of globus pallidus; I, inferior; IC, internal capsule; InThP, inferior thalamic peduncle; LenFas, lenticular fasciculus; ML, medial lemniscus; R, rostral; S, superior; ThFas, thalamic fasciculus; VA, ventroanterior nucleus; VL, ventrolateral nucleus; VPL, ventroposterolateral nucleus)

connections suggest a role for the centromedian nucleus in the motor system. The input from the midbrain is part of the reticular activating system and plays a role in preparing the aroused individual for making a motor response to a specific sensory stimulus (Watson et al., 1981).

The exact role played by the centromedian nucleus in thalamic processing is not at all clear, and studies in humans using the lesion method of analysis are confounded by its adjacent structures. The internal medullary lamina, which surrounds the centromedian nucleus, receives projections from the anterolateral system and from the midbrain reticular activating system. Lesions in this area of the thalamus can result in analgesia and a neglect syndrome. However, it is possible that neither of these two syndromes arises from the centromedian nucleus but is related instead to its surrounding fiber systems.

CLINICAL DISCUSSION: Unilateral lesions of the centromedian nucleus and adjacent internal medullary lamina can cause contralateral thalamic neglect. The patient does not attend to all objects on the contralateral side of the body and is hypokinetic in both limbs in response to stimuli from the affected side. However, the limbs are not paralyzed, since they respond to stimuli from the ipsilateral side of the body. Bilateral lesions of the centromedian complex/internal medullary lamina result in bilateral neglect, considered a form of akinetic mutism (Watson and Heilman, 1979).

Lesions of the area including the centromedian nucleus, posterior internal medullary laminae, and rostral end of the midbrain have produced unarousable sleep (Graff-Radford et al., 1984). This may be due to damage of fibers in the ascending reticular activating system that pass through the internal medullary lamina.

Stereotaxic lesions in the area of the centromedian nucleus have been used to counter intractable thalamic pain; however, it is unclear that this nucleus actually plays a role in pain processing. These lesions may be affecting the anterolateral tract fibers that pass close to the nucleus, or they may be producing a form of neglect (Ohye, 1990).

DORSOMEDIAL NUCLEUS (DMNu)

The dorsomedial nucleus (DMNu) is a large mass of cells lying along the dorsal and medial border of the thalamus (Figure 8-6). It is bounded laterally by the internal medullary lamina and medially by the third ventricle. This nucleus is divided into several components, one of which has extensive reciprocal connections with the prefrontal cortex. The other portions of the nucleus are connected to the amygdala and olfactory cortex through the inferior thalamic peduncle as well as to the substantia nigra. Based on its connections, it has been suggested that the dorsomedial nucleus integrates somatic and visceral information and is involved in maintaining consciousness. When an analysis of lesion data is considered, it appears that the dorsomedial nucleus is also involved in the thalamic pathways related to memory processing and in the mainten-ance of cognitive functions (Masdeu and Brazis, 1996).

CLINICAL DISCUSSION: Destruction of the dorsomedial nucleus or the surrounding area can result in various neuropsychological dysfunctions (Bogousslavsky et al., 1988; Choi et al., 1983). This may take the form of dysfunctions in verbal memory (Squire and Moore, 1979) and topographic memory (Kawahara et al., 1986). Familial degeneration of the dorsomedial nucleus and anterior thalamic nuclei produced insomnia and dysautonomia in a patient (Lugaresi et al., 1986). Lesions of dorsomedial nucleus or its connections to the prefrontal cortex can present with components of the frontal lobe syndrome (Graff-Radford et al., 1984).

LATEROPOSTERIOR NUCLEUS (LP)

The lateroposterior nucleus is a member of the lateral nuclear group, which consists of the pulvinar, lateroposterior, and laterodorsal nuclei. The pulvinar is the most posterior of the three; rostrally, it is replaced by the lateroposterior nucleus (LP) and finally by the laterodorsal nucleus (Figure 8-3). Although its connections in humans are not well known, the lateroposterior nucleus in cats receives afferent fibers from the visual cortex and superior colliculus, thus creating multiple representations of the visual hemisphere. Its efferent connections go to the posterior parietal (association) cortex, and it has been suggested that the structure is involved in visuomotor activity.

CLINICAL DISCUSSION: Exact clinical deficits associated with lesions in the lateral posterior nucleus are unknown. Lesions in the lateral posterior-pulvinar complex result in disturbances of topographic memory and in constructional apraxia (Kawahara et al., 1986).

INTERNAL MEDULLARY LAMINA (IML)

The internal medullary lamina (IML) is a thin velum of cells and fibers that divides the ventral nuclear groups from the medial nuclear groups (dorsomedial nucleus) in the thalamus. Caudally, it surrounds the centromedian nucleus; rostrally, it encapsulates the anterior nuclei. Ascending fibers from the anterolateral system and the mesencephalic reticular formation terminate on cells in the internal medullary lamina. Cells in the internal medullary lamina provide a diffuse innervation of most regions of the ipsilateral cerebral cortex. Since these efferent fibers do not target discrete cortical areas, they are often referred to as nonspecific projections. The internal medullary lamina is involved in the transmission of pain and, through the reticular activating system, in maintenance of the arousal state in cerebral cortex.

CLINICAL DISCUSSION: Sleep dysfunctions and altered levels of consciousness are reported features of lesions in the internal medullary lamina or closely related nuclei (Castaigne et al., 1981; Graff-Radford et al., 1984). Stereotaxic lesions have been placed in the vicinity of the centromedian nucleus, a structure surrounded by the internal medullary lamina, to control intractable thalamic pain (Ohye, 1990).

EXTERNAL MEDULLARY LAMINA (EML)

A band of fibers, the external medullary lamina (EML) makes up the lateral border of the thalamus, separating the major thalamic nuclei from the thin reticular thalamic nucleus (see Plates 21 to 25). This lamina is composed of the thalamocortical and corticothalamic fibers passing in and out of the internal capsule.

THALAMIC RETICULAR NUCLEUS (ThRetNu)

The external medullary lamina forms a thin velum of fibers around the main body of the thalamus. The thalamic reticular nucleus

(ThRetNu) is a thin sheet of cells lying between the external medullary lamina and the internal capsule (see Plates 21 to 25). Although little is known of its organization in humans, in the cat this nucleus receives collateral axons from the corticothalamic and thalamocortical fibers. In turn, it projects to most thalamic nuclei (Steriade et al., 1984). Thus, the thalamic reticular nucleus could be acting as a gate, sampling the activity occurring between thalamus and cortex, and modulating the output of individual thalamic nuclei. It has also been proposed that the thalamic reticular nucleus plays a role in directing attention to novel stimuli and inhibiting attention to repetitive stimuli (Watson and Heilman, 1979).

SUBTHALAMIC NUCLEUS (SThNu)

The subthalamic nucleus (SThNu) is located along the medial side of the internal capsule at approximately the midbrain-thalamic junction. It receives fibers from the external segment of the ipsilateral globus pallidus and projects back to the internal segment of this same structure. Consequently, the subthalamic nucleus represents a station in the "indirect output pathway" for the basal ganglia (see Chap. 11). Its role in the motor system involves modulation of the activities of the internal segment of the globus pallidus. This later structure directly inhibits the ventrolateral and portions of the ventroanterior thalamic nuclei (Alexander and Crutcher, 1990). Through this mechanism, the subthalamic nucleus and basal ganglia play a significant role in controlling the thalamocortical circuitry and thus the output of the cerebral cortex.

CLINICAL DISCUSSION: Lesions of the subthalamic nucleus can result in a loss of excitation to the internal segment of the globus pallidus, which then fails to repress the ventrolateral and ventroanterior nuclei of the thalamus. The elevated output from these two thalamic nuclei to the premotor cerebral cortex results in increased output of motor patterns from the neocortex (DeLong, 1990). The patient experiences violent, uncontrollable, ballistic movements in the proximal muscles of the contralateral extremities.

CEREBELLOTHALAMIC TRACT (CThT)

The thalamic fasciculus (ThFas, see Plate 22) is composed of axons from the dentate nucleus (cerebellothalamic fibers [CThT]) and from the globus pallidus (pallidothalamic fibers). The cerebellothalamic fibers are in Plate 21 and in Figure 8-7. These axons originate in the dentate and interpositus nuclei of the contralateral cerebellum. They cross the midline in the decussation of the superior cerebellar peduncle, pass around the red nucleus, and terminate in the ventrolateral nucleus of the thalamus. On Plate 21, the cerebellothalamic fibers are seen as they encapsulate the red nucleus. The pallidothalamic fibers are present on Plates 22 to 25 (ansa lenticularis and lenticular fasciculus).

CLINICAL DISCUSSION: Lesion of the cerebellothalamic fibers is similar to section of the superior cerebellar peduncle and can present with ataxia and dysmetria in the contralateral limb (Caplan, 1988). If the lesion is superior to the decussation of the dentothalamic fibers in the midbrain, the presentation is on the contralateral side of the body.

BODY OF THE FORNIX

The fornix is a major efferent pathway of the hippocampus. Arising from the dorsal surface of the hippocampus, its body passes over the caudal thalamus, and its columns descend through the rostral thalamus to terminate in the hypothalamus and septal area. The body of the fornix is present in Plate 21. It will be discussed further in Chapter 9.

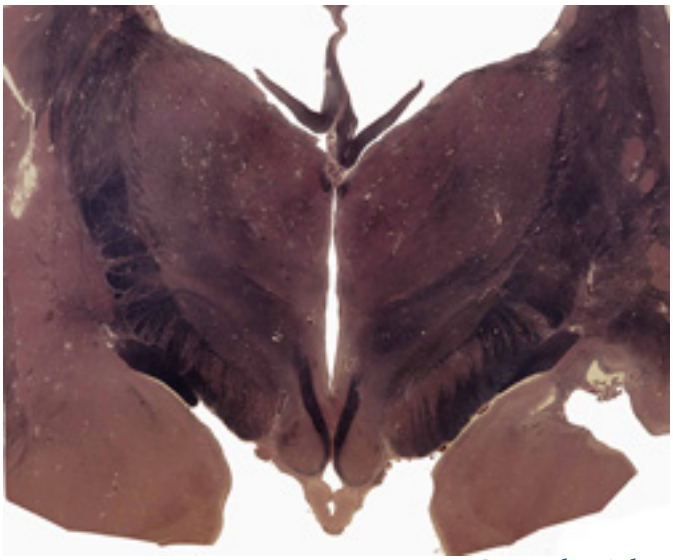
CLINICAL DISCUSSION: Lesions of the fornix, interrupting the hippocampal-hypothalamic connections, have been associated with amnesia (Grafman et al., 1985).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

1. Lateral geniculate nucleus (LGNu)
2. Optic radiations (OpRad)
3. Optic tract (OpTr)
4. Pulvinar nucleus (PulNu)

Atlas Plate 22



Go to the Atlas

The dorsal portion of this section passes through the center of the thalamus; the ventral portion lies on the caudal border of the hypothalamus. A salient feature of Plate 22 is the mammillothalamic tract that wraps around the medial border of the mammillary nuclei.

VENTROLATERAL NUCLEUS (VL)

The ventral group of nuclei extends along the entire posterior to anterior axis of the thalamus (Figure 8-6). This group contains the ventroposterior, ventrolateral, and ventroanterior nuclei. The ventrolateral nucleus (VL) lies anterior to the ventroposterior nuclei. It receives afferent fibers from the contralateral dentate nucleus in the cerebellum (Figure 8-7) and from the ipsilateral globus pallidus of the basal ganglia. These two projections end in separate regions of the ventrolateral nucleus; those from the cerebellum are more posterior than those from the basal ganglia (Thach et al., 1992). A somatotopic representation of the body is present in the ventrolateral nucleus and is in register with that found in the adjacent ventroposterior nucleus (Thach et al., 1992). The ventrolateral nucleus

projects to the ipsilateral primary motor cortex. Its output is excitatory, and at least that from the portion of the nucleus receiving the pallidothalamic fibers most likely sets the level of neural activity in motor cortex, thus influencing the tonic activity of muscles through the output of motor cortex.

CLINICAL DISCUSSION: Large lesions in the vicinity of the ventrolateral nucleus can produce hemiplegia; however this most likely reflects the involvement of the corticospinal fibers in the internal capsule. Pure lesions of the ventrolateral nucleus can result in hypotonia, diminished emotional expression, and a neglect that is transitory (Masdeu and Brazis, 1996).

Loss of cerebellar input (dentothalamic tract) to the ventrolateral nucleus can present as contralateral limb hemiataxia. Lesions in the inhibitory input from the basal ganglia (pallidothalamic tract) that spare the internal capsule can induce unwanted motion (i.e. the choreiform or athetotic movements). Conversely, stereotaxic lesions of the nucleus have been used to block uncontrolled movements and tremor (Bullard and Nashold, 1984).

Language dysfunctions, usually transient, have also been associated with lesions in the ventrolateral thalamus (Masdeu and Brazis, 1996;Graff-Radford et al., 1984). These dysfunctions are characterized by reduced spontaneous speech, paraphasic errors, perseveration, and reduced comprehension in the face of preserved repetition. A small lesion in the ventrolateral nucleus along its border with the lateral-posterior nuclear group has presented with astasia (Masdeu and Gorelick, 1988).

THALAMIC FASCICULUS (ThFas)

In this section, the ascending cerebellothalamic fibers are joined by axons from the ipsilateral globus pallidus (pallidothalamic fibers) traveling in the lenticular fasciculus; the combined fiber bundle is called the thalamic fasciculus (ThFas). The cerebellothalamic fibers terminate in the caudal portion of the ventrolateral nucleus; the pallidothalamic fibers terminate in the rostral portions of the nucleus as well as in the ventroanterior nucleus (Figure 8-7).

CLINICAL DISCUSSION: Lesions of the thalamic fasciculus can result in cerebellar ataxia and dysmetria of the contralateral extremities due to damage to the cerebellothalamic fibers, and sudden, unexpected, chorea-like or dystonic movements of the contralateral limbs caused by loss of the pallidothalamic fibers (Caplan, 1988).

ZONA INCERTA (Zi)

The zona incerta (Zi) is a narrow strip of cells wedged between the thalamic fasciculus dorsally and the lenticular fasciculus ventrally. It receives fibers from ipsilateral motor cortex and projects to the red nucleus and superior colliculus. Its function in clinical neurology are poorly understood.

LENTICULAR FASCICULUS (LenFas)

Fibers from the globus pallidus (pallidothalamic fibers) traveling to the rostral portion of the ventrolateral nucleus pass through the internal capsule to enter the thalamus as the lenticular fasciculus (LenFas). Once in the thalamus, this fasciculus joins with the ascending cerebellothalamic fibers to form the thalamic fasciculus (Figure 8-7).

CLINICAL DISCUSSION: Lesions of the lenticular fasciculus can result in sudden, unexpected, chorealike, or dystonic movements of the contralateral limbs (Caplan, 1988). This expression of unwanted motion most likely comes from the loss of inhibition, which the pallidothalamic fibers usually place on the ventrolateral nucleus (see Chap. 11).

MAMMILLARY BODY (MB)

The posterior end of the hypothalamus contains a prominent external structure, the mammillary body (MB). Each body is partitioned into several nuclei. This structure is integrated into the limbic circuit, receiving projections from the hippocampus and septal area via the fornix, and sending efferent projections to the anterior thalamic nuclei (which then project to cingulate cortex). This circuitry is involved in processing memory and in learning.

CLINICAL DISCUSSION: Neurodegenerative changes in the mammillary nuclei are prominent in chronic alcoholism. This observation has led to the theory that destruction of the mammillary nuclei is involved in the diencephalic amnesia associated with chronic alcoholism. However, the dorsomedial nuclei also exhibit necrosis with prolonged alcohol abuse (Mair et al., 1979), and recent evidence has suggested that lesions of the dorsomedial thalamic nuclei alone can produce a severe memory impairment (Squire and Moore, 1979). Controlled lesions of the mammillary nuclei in primates has resulted in a form of spatial memory impairment, not the global diencephalic amnesia of alcoholics (Aggleton and Mishkin, 1985). Thus, it appears that necrosis of the mammillary nuclei, while contributing to the overall amnesic syndrome in alcoholics, is not responsible for the amnesia of alcoholism in its entirely.

MAMMILLOTHALAMIC TRACT (MTTr)

The projection from the mammillary nuclei to the thalamus is the mammillothalamic fasciculus (MTTr). This prominent fiber bundle can be seen passing rostrally and dorsally from the mammillary nuclei to the base of the fiber capsule surrounding the anterior thalamic nucleus (see Plate 25).

CLINICAL DISCUSSION: Lesions of this tract or its surrounding territory can present with amnesia (von Cramon et al., 1985; Graff-Radford et al., 1990).

POSTERIOR HYPOTHALAMUS (PHyTh)

Surrounding the mammillary bodies are the nuclei of the posterior hypothalamus (PHyTh). This diffuse mass of neurons has descending projections onto the autonomic nuclei of the brain stem and spinal cord and is involved in controlling activity of the sympathetic nervous system.

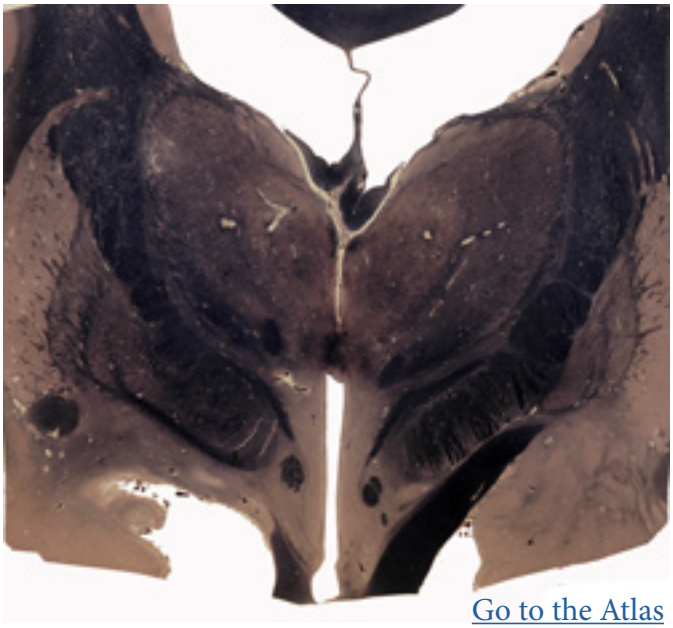
CLINICAL DISCUSSION: Lesions in the posterior hypothalamus can disrupt autonomic regulation. Symptoms that have been reported are hypothermia ranging to poikilothermy and Horner syndrome. Apathy and hypersomnia or coma have also been noted in lesions of this area (Masdeu, 1996b).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

1. Stria medullaris (StMed)
2. Lateroposterior nucleus (LPNu)
3. Dorsomedial nucleus (DM)
4. Internal medullary lamina (IML)
5. External medullary lamina (EML)
6. Subthalamic nucleus (SThNu)
7. Fornix (Fx)
8. Thalamic reticular nucleus (ThRetNu)

Atlas Plate 23



Go to the Atlas

This section passes through the thalamus and hypothalamus. The mammillothalamic tract in the thalamus, the fornix in the hypothalamus, and the prominent optic tracts bordering the hypothalamus and cerebral peduncles represent its unique characteristics.

LATERAL DORSAL NUCLEUS (LD)

The lateral nuclear group is composed of three nuclei: lateral dorsal, lateral posterior, and pulvinar (Figure 8-6). The lateral dorsal nucleus (LD) is housed in a separate, myelinated fiber capsule along the dorsal surface of the thalamus. Projections to this nucleus arise in the hippocampus, pretectum, and lateral geniculate. In turn, the nucleus sends projections to the cingulate and parahippocampal gyrus. It has been suggested that the lateral dorsal nucleus is a gateway for visual sensory information reaching the limbic system (Thompson and Robertson, 1987). Specific clinical deficits have not been associated with damage affecting the the lateral dorsal nucleus.

MASSA INTERMEDIA (MI)

In approximately 80% of brains examined, the midline nuclear group is continuous with the opposite thalamus (mi, Figure 8-4). This continuity, composed of neurons and fibers, represents a bridge of gray matter; it is not a fiber tract.

ANSA LENTICULARIS (AnLen)

The ansa lenticularis (AnLen) is a fiber tract that passes out of the globus pallidus, ventral to the internal capsule, and curves dorsally to join the thalamic fasciculus, eventually terminating in the rostral portion of the ventrolateral nucleus and the ventroanterior nucleus of the thalamus (Figure 8-7). These pallidothalamic fibers are inhibitory in their actions on the thalamic neurons. The clinical deficits associated with interruption of the pallidothalamic fibers have been presented with the lenticular fasciculus.

LATERAL HYPOTHALAMIC AREA (LHyTh)

The lateral hypothalamic area (LHyTh) extends from the midbrain tegmentum to the preoptic area, situated lateral to the fornix. Distinct nuclear boundaries are difficult to locate in this zone of the hypothalamus. Stimulation of the lateral hypothalamic area can result in the desire to eat.

CLINICAL DISCUSSION: Lesions of the lateral hypothalamus can present with loss of appetite, emaciation, adipsia, and apathy (Masdeu, 1996b).

MEDIAL HYPOTHALAMUS (MHyTh)

The region medial to the fornix is the medial hypothalamus (MHyTh). Like the lateral hypothalamic area, it lacks distinct nuclear boundaries. The medial hypothalamic area contains a satiety center that, if lesioned, can result in obesity. Several of its nuclei also produce regulatory factors that function in controlling the pituitary gland.

CLINICAL DISCUSSION: Destruction of the medial hypothalamus can result in diabetes insipidus and hyperdipsia. Hyperphagia to the point of obesity can occur as well as the syndrome of inappropriate antidiuretic hormone release (SIADH) and dwarfism. Behavioral dysfunctions such as rage or amnesia can also occur with these lesions (Masdeu, 1996b).

OPTIC TRACT (OpTr)

The anterior boundary of the hypothalamus is the optic tract (OpTr). This tract contains the axons of the retinal ganglion cells.

CLINICAL DISCUSSION: Pressure on the optic tract, resulting from a mass expanding lesion in the hypothalamus, can result in visual field defects such as hemianopsia.

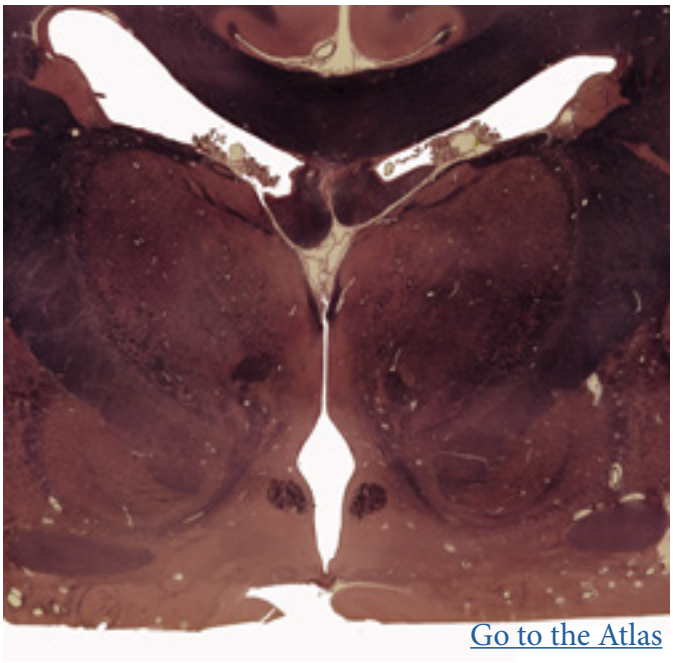
Review Structures From Preceding Plates

Identify the following structures from previous sections:

1. Stria Medullaris (StMed)
2. Thalamic reticular nucleus (ThRetNu)
3. External medullary lamina (EML)
4. Internal medullary lamina (IML)
5. Ventrolateral nucleus (VL)
6. Dorsomedial thalamus (DM)
7. Zona incerta (Zi)
8. Mamillothalamic tract (MTTr)

9. Thalamic fasciculus (ThFas)
10. Lenticular fasciculus (LenFas)
11. Fornix (Fx)

Atlas Plate 24



Go to the Atlas

The dorsal portion of this section passes through the thalamus; the ventral portion traverses the rostral border of the hypothalamus and preoptic area. The inferior thalamic peduncle and ansa lenticularis are seen entering the ventral aspect of the thalamus.

ANTERIOR HYPOTHALAMUS (AHyTh)

The anterior hypothalamus (AHyTh) is located rostrally in the hypothalamus. At the level of the optic chiasm it merges into the preoptic area. Cells in the anterior hypothalamic nucleus contain receptors for sex hormones and produce regulating factors for the anterior pituitary gland. Neural circuits that determine set points for the control of temperature in the body are also located in the anterior hypothalamus. This area is involved in control of the pituitary gland and of the parasympathetic nervous system.

CLINICAL DISCUSSION: Lesions of the anterior hypothalamus can result in hyperthermia. This alteration in temperature can be cyclic and accompanied by fever, shivering, and chills. Diabetes insipidus and insomnia can also present with lesions in this area (Masdeu, 1996b).

INFERIOR THALAMIC PEDUNCLE (InThP)

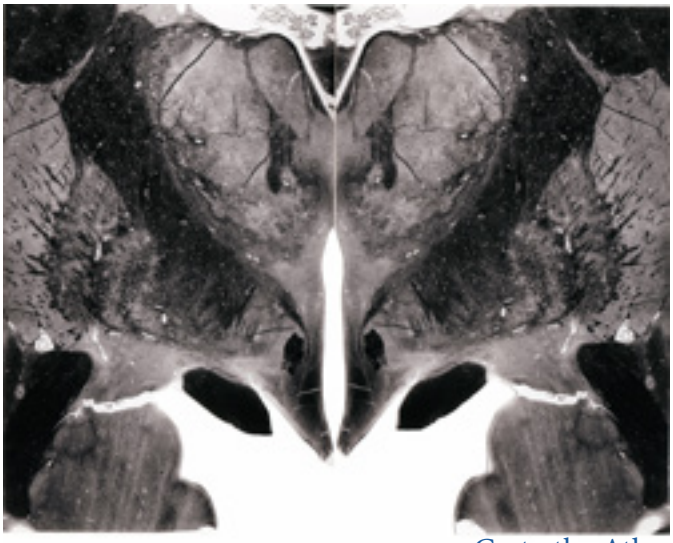
The inferior thalamic peduncle (InThP) enters the thalamus from the ventral surface and carries fibers from the orbitofrontal cortex, medial temporal cortex, and amygdala to the dorsomedial nucleus of the thalamus.

Review Structures From Preceding Plates

Identify the following structures from previous sections:

1. Stria medullaris (StMed)
2. Dorsomedial thalamic nucleus (DM)
3. Internal medullary lamina (IML)
4. Ventrolateral thalamic nucleus (VL)
5. Lateral dorsal thalamic nucleus (LD)
6. Ansa lenticularis (AnLen)
7. Fornix (Fx)
8. Lateral hypothalamic area (LHyTh)
9. External medullary lamina (EML)
10. Hypothalamus (HyTh)

Atlas Plate 25



Go to the Atlas

The superior (dorsal) portion of this section passes through the rostral pole of the thalamus; the inferior portion passes through the central portion of the hypothalamus. Its salient feature is the encapsulated anterior thalamic nucleus.

ANTERIOR THALAMIC NUCLEUS (AN)

The mammillothalamic tract rises out of the hypothalamus (see Plates 22 to 24) into the anterior portion of the thalamus, where it meets the internal medullary lamina. These two structures form a fibrous capsule surrounding the anterior thalamic nucleus (AN; Plate 25). The major afferent connections of this nucleus are the mammillothalamic tract and the cingulate gyrus of cortex; its efferent projections go to the cingulate gyrus. These projections are part of a major limbic circuit that extends from the hippocampus to mammillary bodies via fornix and from mammillary bodies through the anterior nucleus to the cingulate cortex (see Chapter 10). Given its involvement in this circuit, the anterior thalamic nucleus joins with the dorsomedial nucleus to form the limbic thalamus (Armstrong, 1990).

The functions of the anterior nucleus are not well known. It is associated with a limbic circuit thought to play a role in memory (Armstrong, 1990).

CLINICAL DISCUSSION: Surgical lesions of the anterior thalamic nuclei have been used to ameliorate agitation and anxiety; they induce some confusion in the patient, especially with relation to time, date, and place. Degeneration of the mammillary bodies, mammillothalamic tract, and, to a lesser extent, the anterior thalamic nucleus is seen in chronic alcoholism. This is accompanied by Korsakoff's psychosis, which features profound memory loss. It is not clear just how much of a role the thalamic nuclei play in this syndrome since surgical lesions directed at the anterior thalamic nucleus have not replicated the amnesia (Armstrong, 1990).

VENTROANTERIOR THALAMIC NUCLEUS (VA)

The ventroanterior nucleus (VA) is the rostral pole of the ventral group of thalamic nuclei (Figure 8-6) that includes ventroposterior (see Plate 21) and ventrolateral (see Plates 22 to 24) nuclei. Medially, the mammillothalamic tract and the anterior thalamic nucleus are bound the ventroanterior nucleus. The afferent projections to the ventroanterior nucleus arise in the internal segment of the globus pallidus (see Plates 22 to 24) and enter the thalamus through the lenticular fasciculus (see Plates 22 and 23) and the ansa lenticularis (see Plates 23 to 25). The ventroanterior nucleus projects axons to the premotor and supplementary motor portions of frontal cerebral cortex (see Chapter 9). Stimulation of the ventroanterior nucleus produces motor behavior that resembles the movements obtained from stimulation of the supplementary motor cortex (Ohye, 1990).

The ventroanterior nucleus participates in a looped circuit involving cerebral cortex, corpus striatum, globus pallidus, ventroanterior nucleus, and cerebral cortex. This circuit functions to set the scale of intensity in the motor system (Alexander and Crutcher, 1990) as well as in other systems (see Chapter 10). Unfortunately, little is known concerning lesions restricted to the ventroanterior nucleus (Ohye, 1990).

Review Structures From Preceding Plates

Identify the following structures from previous sections:

1. Stria medullaris (StMed)
2. Internal medullary lamina (IML)
3. Fornix (Fx)
4. Thalamic reticular nucleus (ThRetNu)
5. External medullary lamina (EML)
6. Mamillothalamic tract (MTTr)
7. Lenticular fasciculus (LenFas)
8. Ansa lenticularis (AnLen)
9. Hypothalamus (HyTh)
10. Optic tract (OpTr)
11. Stria terminalis (StTer)

Case Study 8-3

Chief Complaint
A 55-year-old man presents with left-sided sensory loss and athetotic movements

History of Chief Complaint
This 55-year-old man experienced a sudden onset of numbness in his left upper limb while eating supper. When it persisted, he consulted his family physician.

Medical History
At the time of examination he was unmarried and worked in a factory performing quality-control inspections. Both of his parents were alive, and he had lived with them all his life. He was diagnosed with myotonic dystrophy at 33 years of age; its course had been a slow, progressive increase in proximal muscle weakness since that time.

General Physical Examination
The patient was an awake and oriented male with significant muscle wasting, especially in the proximal limb muscles. His movements were punctuated by occasional tonic muscle contractions of considerable force. He appeared older than his stated age. The center of the lens in each eye was significantly grayed, obscuring observation of the optic discs. His blood pressure, respiration, and temperature were all within the normal ranges. His chest was clear to auscultation. The abdomen was soft with no tenderness. A reducible mass was present in the inguinal region on the right. The cataracts, myotonia, and proximal muscle weakness were of long duration.

Neurologic Examination
Mental Status. He was awake and oriented to time and place. Normal mental status was found on all tests except for a short-term visual memory deficit discovered during a neuropsychological examination at a later date; there was no significant amnesia or aphasia.

Cranial Nerves. Visual fields were full to confrontation (however, visual acuity was poor), a full range of eye movements was possible, and no nystagmus was present. Facial expression was full and smiling was symmetric. His hearing was normal in both ears. Jaw-jerk and corneal reflexes were physiologic. The palate was elevated on the midline and tongue protruded midline. Shoulder shrug was bilaterally symmetric. Swallowing and voice were normal.

Motor Systems. Extended periods of tonic muscle contractions followed some of his movements in all extremities; these lessened with repetitive motion. Muscle strength was diminished, with considerable wasting present in the proximal muscles of the shoulders and pelvis. His tendon reflexes were diminished but symmetric in all extremities, and plantar reflexes were flexor. His left hand exhibited movements of an athetoid character, but only when he closed his eyes.

Sensation. He had loss of sensation on the left side of his torso and face, and left extremities for pinprick, light touch, proprioception, vibration, two-point discrimination, graphesthesia, and stereognosis. There was an abrupt vertical boundary to the sensory loss along the midline of the torso. No hyperesthesia or dysesthesia was noted.

Follow-up
Examination five months following this incident found the dystonic character of his movements unchanged, and his strength remained diminished. The athetotic movements of the left hand still occurred when he closed his eyes, however the sensory losses on the left side of his body were no longer detectable.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level

defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

Case Study 8-4

Chief Complaint

A 78-year-old woman presents with confusion, memory dysfunction, and sleep disturbances.

History of Chief Complaint

This 78-year-old woman was brought to the emergency room from a local nursing home after she became very agitated and disoriented, alarming the other residents.

Medical History

At the time of admission she had been retired for 13 years from her position as an elementary schoolteacher. She had been married and her husband was deceased. She had no children. Five years previously she had moved from her house to a nursing home. Two years previously she had experienced a period of right facial weakness with language dysfunction, which had resolved over a 2-week period. Until the day of admittance she had been a pleasant person, sociable with other residents of the nursing home, and with good memory.

General Physical Examination

She was in an agitated state and uncooperative, making a detailed examination difficult. She was well nourished and well hydrated and appeared her stated age. She had increased pulse, respiration, and blood pressure (190/100 mmHg). She appeared flushed and her skin was moist.

Neurologic Examination

Mental Status. She was disoriented with respect to time and place. She insisted she was going shopping and that the driver had let her out at the hospital by mistake. She was aggravated and abusive with the attending personnel. She was a poor historian. At the time of admission she could not be tested for memory, since she refused to answer most questions.

Cranial Nerves. Visual fields appeared full to confrontation, a full range of eye movements was possible, and no nystagmus was present. Facial expression was full and hearing was normal. Jaw-jerk reflex was normal and corneal reflex was present. Palate was elevated on the midline and tongue protruded midline. Shoulder shrug was bilaterally symmetric. Swallowing and voice were normal.

Motor Systems. Movements were normal; strength and deep tendon reflexes were physiologic throughout the patient's body.

Sensation. Response to pinprick was normal; no detectable loss of proprioception was found. Testing was complicated by her uncooperative nature.

Follow-up

The patient esperienced insomniac for 3 days while under observation in the hospital. On discharge she was calm but had marked memory dysfunction and continued to confabulate explanations to cover the memory loss. One month after returning to the nursing home she developed marked hypersomnia and was difficult to rouse. She returned to the hospital where she died one week later.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

Thalamic Vascular Supply

The blood supply to the thalamus is complex and highly variable. It comes from numerous penetrating vessels that branch from the circle of Willis, closely related portions of the basilar artery, posterior cerebral artery, and middle cerebral artery. Rather than consideriing the distribution of each artery, it is more instructive to describe groups of arteries that supply a reasonably constant thalamic territory. Infarction within a vascular territory can be related to a reasonably specific constellation of neurologic signs and symptoms.

Although terminology varies, most clinical authors recognize three major thalamic territories that can be described by their related blood supply: midline or paramedian, anterolateral, and posterolateral (see Plates 20 to 25). Some authors describe an additional lateral thalamic-internal capsule territory (Graff-Radford et al., 1985).

Paramedian Group

The paramedian group is supplied by a tuft of small arteries that branch off of the top of the basilar and proximal cerebral arteries (PMbr in Figure 8-8A). They supply the midline of the diencephalon, being more prevalent posteriorly and diminishing in number anteriorly. In some cases many of the bilateral branches arise from a common stem at the top of the basilar artery. In such situations, a stem infarction can present with bilateral signs.

Anterolateral Group

The anterolateral group consists of the posterior communicating artery and its tuberothalamic branches (PComA and TuTh in Figure 8-8B). Small penetrating arteries from the posterior communicating artery supply a band of tissue along the lateral and anterior borders of the thalamus.

Posterolateral Group

The posterolateral group consists of several long, circum-ferential arteries, such as the posteromedial choroidal, that arise from the posterior cerebral artery (PMChA and PCA in Figure 8-8C). These circumferential arteries wrap around the cerebral peduncle, curve

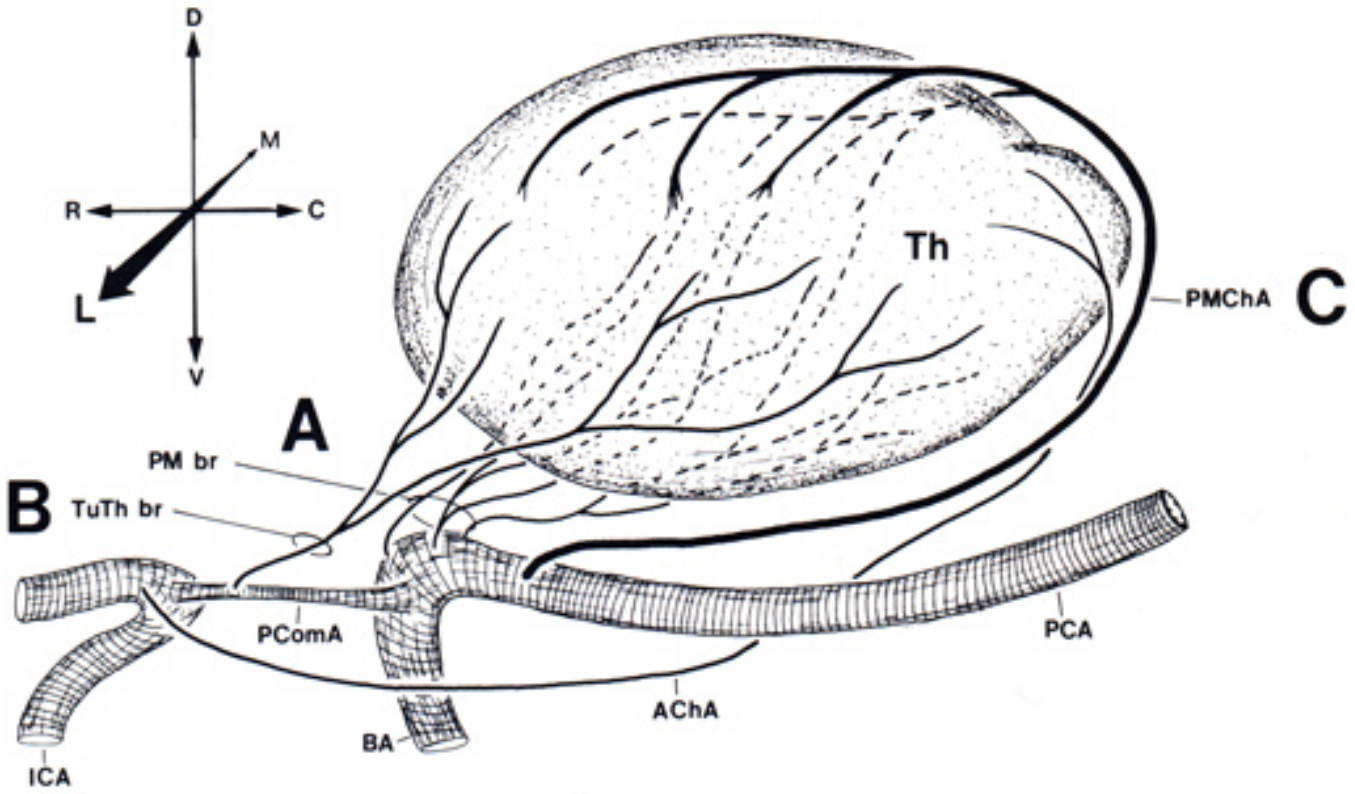


Figure 8-8. Arterial supply of the left thalamus. (AChA, anterior choroidal artery; BA, basilar artery; PCA, posterior cerebral artery; PComA, posterior communicating artery; PM br, paramedian branches; PMChA, posteromedial choroidal artery; Th, thalamic hemisphere; TuTh br, Tuberothalamic branches of the posterior communicating artery)

dorsally to arch over the posterior end of the thalamus, and finally course rostrally along the superior aspect of the thalamus, diminishing in prevalence from caudal to rostral. These vessels course in close association with the stria terminalis and stria medullaris; their penetrating branches enter the thalamic tissue from its superior surface.

Lateral Group

The lateral group consists of the anterior choroidal artery and its penetrating branches. The anterior choroidal arises from the internal carotid and passes posteriorly around the cerebral peduncle (AChA Figure 8-8). Penetrating branches from this artery perfuse a zone along the lateral border of the thalamus involving the posterior limb of the internal capsule and globus pallidus. The anterior choroidal terminates as small branches wrapping around the caudal border of the thalamus and perfusing portions of the lateral geniculate nucleus.

There is variation and considerable overlap in the distribution of cerebral arteries within the thalamus; thus, it is difficult to assign specific arteries to individual thalamic nuclei. However, general zones of the thalamus can be related to the vascular territory of specific groups of cerebral arteries. Constellations of neurologic signs and symptoms are associated with perfusion failure within

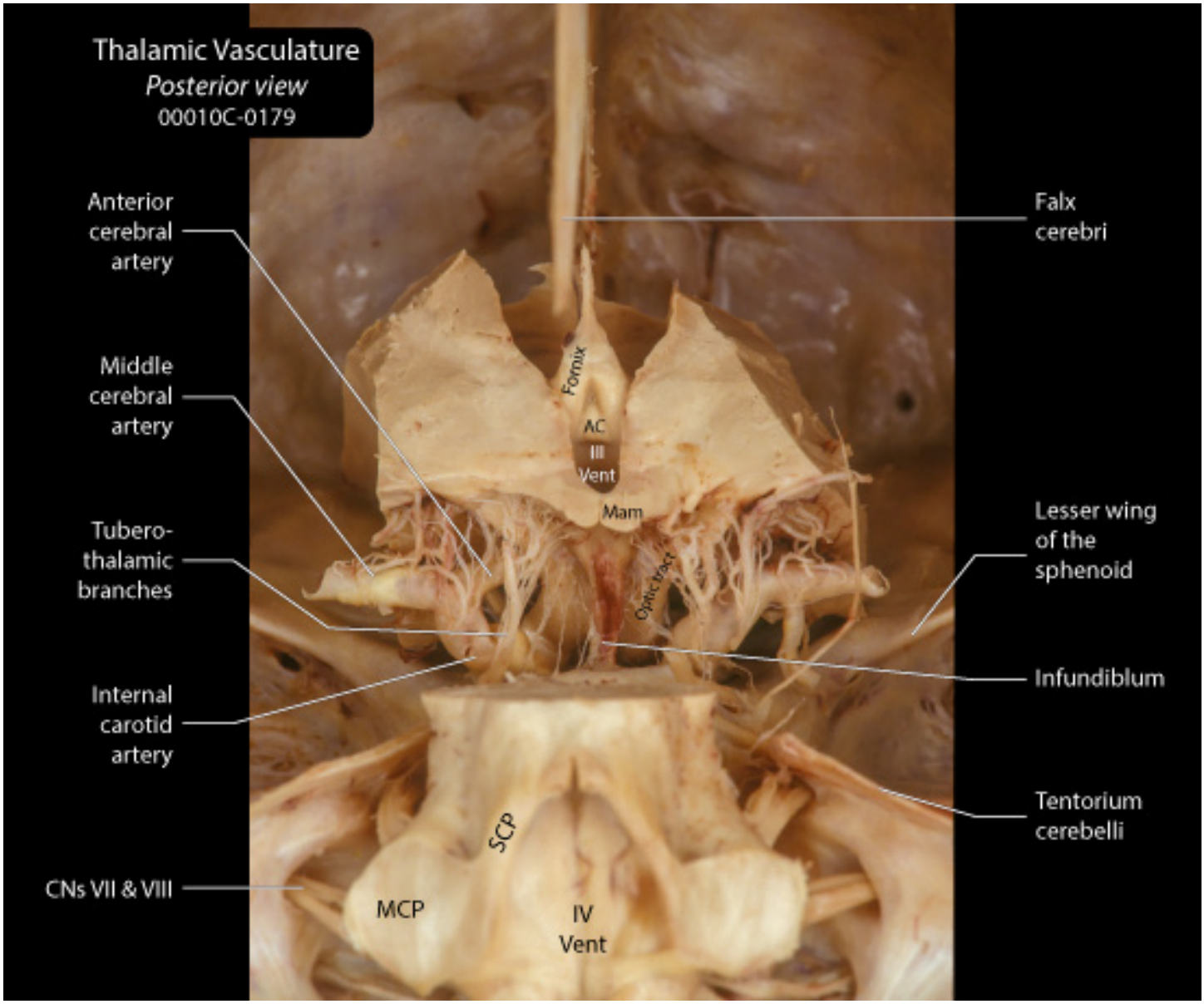


Figure 8-9. This is a posterior view into the cranium following the removal of the cerebral hemispheres and the cerebellar hemispheres. The brainstem was sectioned in the axial plane at the level of the caudal midbrain and the ventral forebrain was sectioned in the coronal plane at the level of the hypothalamus. The infundibular stalk is seen on the midline, is ruddy color due to the extreme vascularization of this structure. The internal carotid artery is seen dividing into middle and anterior cerebral arteries. The posterior communicating artery is out of view but its tuberothalamic branches can be visualized ascending into the ventral aspect of the thalamus.

these vascular territories (Kawahara et al., 1986;Graff-Radford et al., 1985;Percheron, 1973). The following is a compilation of vascular territories, their distribution within the thalamus, and the known neurologic sequelae caused by perfusion compromise.

Thalamic Vascular Syndromes

Midline Territory Syndrome

Arteries. The paramedian branches arise from the apex of the basilar artery or proximal portion of the posterior cerebral artery (other names for these branches include interpeduncular profundus artery, thalamoperforating artery, and thalamic-subthalamic artery)

Distribution. The midline territory is widest caudally and narrows to a point rostrally. It contains the midline nuclei, centromedian nucleus, dorsomedial nucleus, posterior portion of the internal medullary lamina, and rostral portion of ventrolateral nucleus, as well as subthalamic nucleus and rostral interstitial nucleus of the median longitudinal fasciculus.

Deficits. Coma or drowsiness, confusion, amnesia, confabulation, disorientation, hypersomnolence (bilateral lesions), cognitive impairment, gaze palsies, constructional apraxias and sometimes ataxia, and delayed movements (Graff-Radford et al., 1984;Caplan, 1988).

Anterolateral Territory Syndrome

Arteries. Tuberothalamic arteries branch from the posterior communicating artery (other names for these branches include polar artery, anterior optic artery, centralis anterolaterales artery, or premamillary pedicle).

Distribution. The anterolateral territory is a ventral wedge coursing from a lateral position in the caudal thalamus to a medial position in the rostral thalamus. Structures serviced by these vessels are the paraventricular nuclei; massa intermedia; ventrolateral and ventroanterior nuclei; portions of the thalamic reticular, dorsomedial, and posterior nuclear groups; mamillothalamic tract; and posterior limb of the internal capsule.

Deficits. Neuropsychological deficits in language, temporal orientation, intellect, memory (amnesias), and visual perception, as well as constructional apraxias, dysphasia (lesion on dominant side), neglect, and abulia (including facial paresis for emotion, and transient hemiparesis). Speech is characterized by reduced volume and quantity, paraphasic errors, and verbal perseveration (Bogousslavsky et al., 1988;Kawahara et al., 1986;Graff-Radford et al., 1984;Caplan, 1988;Gorelick et al., 1984;Mori et al., 1986).

Posterolateral Territory Syndrome

Arteries. Thalamogeniculate and posterior choroidal arteries that branch off the posterior cerebral artery (other names for these branches include thalamoperforating, posterior thalamic, or posteroinferior arteries).

Distribution. The posterolateral territory is a dorsal wedge extending from a lateral position caudally to a medial position rostrally. These vessels service the ventroposterior and portions of the ventrolateral nuclei, pulvinar and portions of the lateroposterior nuclear group, and make contributions to the centromedian nucleus.

Deficits. Hemibody sensory loss and paresthesia; hemianopsia; hemiparesis and choreiform or athetotic movements; astasia; visual memory and visual perceptual dysfunction (Bogousslavsky et al., 1988;Kawahara et al., 1986;Graff-Radford et al., 1984;Masdeu and Gorelick, 1988;Caplan et al., 1988).

Lateral Thalamic/Internal Capsule Zone Syndrome

Arteries. Anterior choroidal arteries that branch off the internal carotid or middle cerebral artery.

Distribution. This territory forms a cusp along the lateral border of the thalamus. It contains the posterior limb of internal capsule, lateral portion of ventrolateral nucleus, and both segments of globus pallidus.

Deficits. Hemiparesis, diminished pinprick, and light touch sensation (Graff-Radford et al., 1984;Caplan et al., 1988).

References

Aggleton JP, Mishkin M (1985) Mammillary-body lesions and visual recognition in monkeys. Exp Brain Res 58: 190-197.

Alexander GF, Crutcher MD (1990) Functional architecture of basal ganglia circuits: neural substrates of parallel processing. Trends Neurosci 13: 266-271.

Armstrong E (1990) Limbic thalamus: anterior and mediodorsal nuclei. In: The Human Nervous System (Paxinos G, ed), pp 469-481. San Diego: Academic Press, Inc.

Barr ML, Kiernan JA (1993) The Human Nervous System: An Anatomical Viewpoint. Philadelphia: J.B. Lippincott.

Bogousslavsky J, Regli F, Uske A (1988) Thalamic infarcts: clinical syndromes, etiology, and prognosis. Neurol 38: 837-848.

Bullard DE, Nashold BS (1984) Stereotaxic thalamotomy for treatment of posttraumatic movement disorders. J Neurosurg 61: 316-321.

Caplan LR (1988) Posterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 409-415.

Caplan LR, DeWitt LD, Pessin MS, Gorelick PB, Adelman LS (1988) Lateral thalamic infarcts. Arch Neurol 45: 959-964.

Castaigne P, Lhermitte F, Buge A, Escourolle R, Hauw JJ, Lyon-Caen O (1981) Paramedian thalamic and midbrain infarcts: clinical and neuropathological study. Ann Neurol 10: 127-148.

Choi D, Sudarsky L, Schachter S, Biber M, Burke P (1983) Medial thalamic hemorrhage with amnesia. Arch Neurol 40: 611-613.

Damasio H, Damasio AR (1989) Lesion Analysis in Neuropsychology. New York: Oxford University Press.

DeLong MR (1990) Primate models of movement disorders of basal ganglia origin. Trends Neurosci 13: 281-285.

Erlich SS, Apuzzo MLJ (1985) The pineal gland anatomy, physiology, and clinical significance. J Neurosurg 63: 321-341.

Fisher CM (1978) Thalamic pure sensory stroke: a pathologic study. Neurol 28(11): 1141-1144.

Gorelick PB, Hier DB, Benevento L, Levitt S, Tan W (1984) Aphasia after left thalamic infarction. Arch Neurol 41(12): 1296-1298.

Graff-Radford N, Eslinger PJ, Damasio AR, Yamada T (1984) Nonhemorrhagic infarction of the thalamus: behavioral, anatomic, and physiologic correlates. Neurol 34: 14-23.

Graff-Radford NR, Damasio H, Yamada T, Eslinger PJ, Damasio AR (1985) Nonhaemorrhagic thalamic infarction. Brain 108: 485-516.

Graff-Radford NR, Tranel D, Van Hoesen GW, Brandt JP (1990) Diencephalic amnesia. Brain 113: 1-25.

Grafman J, Salazar AM, Weingartner H, Vance SC, Ludlow C (1985) Isolated impairment of memory following a penetrating lesion of the fornix cerebri. Arch Neurol 42: 1162-1168.

Jarrell TW, Gentile CG, McCabe PM, Schneiderman (1986) The role of the medial geniculate region in differential Pavlovian conditioning of bradycardia in rabbitts. Brain Res 374: 126-136.

Jenkins WM, Masterton RB (1982) Sound localization: effects of unilateral lesions in central auditory system. J Neurophysiol 47: 987-1016.

Kawahara N, Sato K, Muraki M, Tanaka K, Kaniko M, Uemura K (1986) CT classification of small thalamic hemorrhages and their clinical implications. Neurol 36(2): 165-172.

Lugaresi E, Medori R, Montagna P, Baruzzi P, Cortelli P, Lugaresi A, Tinuper P, Zucconi M, Gambetti P (1986) Fatal familial insomnia and dysautonomia with selective degeneration of thalamic nuclei. N Engl J Med 315: 997-1003.

Mair WG, Warrington EK, Weiskrantz L (1979) Memory disorder in Korsakoff's psychosis. A neuropathological and neuropsychological investigation of two cases. Brain 102: 749-783.

Masdeu JC (1996a) The localization of lesions affecting the visual pathways. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 115-154. Boston: Little, Brown and Company.

Masdeu JC (1996b) The localization of lesions of the hypothalamus and pituitary gland. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 381-401. Boston: Little, Brown and Company.

Masdeu JC, Brazis PW (1996) The localization of lesions in the thalamus. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 401-426. Boston: Little, Brown and Company.

Masdeu JC, Gorelick PB (1988) Thalamic astasia: inability to stand after unilateral thalamic lesions. Ann Neurol 23: 596-603.

Mori E, Yamadori A, Mitani Y (1986) Left thalamic infarction and disturbance of verbal memory: a clinicoanatomical study with a new method of computed tomographic stereotaxic lesion localization. Ann Neurol 20: 671-676.

Motomura N, Yamadori A, Mori E, Tamaru F (1986) Auditory agnosia. Brain 109: 379-391.

Ohye C (1990) Thalamus. In: The Human Nervous System (Paxinos G, ed), pp 439-468. San Diego: Academic Press, Inc.

Percheron G (1973) The anatomy of the arterial supply of the human thalamus and its use for the interpretation of thalamic vascular pathology. Z Neurol 205: 1-13.

Squire LR, Moore RY (1979) Dorsal thalamic lesion in a noted case of human memory dysfunction. Ann Neurol 6: 503-506.

Steriade M, Parent A, Hada J (1984) Thalamic projections of nucleus reticularis thalami of cat: a study using retrograde transport of horseradish peroxidase and fluorescent tracers. J Comp Neurol 229: 531-547.

Szelies B, Herholz K, Pawlik G, Karbe H, Hebold I, Heiss W-D (1991) Widespread functional effects of discrete thalamic infarction. Arch Neurol 48: 178-182.

Thach WT, Goodkin HP, Keating JG (1992) The cerebellum and adaptive coordination of movement. Ann Rev Neurosci 15: 403-442.

Thompson SM, Robertson RT (1987) Organization of subcortical pathways for sensory projections to the limbic cortex II. Afferent projections to the thalamic lateral dorsal nucleus in the rat. J Comp Neurol 265: 189-202.

von Cramon DY, Heibel N, Schuri U (1985) A contribution to the anatomical basis of thalamic amnesia. Brain 108: 993-1008.

Walshe TM, Davis DR, Fisher CM (1977) Thalamic hemorrhage: A CT clinical correlation. Neurol 27(3): 217-222.

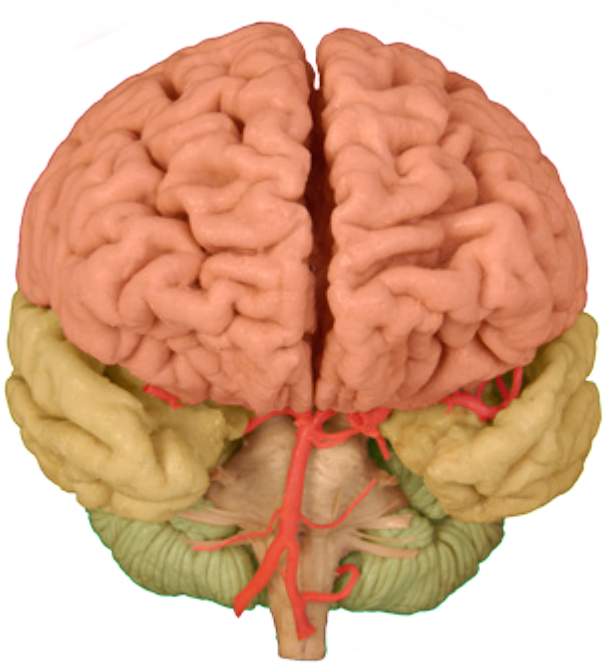
Watson RT, Heilman KM (1979) Thalamic neglect. Neurol 29: 690-694.

Watson RT, Valenstein E, Heilman KM (1981) Thalamic neglect: Possible role of the medial thalamus and nucleus reticularis in behavior. Arch Neurol 38: 501-506.

Wetterberg L (1983) The relationship between the pineal gland and the pituitary adrenal axis in health, endocrine and psychiatric conditions. Psychoneuroendocrinology 8: 75-80.

Winer JA (1984) The human medial geniculate body. Hearing Res

Chapter 9
Neocortex



▶ INTRODUCTION

The cerebral hemispheres are the most prominent structures of the brain. Starting in the 4th week of development as small, lateral protrusions off the diencephalon, they expand rapidly to eventually envelop the rostral end of the brain stem as well as portions of the cerebellum. When mature, each hemisphere is composed of a thin, folded cortical mantle of neurons overlying a massive accumulation of white matter. The axons of the white matter form an elaborate network of intracerebral communication, both within a hemisphere and between hemispheres. In addition, some of these axons represent the efferent projections of the cerebral cortex, which descend through the white matter, enter the internal capsule, and eventually reach the brain stem and spinal cord.

The cortical mantle can be divided into two general regions: neocortex and allocortex. Neocortical areas form the prominent convoluted mantle on the surface of the hemisphere. They establish reciprocal connections with thalamic nuclei and also project axons to the brain stem and spinal cord.

The allocortex lies along the medial edge or limbus of the cortical mantle. This region represents the oldest portion of the cerebral cortex. Information from the neocortex is passed to allocortical structures via pathways referred to collectively as the limbic system. Through these circuits, sensory input from neocortical areas is processed, and complex behavioral responses involving somatomotor and secretomotor, as well as intellectual activities, are generated (see Chap. 10).

Buried deep inside the white matter of the cerebral hemisphere, and in close association with the thalamus, are the subcortical nuclei or basal ganglia (the corpus striatum, globus pallidus, and amygdala). The neocortex has extensive projections onto these subcortical nuclei that in turn feed back to the neocortex through the thalamus. This looped network is involved in modulating or

scaling the amount of neural activity in specific portions of neocortex (see Chapter 11).

The organization of the neocortical mantle of the cerebral hemisphere and its connections will be examined in this chapter. Using data derived from the lesion method of analysis (Damasio and Damasio, 1989), the clinical effects of neocortical damage will be described and several related clinicopathologic cases will be presented.

GENERAL OBJECTIVES

1. To learn the locations and functions of the major sensory, motor, and association areas of neocortex
2. To learn the clinically detectable deficits associated with destruction of specific neocortical areas
3. To use the preceding information to localize the extent of cerebral damage based on a patient's clinical signs and symptoms

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before attempting to answer the questions, compile a list of the patient's neurologic signs and symptoms, then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and answer the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. A whole brain
2. A sagittal brain
3. Brain sections
4. A medical dictionary

Chapter Nine Topics:

Case Study 9-1

Chief Complaint
A 73-year-old, right-handed male with rapid onset of right-sided weakness and aphasia

History of Chief Complaint
This 73-year-old, right-handed male was in excellent health until 7 o'clock on the evening of his admission, when he suddenly dropped his pipe out of his right hand while sitting on the back porch of his daughter's house. Although he did not experience a syncopal episode, his family reported that he was obtunded for a few minutes. Since this episode, he has been unable to speak. He was brought directly to the emergency room.

Medical History
His medical history was unremarkable. There was no history of peptic ulcer disease or of any previous myocardial infarction or rheumatic fever.

Social History
At the time of admission, the patient had been retired for 4 years from his position as an executive with a large firm in the southern portion of the country. He had been active in recreation for the past 10 years. He was in Maine visiting his daughter's family as part of an extended vacation touring the country in a recreation vehicle.

Medications
He was not on any prescription medications and the family denied that he had used any non-prescription medications outside of an occasional NSAID for periodic musculoskeletal pains.

General Physical Examination
The patient was an elderly male who appeared younger than his stated age. He was alert, cooperative, and followed three-step commands. His neck was supple with bilateral high-pitched carotid bruits. No hemorrhages were present in the conjunctiva. No nail bed hemorrhages were present. Heart sounds were regular with no murmurs, rubs, or gallops. No easy bruising, bleeding, hematochezia, hemoptysis, or hematuria were noticeable. He denied any stomach pain. Skull and spine were atraumatic. No cranial or orbital bruits were heard. Also, no history of migraine or other previous neurologic illnesses was given.

Neurologic Examination
Mental Status. The patient was awake and oriented to person, place and time. He had a markedly decreased output of speech and answered only in monosyllables of yes or no. If asked for names, he pointed to the object or person, rather than responding with the word. By using yes or no responses and by following commands, he could demonstrate that he comprehended spoken and written language. He was incapable of writing his name or the days of the week, but could point to the correct day from a list. He quickly recognized family members and attending hospital staff as they entered the room. He could follow three-step commands accurately with his left arm and hand.

Cranial Nerves. The optic disks were flat; visual fields were intact. No hemorrhages or other embolic phenomena were present. He had a full range of extraocular motion. His pupils had a range of motion of 2.5mm to 1.5 mm to both direct and consensual light reflexes. Both eyes could close tightly. Wrinkle lines were symmetric across the forehead, and eyebrows elevated symmetrically. The lower right quadrant of his face showed some paresis when he was asked to grimace or smile. Corneal, jaw-jerk, and gag reflexes were intact. His uvula elevated symmetrically, his tongue protruded along the midline, and his shoulder shrug was symmetric.

Motor Systems. Motor examination revealed a right upper limb monoparesis with a right pronator drift. Motor power was approximately 4/5 in the right upper extremity. Motor power in the right leg was 5/5. Deep tendon reflexes in his right upper extremity were 4/4 at the elbow and wrist, 3/4 at the knee, and 2/4 at the ankle. His right toe was up-going.

Sensation. Sensation to touch, vibration, proprioception, and pain were decreased on the right arm and thigh but were intact on the left side of his body. This portion of the examination was somewhat equivocal because of the patient's poor communication skills.

Follow-Up

Examination at 3 months after discharge found his gross strength on the right much improved at 5/5 in both upper and lower extremities. Deep tendon reflexes were 3/4 at the elbow and wrist, 2/4 at the knee and 2/4 at the ankle. He had regained normal sensation through his right side. His speech consisted of numerous words but was not flowing. Many words were broken in sound and he occasionally perseverated on sounds such as no-no-no or ta-ta-ta when he was unable to produce the correct word.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

Cerebral Structures

The cerebral cortex can be divided into two general regions based on anatomic, phylogenetic, and embryologic studies. These are the following: neocortex (six-layered cortex) and allocortex (three-layered cortex). The allocortex is further divided into olfactory cortex (paleocortex) and hippocampus (archicortex). The allocortical structures will be discussed in Chapter 10.

The neocortex is the youngest and largest portion of the cerebrum. Its outermost velum, or cortical ribbon, is distinguishable by its six layers of cells and fibers. Its surface is divided into six lobes, four of which can be seen in a lateral view: frontal, parietal, occipital, and temporal (Figure 8-1). The fifth, the limbic lobe, can be seen in a sagittal view (Figure 8-2). The sixth, the insular lobe, is tucked deep into the lateral fissure and requires dissection for exposure (Figure 8-3). Some of the borders between lobes of the cerebrum are not well defined and different partitioning schemes are employed by various texts. Each cerebral lobe encompasses several specific gyri (folded ridges) and sulci (valleys between the gyri).

The cerebral lobes are further divided into specific cortical areas, each of which is characterized by its cytology, afferent projections, and efferent targets. These areas, of which there are approximately 50, were described initially by Brodmann and given numeric designations. Although this work was around the turn of the century, these areas have proven useful in recent physiologic studies and have become a standard for describing territory in the human cerebral cortex. Only the most prominent of the Brodmann areas will be presented in this text along with details on cortical cytology and a map of the Brodmann areas (Barr and Kiernan, 1993).

The Brodmann areas of cerebral cortex can be arranged in a hierarchy of functional groupings (Changeux, 1986). The subcortical sensory systems relay information to the primary sensory cortex, the first level in the cortical hierarchy. Well-organized, topographic maps of the external environment exist in these areas. Surrounding the primary sensory areas are regions of the secondary sensory cortex, representing the second level in the hierarchy. The secondary areas are involved in feature extraction from the sensory data represented in primary sensory cortex. Examples of such features are motion, color and texture of the stimuli. Finally, surrounding

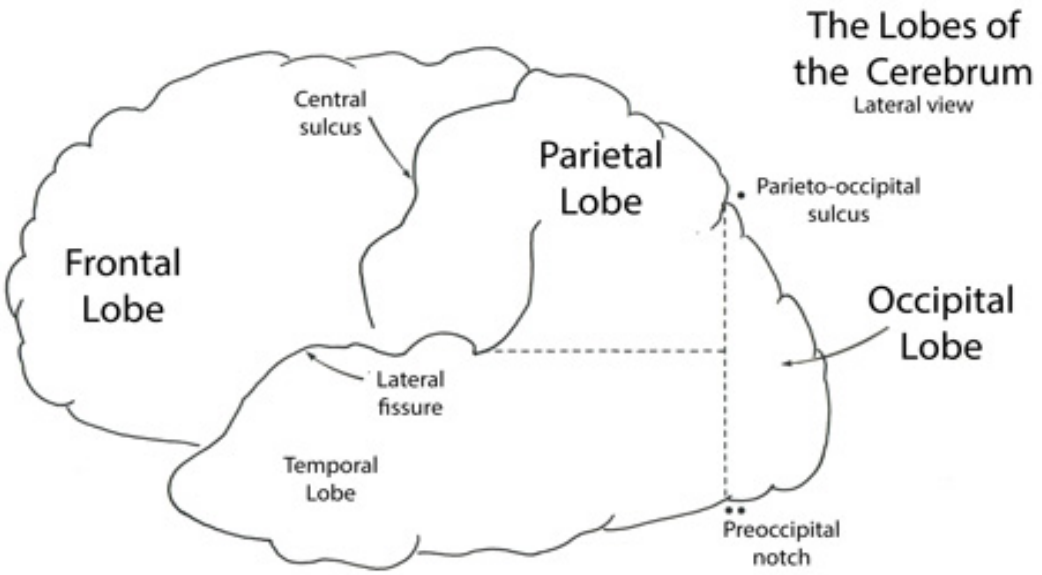


Figure 9-1. This schematic outline illustrates the four lobes seen on a lateral view of the cerebral cortex. The junction separating parietal, occipital, and temporal cortex is defined by dashed lines connecting the parieto-occipital sulcus (*) to the preoccipital notch (**) and the distal one-third of the lateral fissure.

the primary and secondary areas are large regions called the association cortex, the tertiary level in the hierarchy. Here polymodal sensory convergence from the cortical sensory areas takes place; it is speculated that images of environmental events are formed and that behavioral patterns are initiated in the association cortex.

Although information flows into the cortex in a hierarchic fashion, processing of this information for attention, memory, language, and cognition cannot be thought of as being derived strictly from the hierarchy array. Numerous interconnections exist between primary, secondary, and tertiary regions of the cerebral cortex, forming vast neural networks. Simultaneous processing of information occurs in these networks in a parallel fashion rather than in a serial order (Mesulam, 1990). This method of parallel distributed processing affords the brain a far more powerful strategy for extracting features from information than a serial method of processing.

FRONTAL LOBE

The frontal lobe extends rostrally from the central sulcus to the frontal pole (Figure 9-1 and Figure 9-2). It is divided into three regions: prefrontal, premotor, and motor cortex. Each region is composed of multiple gyri and sulci (Figure 9-4). The motor cortex contains the primary motor representation; the premotor cortex is a secondary level; and the prefrontal cortex is a tertiary or associational level.

Prefrontal Cortex

The rostral portions of three longitudinal gyri (superior, middle, and inferior frontal) form the prefrontal cortex (Figure 9-4). The three gyri are partitioned by two sulci. The superior and middle gyri are separated by the superior frontal sulcus; the middle and inferior gyri are separated by the inferior frontal sulcus. The inferior frontal gyrus has three named parts (from caudal to rostral): the pars opercularis, triangularis, and orbitalis (Figure 9-4).

In fulfilling its role as an associational level in the cortical hierarchy, the prefrontal cortex has established extensive connections with the rest of the brain. It receives a major fiber projection from the dorsomedial nucleus of the thalamus, from other regions of the cerebral cortex, particularly the secondary sensory areas of the parietal, temporal, and occipital cortex as well as from the posterior parietal and inferotemporal association cortex. Thus, neurons in the prefrontal association cortex are heteromodal in their response to sensory stimuli. The efferent fibers from the prefrontal cortex radiate out to association areas of the parietal, occipital, temporal, and cingulate cortex as well as to allocortical areas (parahippocampal gyrus). Its descending efferent fibers provide considerable innervation to the corpus striatum (corticostriate fibers), cerebellum

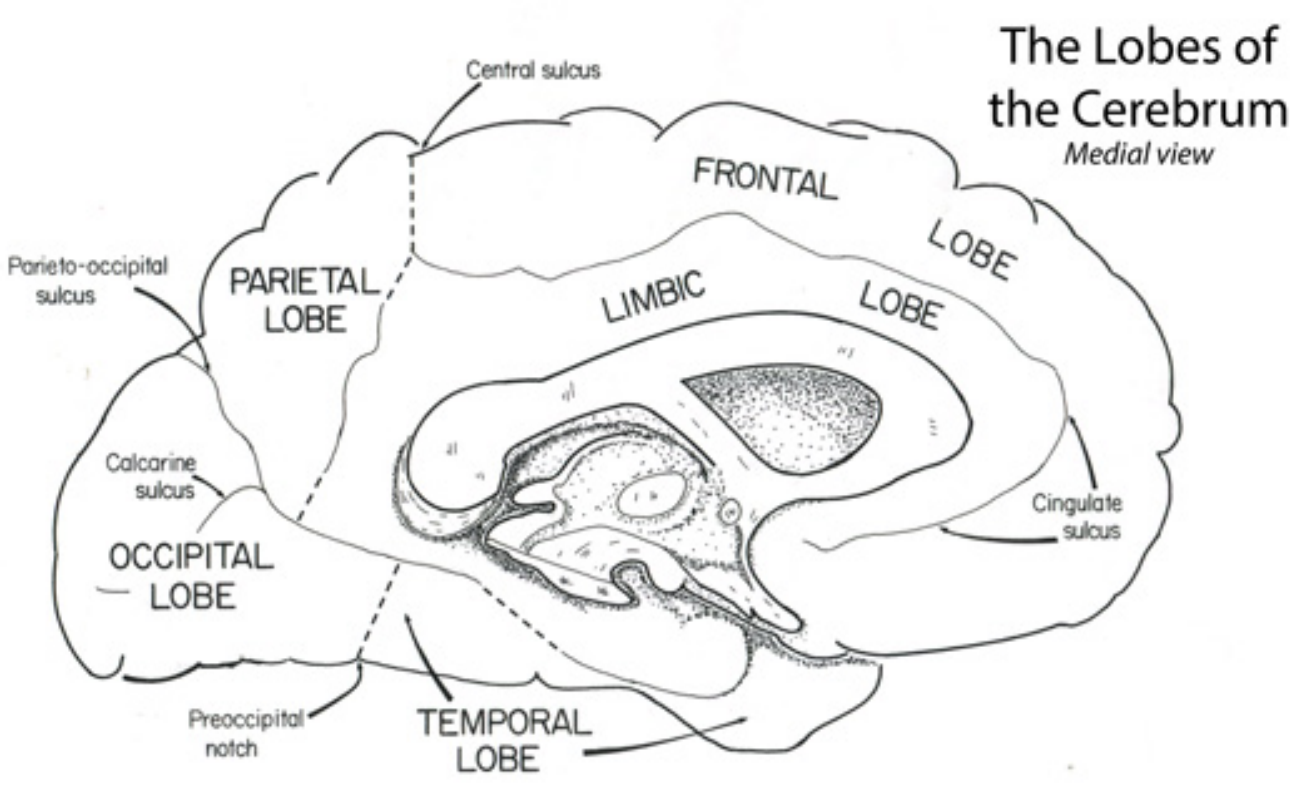


Figure 9-2. This schematic outline illustrates the lobes as seen on a medial view of the cerebral cortex. Where there are no outward landmarks, the dashed lines have been used to approximate the borders of the lobes.

(frontopontocerebellar fibers), and many brain stem nuclei (frontonuclear fibers) as well.

In summary, the prefrontal association cortex can be depicted as receiving input from multiple secondary cortical sensory and motor areas and, after processing, passing this sensory information on to the limbic lobe through the cingulate and parahippocampal gyri. In this sense, the prefrontal cortex represents a gateway from the neocortex into the limbic system. Through these extensive connections, the prefrontal cortex plays a major role in controlling the complex patterns of motor and social behavior elicited by external stimuli.

CLINICAL DISCUSSION: The signs and symptoms of prefrontal lobe damage are controversial and have presented considerable confusion in the literature (Nauta, 1971). Given the laterality of function in the cerebrum, any analysis of prefrontal cortex damage is best considered in terms of unilateral and bilateral lesions (Adams et al., 1997).

Unilateral lesions can result in an elevation of mood, with increased talkativeness, recitation of silly jokes and inappropriate comments, as well as a lack of tact characterized by loss of social inhibition. Inability to adapt to changing circumstances and a loss of initiative can also be seen. Bilateral prefrontal cortex lesions can result in a general depression of activity, an idleness of thought and speech, an inability to sustain attention, a rigidity or concreteness in thinking, bland affect, and labile mood. The general reduction in activity takes the form of diminished movement, spoken words, and thoughts per unit of time. In mild cases, this is referred to as abulia; profound cases result in akinetic mutism (Adams et al., 1997).

Characteristic of some prefrontal lobe lesions is a perseveration of behavior. The patient fixes on a particular step (usually an early step) in a sequence and repeats that step even though it means that the overall task is not completed correctly (Nauta, 1971). This perseveration of task can occur even though the patient acknowledges that it is not the correct sequence. The underlying deficit may be the patient's inability to adjust to changing circumstances in the external environment (Mesulam, 1986).

Memory loss also occurs in some prefrontal lobe lesions. Loss of memory resulting from anterolaterally positioned lesions tends to present as a failure to assimilate new material, whereas lesions in the ventral portion of prefrontal cortex result in memory loss resembling the Korsakoff amnesic syndrome (Adams et al., 1997).

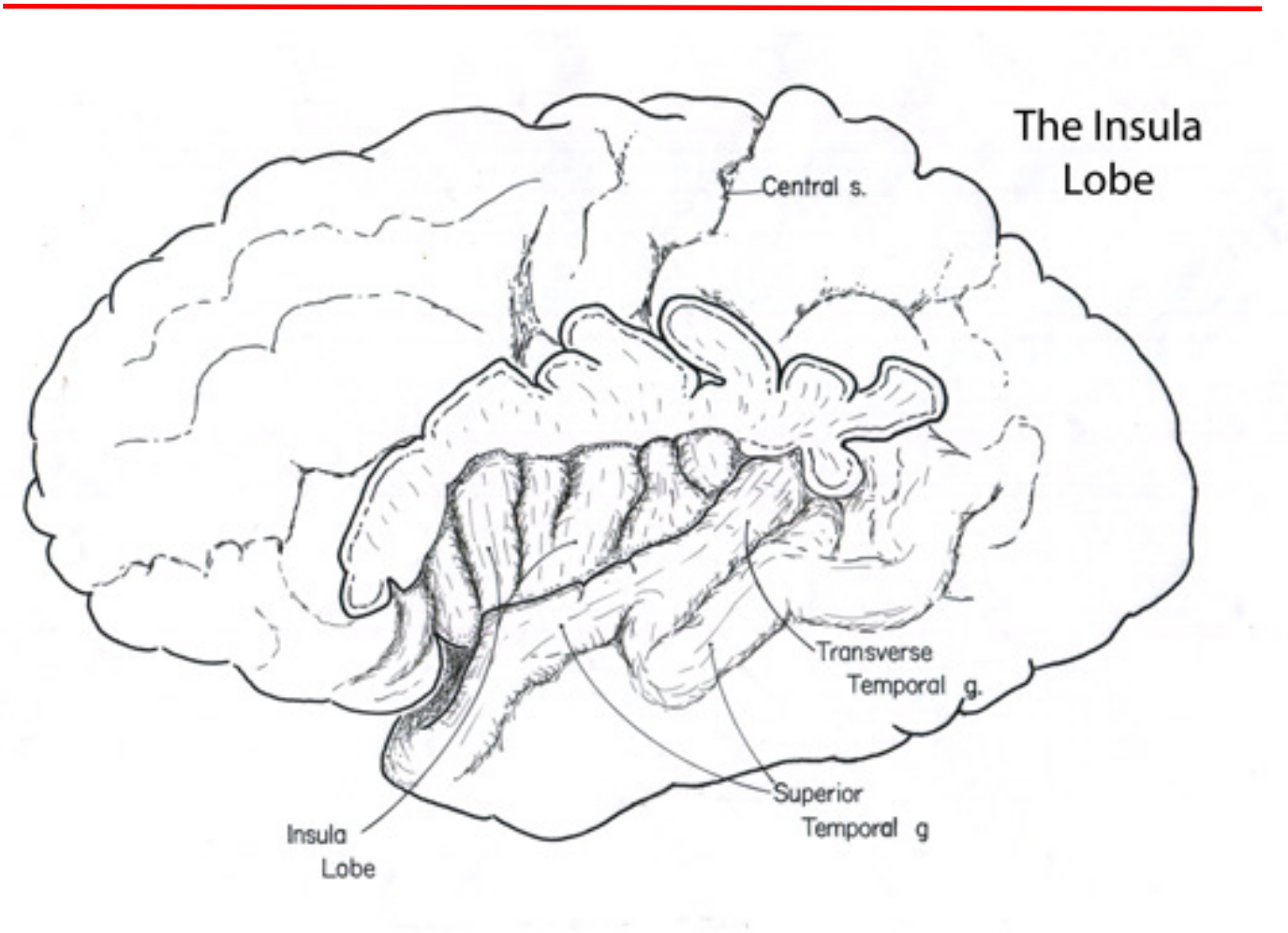


Figure 9-3. This drawing illustrates the insular cortex as seen after the walls of the lateral fissure have been removed.

Recently, a common theme of behavioral disturbance has been proposed for frontal lobe damage (Mesulam, 1986). Loss of attention, shallowness and impulsiveness of thought (increased distractibility), and a disintegration of those behaviors that lack pronounced external guidance are characteristics of this behavior. The term environmental dependency syndrome has been proposed for this complex. Typical of this syndrome are the "imitation behaviors" and "utilization behaviors" described by Lhermitte and colleagues (Lhermitte et al., 1986).

Premotor and Supplementary Motor Cortex

The caudal portions of the superior and middle frontal gyri, as well as the rostral border of the precentral gyrus, are involved in motor functions controlling the axial and proximal limb musculature, and constitute the premotor and supplementary motor cortex (Figure 9-4). These two regions are considered part of the medial motor system (Nieuwenhuys et al., 1988).

Premotor and supplementary motor cortices are located in area 6 and part of area 8. Afferent projections to these portions of cortex are received from the ipsilateral ventroanterior and ventrolateral thalamic nuclei and from the ipsilateral posterior parietal cortex. The premotor and supplementary motor cortices have many targets for their efferent projections. Corticocortical fibers interconnect these portions of frontal cortex with primary motor cortex bilaterally. Descending corticonuclear fibers from these two regions of neocortex terminate in the reticular formation of the brainstem, and their corticospinal fibers terminate in the contralateral medial portions of the ventral horn of the spinal cord.

A distinction between premotor and supplementary motor cortex is seen in the subtleties of their afferent connections and their proposed function (Kandel et al., 1991). The premotor cortex receives afferent fibers from the ventrolateral thalamic nucleus (the portion of the thalamus receiving the dentothalamic fibers) and is reported to function by guiding limb trajectory based on information derived from the cerebellum. The cerebellar signals are strongly influenced by sensory information provided by the spinocerebellar tracts. The supplementary motor cortex receives afferent axons from the ventroanterior thalamic nucleus (the recipient of pallidothalamic fibers) and is reported to function in programming motor sequences derived from the basal ganglia. The basal ganglia are strongly influenced by input from the association portion of the cerebral cortex.

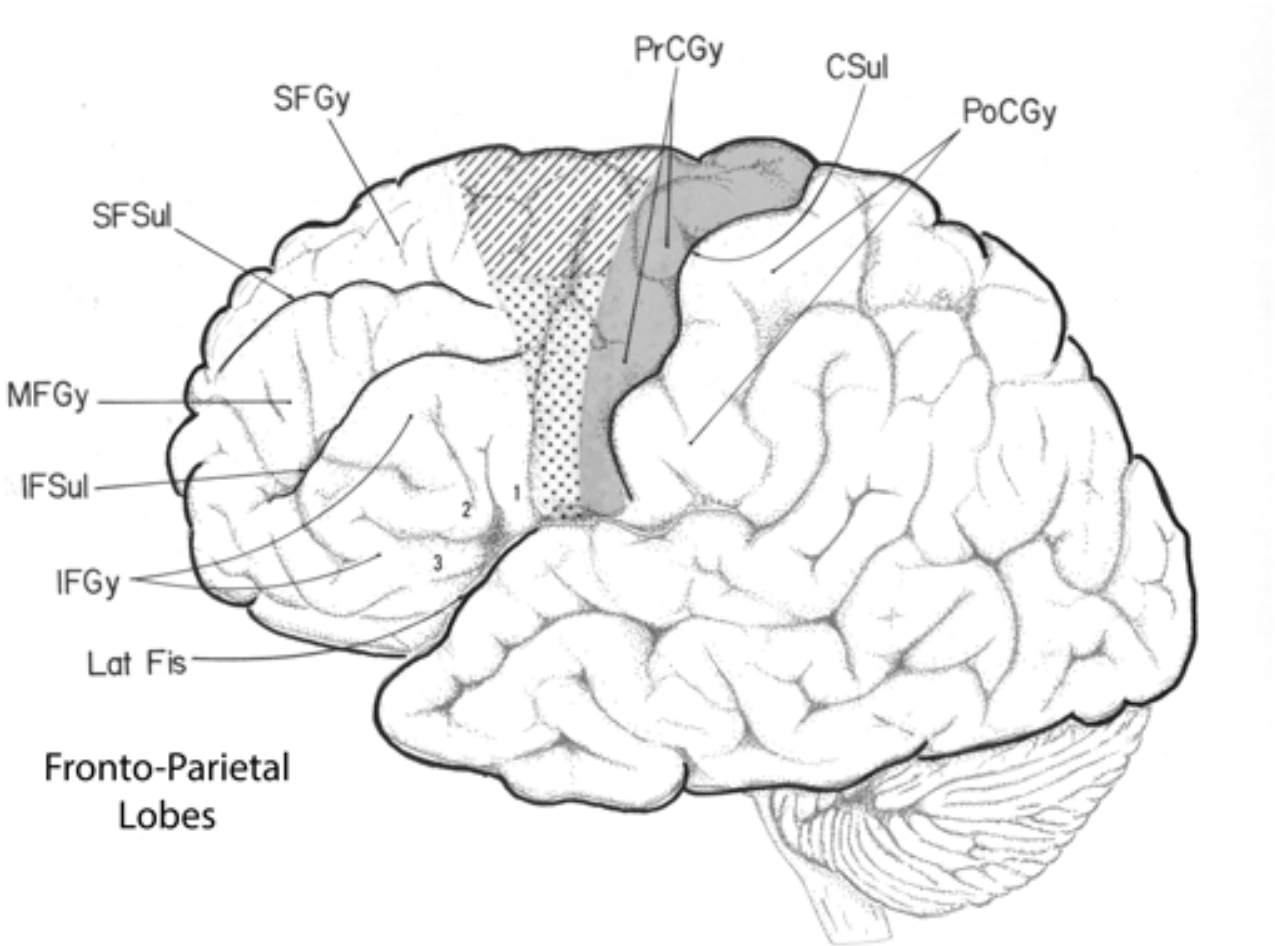


Figure 9-4. Schematic diagram of the gyri and sulci of the frontal cortex. Primary motor cortex is indicated by the gray shading; supplementary motor cortex by the diagonal lines; and premotor cortex by the small crosses. The three horizontal gyri (superior, middle, and inferior frontal gyri) are collectively called prefrontal cortex. (CSul, central sulcus; IFGy, inferior frontal gyrus; 1, pars opercularis; 2, pars triangularis; 3, pars orbitalis; IFSul, inferior frontal sulcus; LatFis, lateral fissure; MFGy, middle frontal gyrus; PoCGy, postcentral gyrus; PrCGy, precentral gyrus; SFGy, superior frontal gyrus; SFSul, superior front sulcus)

Precentral Cortex

The posterior portion of the frontal cortex is termed the pre-central gyrus (area 4), which contains the primary motor cortex. This region is involved in controlling distal limb musculature and is considered part of the lateral motor system of Kuypers (Nieuwenhuys et al., 1988).

The motor cortex contains the large pyramidal neurons of Betz, located in the fifth layer. This portion of neocortex receives afferent fibers from the ventrolateral nucleus of the thalamus, the primary somatic sensory cortex, and the premotor and supplementary motor cortex. It gives rise to corticospinal fibers that terminate in the lateral portions of the ventral horn.

Cells in the motor cortex are arranged in a body map; the head is represented lateral and inferior along the precentral gyrus, and the arm is found medial and superior. The representation of the leg is found on the medial aspect of the precentral gyrus as it rolls over the edge of the longitudinal fissure to become the anterior paracentral lobule.

The cells of the primary motor cortex exert control over the reflex circuits in the spinal cord and directly control activity of alpha motoneurons, especially over those innervating the distal musculature of the limbs. Stimulation of the primary motor cortex with weak currents produces twitches in one or several muscles in the extremity (Henneman, 1980).

One role of the primary motor cortex is to encode the force of contraction of the muscle groups about a joint and to prepare these ventral horn neurons to act by adjusting the spinal reflex circuits. However, prior to sending instructions from motor cortex to spinal cord, they are tempered with data concerning the programming of muscle groups around surrounding joints, and the guidance of trajectory derived from the supplementary motor and premotor cortices. These modified instructions are delivered to the spinal neurons producing smooth, coordinated, and balanced movements of the extremities (reviewed in Kandel et al., 1991).

Two specialized areas of motor cortex extend rostrally into the premotor cortex. These regions are concerned with eye movements and speech. The frontal eye fields (inferior portion of area 8 plus part of areas 6 and 9) are found on the caudal border of the middle frontal gyrus; they direct the movement of the eyes into the oppo-

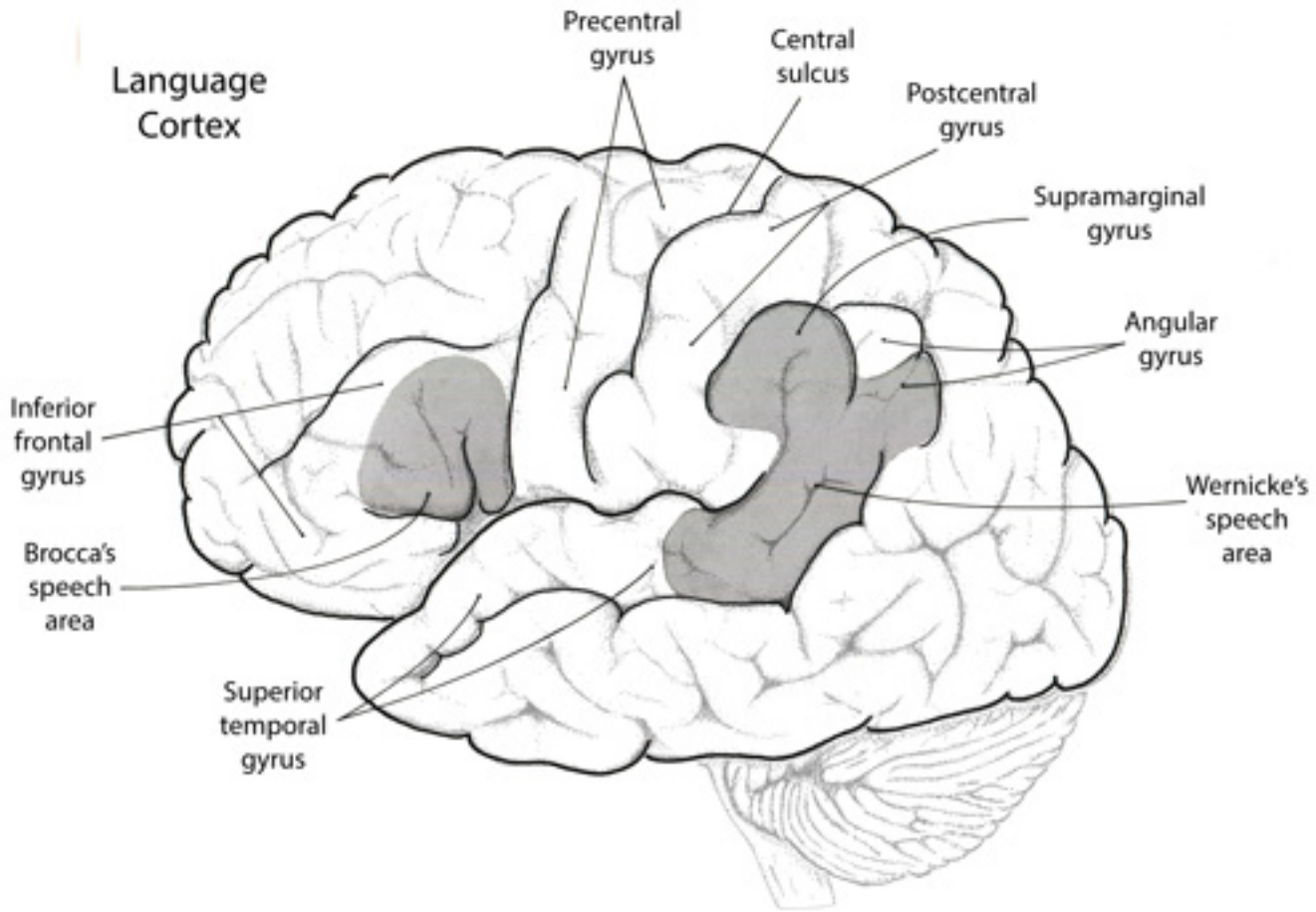


Figure 9-5. A diagram of sensorimotor structures at the parietofrontal junction and the major language areas of cerebral cortex. (AnGy, angular gyrus; CSul, central sulcus; IFGy, inferior frontal gyrus; PoCGy, postcentral gyrus; PrCGy, precentral gyrus; SMGy, supramarginal gyrus; STGy, superior temporal gyrus)

site visual hemisphere.

On the inferior border of the precentral gyrus and spreading onto the pars opercularis of the inferior frontal gyrus is Broca's speech area (areas 44 and 45; Fig. 9-5). Broca's area contains the motor patterns for speech. Right-handed persons have Broca's area only in the left or dominant cortex. Superior to Broca's area is a related region of cortex controlling the hand and containing the motor patterns for writing.

CLINICAL DISCUSSION: Damage to the precentral gyrus (motor cortex) results in spasticity and hemiplegia on the contralateral side of the body. If the lesion is confined to the lateral portion of the precentral gyrus, supplied by the middle cerebral artery, the paresis affects movements of the arm (monoparesis) as well as the muscles in the lower quadrant of the face. If the lesion involves the medial portion of the gyrus, supplied by the anterior cerebral artery, the resulting paresis involves the lower extremity. In primates, experimental lesions in motor cortex (area 4) resulted in spasticity and paresis of the affected limb. Recovery from the paresis followed; however, the animal never regained dexterity in the digits or exploratory behavior with the affected extremity (Henneman, 1980). Lesions of the premotor cortex in humans can result in weakness of the proximal limb muscles (Freund and Hummelsheim, 1985). However, the weakness was characterized, on EMG study, by significant delays in the pre-activation of proximal limb muscles, an event that interfered with the normal sequencing of contractions between the proximal and distal musculature of the limb.

A notable result of damage to the supplemental motor cortex seems to be the expression of the grasp response (Henneman, 1980). Slight contact with the hands leads to instinctive grasping of the object. Unilateral lesions involving the left supplementary motor cortex in right-dominant individuals produced a form of apraxia bilaterally in the upper extremities as well as the grasp reflex in the right hand (Watson et al., 1986).

Damage to Broca's area can result in nonfluent speech called motor, or anterior, aphasia. The patient's vocabulary is reduced to a few monosyllabic words or sounds such as yes or no. Speech is agrammatic, effortful, and slow. However, comprehension may be intact, as may the ability to write. Larger lesions can infringe on the premotor areas of hand representation dorsal to Broca's and interfere with writing. Although the patient may have only a mild paresis of the dominant extremity, when attempting to write he or she may produce scribbling or illegible characters (dysgraphia) or be unable to move the instrument at all, termed agraphia (Damasio,

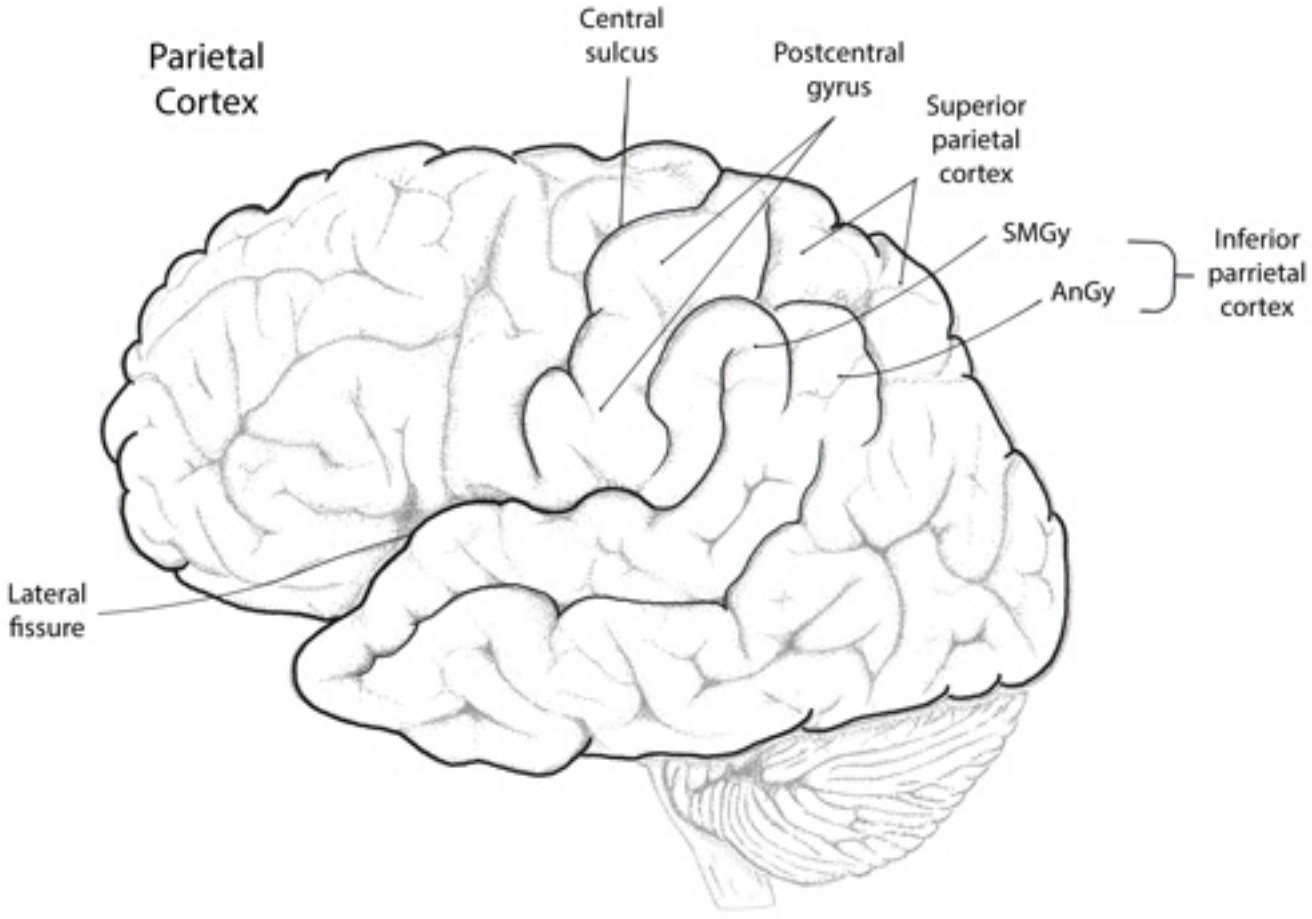


Figure 9-6. Diagram of general organization of the parietal cortex. The parietal lobe is bounded by the dashed line posteriorly and by the central sulcus anteriorly. The inferior parietal lobule is composed of the angular gyrus (ANGy) and supramarginal gyrus (SMGy).

1981;Levine and Sweet, 1983).

If the damage involves premotor cortex representation of the hand, apraxias can be present unilaterally or bilaterally (Geschwind, 1975). Although the patient can hear and understand a command, he or she is unable to access the hand representation in motor cortex volitionally and thus cannot initiate a requested movement. Yet the hand is not paralyzed and can be moved in spontaneous tasks.

Damage to the medial frontal lobe can result in transcortical motor aphasia as well as hemiplegia of the lower portion of the lower limb. In transcortical motor aphasia the patient has nonfluent aphasia but maintains good repetition of words or phrases and some comprehension of language (Rubens and Kertesz, 1983).

PARIETAL LOBE

The parietal lobe extends from the central sulcus to the parieto-occipital sulcus (Figure 9-4). Inferiorly, it blends with the temporal and occipital cortex at the base of the supramarginal and angular gyri. Superiorly, it wraps over the medial edge of the longitudinal fissure and descends along the medial wall to reach the limbic lobe (Figure 9-2).

The parietal lobe contains several subdivisions (Figure 9-6); these are the postcentral gyrus, posterior parietal lobule, and medial parietal lobule. The posterior parietal lobule is separated from the postcentral gyrus by the postcentral sulcus and is divided into superior and inferior portions by the intraparietal sulcus. The inferior portion contains two important gyri: the supramarginal gyrus surrounding the distal terminus of the lateral fissure, and the angular gyrus surrounding the distal terminus of the superior temporal sulcus. The medial parietal lobule is located on the wall of the longitudinal fissure and is divided into two areas: the posterior paracentral cortex, located rostrally, and the precuneate cortex, located caudally.

Postcentral Gyrus

The postcentral gyrus is immediately posterior to the central sulcus. Contained in this gyrus is the primary somatic sensory cortex, composed of Brodmann's areas 3, 1, and 2. These areas are arranged as three bands parallel to the long axis of the postcentral gyrus. Medially, the postcentral gyrus extends over the edge of the longitudinal fissure and onto the medial parietal lobule.

The primary somatic sensory cortex receives afferent fibers from the ventroposterior medial and lateral nuclei of the thalamus. Its cells are arranged in a topographic body map in register with the motor map present in the precentral gyrus directly across the central sulcus. The head representation is located on the edge of the lateral fissure; the leg representation is positioned in the longitudinal fissure. Projections from postcentral gyrus travel to the superior and inferior parietal lobule (collectively called posterior parietal cortex) and to the primary motor cortex.

Secondary somatic sensory areas are also present in the cerebral cortex. One such area is found on the upper bank of the lateral fissure at the lateral end of the postcentral gyrus. It has a separate body representation. Another area is the supplementary somatic sensory cortex on the medial wall of the longitudinal fissure, opposite the supplementary motor cortical area. The function of these secondary areas is unclear; however, it is known that they receive information from the primary somatic sensory cortex and that they project to the posterior parietal association cortex and the limbic system through the cingulate cortex (see Chap. 10).

CLINICAL DISCUSSION: Damage to the "body map" in the postcentral gyrus results in a dysfunction of somatic sensation from the contralateral portion of the body. This is characterized by loss of position sense and two-point discrimination, as well as astereognosis, an inability to identify objects by tactile sense of size and shape alone (Kaas, 1990). Damage to only a small portion of the cortical map results in dysfunction of sensory input from the corresponding portion of the body. However, the losses tend to be most profound when they involve the contralateral distal extremities, since they receive the greatest amount of cortical representation. In general, given the large amount of cortical area devoted to representing the somatic sensory system, lesions typically present with only a patchy loss of sensory function. This contrasts with the more massive loss and precise midline border seen in lesions of the ventroposterior nuclei in the thalamus.

Paresthesias, such as a tingling sensation, are also common features of lesions in the postcentral gyrus (Masdeu, 1996). In addition, poorly localized pain and thermal sensation can remain intact in the presence of discriminative sensory loss.

It is also possible to dissociate localization of touch from discrimination of the object. Patients with cortical lesions have been observed to be capable of identifying the approximate location of the touch on their affected limb while being unable to recognize the object with which they were touched (Paillard et al., 1983).

Medial Parietal Lobule

The parietal cortex wraps over the medial wall of the longitudinal fissure (Figure 9-2). This portion of cortex is the medial parietal lobule and is composed of posterior paracentral cortex and precuneate cortex. The posterior paracentral cortex is a direct continuation of the postcentral gyrus. It contains the body representation for the lower part of the leg and foot. Also present is a second body map, analogous to that of the supplementary motor cortex (Kaas, 1990). The major source of afferent fibers to the medial parietal lobule is the ventroposterior lateral nucleus of the thalamus. The precuneate extends caudally to the occipital cortex. Its major source of afferent fibers is the pulvinar nucleus of thalamus.

CLINICAL DISCUSSION: Lesions of the posterior paracentral cortex affect the sensory representation of the distal lower extremity, resulting in loss of two-point discrimination and position sense. Since branches of the anterior cerebral artery supply this region, it is possible to disassociate it from the head, torso, and upper extremity representation located laterally in the postcentral gyrus. Branches of the middle cerebral artery supply the region containing representation of the torso, upper extremity and head.

Posterior Parietal Lobule

The posterior parietal lobule is divided into two parts, superior and inferior, by the intraparietal sulcus (Figure 9-6). Both portions re-

ceive thalamic afferent fibers from the lateral posterior nucleus and pulvinar nucleus. The posterior parietal lobule is considered association cortex; it receives polysensory input from somatic, visual, and auditory cortical areas. Its major efferent projections extend to premotor cortex, prefrontal association cortex, and inferior temporal association cortex as well as to lateral posterior thalamic nuclei.

The inferior portion of the posterior parietal cortex is composed of the supramarginal and angular gyri (Figure 9-6). These association levels of cortex receive projections from the somatic, auditory, and visual sensory areas. In the dominant hemisphere, this region, along with portions of the superior temporal gyrus, contains Wernicke's area (Figure 9-5) and represents a location involved in language comprehension (Williams, 1995). In the nondominant hemisphere the analogous region is thought to function in the comprehension of mechanicospatial relationships.

The superior portion of the posterior parietal cortex includes areas 5 and 7 of Brodmann (Kaas, 1990). This portion of the neocortex receives projections from the primary somatic sensory cortex and the superior temporal cortex (visual information) and from several thalamic nuclei such as the ventroposterior nucleus, pulvinar, and lateral posterior nucleus. The superior portion of posterior parietal cortex projects axons to the other portions of the parietal cortex bilaterally, and to the prefrontal cortex, premotor cortex, limbic cortex, and the superior temporal gyrus ipsilaterally. Its subcortical projections reach the basal ganglia, thalamus, and pons ipsilaterally and the spinal cord contralaterally. A particularly strong connection exists between the neocortex along the walls of the intraparietal sulcus and the frontal eye fields; these are involved in guiding the eyes toward an object to which we want to attend. The region around the junction of the superior posterior parietal cortex with the supramarginal gyrus on the dominant side is involved with the spatial representation of writing and directs the learned motor patterns in the extremities for forming letters (Alexander et al., 1992).

It is clear from its pattern of connections that the posterior parietal lobule, a tertiary level in the cortical hierarchy, serves to integrate polymodal sensory stimuli and communicate with other areas of association cortex. It has been hypothesized that, through this process, our awareness of the extrapersonal world is transformed into a sensory map that attaches relevance to the specific sensory experience (Mesulam, 1981).

CLINICAL DISCUSSION: Damage to Wernicke's area in the dominant hemisphere can result in a form of fluent or posterior aphasia; such patients can produce an effortless volume of words rapidly, but they are not related meaningfully to each other (Damasio, 1981;Kertesz, 1983). This is sometimes called a "word salad," for obvious reasons, and it affects both the volitional and repetitive forms of speech. Damage to a broad belt around Wernicke's area, including the medial parietal cortex, can result in transcortical sensory aphasia (Rubens and Kertesz, 1983). The patient demonstrates fluent aphasia on attempted volitional speech, however, unlike pure fluent aphasia, the patient can repeat words as well as complex phrases accurately after the examiner. Right homonymous hemianopsia frequently accompanies lesions to the inferior parietal lobule, since the optic radiations pass close to this portion of cortex on their way to the occipital lobe.

A hemorrhagic lesion in the superior portion of the posterior parietal cortex on the dominant side, verified by computed tomography, resulted in an apraxia for the geometric aspects of writing called apraxic agraphia (Alexander et al., 1992). The patient initially expressed paresis in the right extremity, which resolved with time. Although the patient had fluent speech with only mild word-finding difficulties and could spell orally as well as type correctly, she was unable to write with either hand despite having knowledge of the letters and words. Over several weeks a limited writing capability returned; however, her writing was described as laborious and time consuming at best, and letters had poor geometric order.

The non-dominant inferior parietal lobule seems to be involved in mechanicospatial perception. Along with left homonymous hemianopsia, patients with damage to the nondominant inferior parietal lobule displayed constructional apraxia (Caplan et al., 1986), an inability to construct models of common objects with blocks or cards due to a lack of spatial order.

Large lesions in the nondominant posterior parietal lobule result in a neglect syndrome (asomatognosis) and loss of topographic memory (Masdeu, 1996). Varying degrees of the neglect syndrome exist, ranging from only mild extinction of bilateral sensory information on the affected side to extreme neglect of the entire affected hemisphere of personal and extrapersonal space (Kaas, 1990;Mesulam, 1981). In the extreme form, the hapless patient refuses to acknowledge that the contralateral side of his or her body belongs to him or her and fails to recognize contralateral extrapersonal space as well!

TEMPORAL LOBE

There are four longitudinally oriented gyri in the temporal lobe: the superior temporal gyrus (with its extension, the superficial transverse temporal gyrus, on which auditory functions are located (Figure 9-3)), the middle temporal gyrus, the inferior temporal gyrus, and the occipitotemporal gyrus. The first three are located on the lateral and inferolateral surfaces of the temporal lobe (Figure 9-7). The latter is located on the inferior surface of the temporal lobe, and its medial border with the parahippocampal gyrus is determined by the collateral sulcus (Figure 9-8).

The superficial transverse temporal gyrus and adjacent portions of the superior temporal gyrus receive thalamic afferent fibers from the medial geniculate nuclei and represent the primary auditory cortex (Brodmann's area 41 and part of 42). The neural components of this cortex are arranged in a topographic map of frequency representation on the basilar membrane. This organization is referred to as tonotopy (Webster and Garey, 1990;Clopton et al., 1974). Its efferent projections are to the adjacent temporal cortex, Wernicke's area, and the posterior parietal cortex. The auditory cortex is necessary for discerning the temporal component of language.

Secondary areas surround the primary auditory area, similar to the organization of the somatic sensory cortex. Several secondary auditory areas, each with tonotopic representations, are present in the temporal cortex. The specific functions of these areas are unknown at this time.

The remaining temporal gyri (collectively called the inferior tem-

poral association cortex) are influenced by the pulvinar nuclei and the visual cortex. Superiorly, this region blends with the posterior parietal association cortex; posteriorly, it blends with the occipital association cortex. They are involved in visual and acoustic cognition, visual discrimination, and pattern perception. The general function of this large expanse of the association cortex was discussed previously.

CLINICAL DISCUSSION: Damage to the primary auditory cortex is not readily detectable unless it is bilateral. Damage on both sides results in loss of the ability to hear speech, called cortical deafness, although in at least one reported case, sounds could be detected (Webster and Garey, 1990). Apparently, the auditory cortex is necessary for us to understand the temporal pattern (acuity) of sounds involved in speech. Verbal auditory agnosia can result from either bilateral or unilateral lesions of the region in or around the auditory cortex. Affected individuals are capable of identifying environmental sounds, but cannot recognize speech patterns. However, the opposite can also occur; in rare cases temporal lesions can result in a patient who cannot recognize nonverbal (environmental) sounds but can understand speech, called nonverbal auditory agnosia.

Lesions that affect the superolateral portion of the superior temporal gyrus can result in auditory illusions and hallucinations. Damage to any of the rest of the temporal lobe can present with various forms of visual agnosia (loss of the ability to identify common objects when seen), as disturbances of visual perception and visual learning, and as disturbances of time scale, such as diminished capacity to reckon personal events in terms of a time scale (Adams et al., 1997).

OCCIPITAL LOBE

The occipital lobe is the caudal most portion of the cerebrum and is represented on its lateral (Figure 9-1), medial (Figure 9-2), and inferior (Figure 9-8) surfaces. The borders between occipital, parietal, and temporal lobes are not well defined. On the lateral aspect of the cerebrum, these borders have been depicted by a vertical line connecting the parieto-occipital sulcus with the preoccipital notch and a horizontal line at the beginning of the distal one third of the

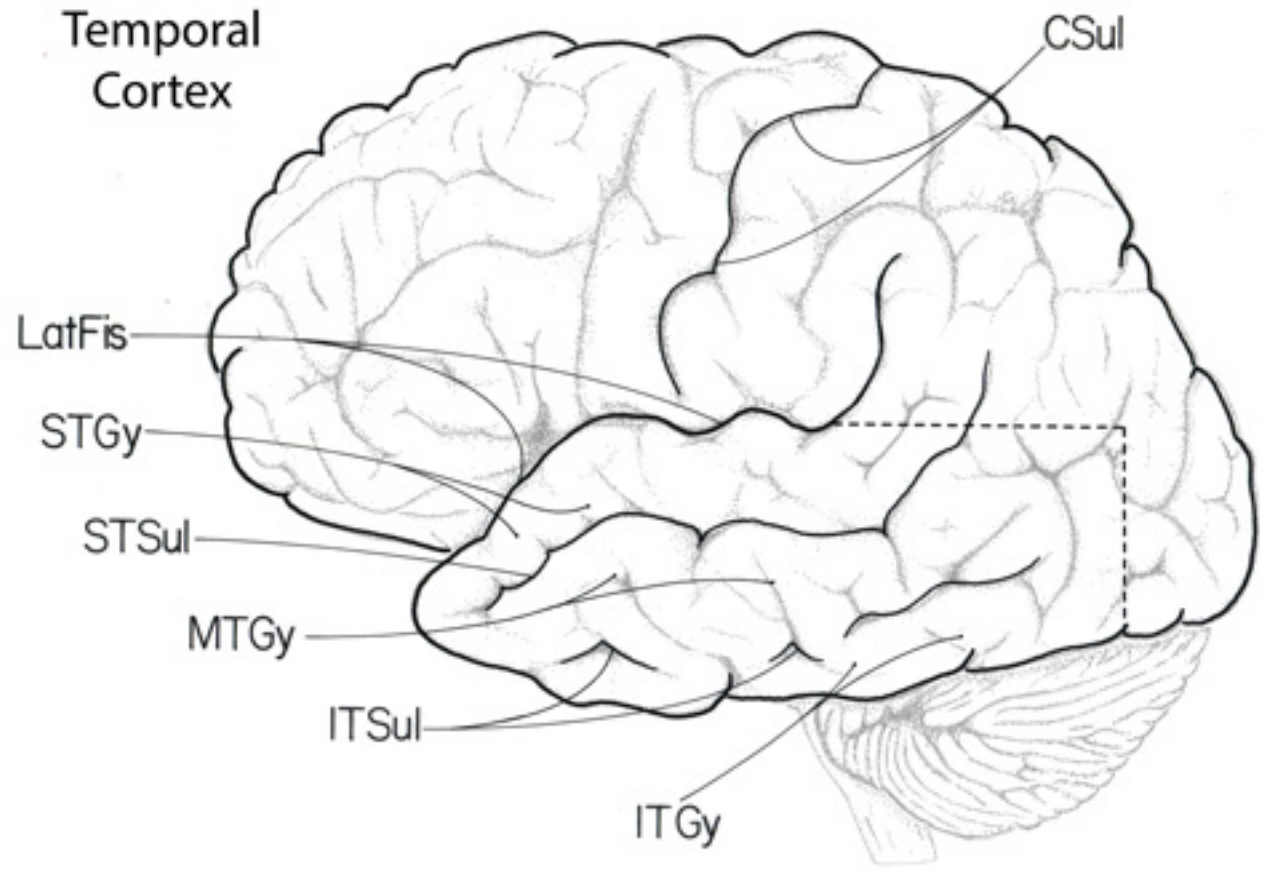


Figure 9-7. Diagram of general organization of the temporal cortex. (CSul, central sulcus; ITGy, inferior temporal gyrus; ITSul, inferior temporal sulcus; LatFis, lateral fissure; MTGy, middle temporal gyrus; STGy, superior temporal gyrus; STSul, superior temporal sulcus)

lateral fissure (Figure 9-1). On the medial aspect of the cerebrum (Figure 9-2), the borders of the occipital lobe are formed by the parieto-occipital sulcus, the medial portion of the calcarine sulcus, and a line drawn from the splenium of the corpus callosum to the preoccipital notch.

The medial aspect of the occipital lobe contains a prominent, curvilinear groove on its surface called the calcarine sulcus (Figure 9-9). Primary visual cortex (Brodmann's area 17) is located on both sides of this groove, posterior to its junction with the parieto-occipital sulcus. This area is often called striate cortex in recognition of the prominent bands of fibers in the cortical cytoarchitecture. Primary visual cortex is surrounded by bands of secondary visual or extrastriate cortex (Brodmann's areas 18 and 19).

Primary visual cortex is arranged as a visuotopic map of space, superimposed on the calcarine sulcus. The map is generated by thalamic afferent fibers from the lateral geniculate nuclei and is inverted in its representation of space. The superior visual field is represented on the inferior lip of the calcarine sulcus, while the inferior visual field is located on the superior lip (Barr and Kiernan, 1993).

Several secondary visual cortical areas surround the primary visual cortex, area 17. They receive cortical projections from area 17 as well as thalamic projections from portions of the pulvinar nuclei. Secondary visual cortical areas function in feature extraction from the sensory information represented in primary visual cortex. Differential activity has been reported for secondary visual cortex. Those regions inferior to area 17 are involved in perception of object shape and color, while the superior regions are involved in spatial relationships (Damasio and Damasio, 1989). Efferent projections from secondary visual cortex travel to posterior parietal cortex, premotor cortex (frontal eye fields), and inferior temporal cortex. The remainder of the occipital cortex (outside of areas 18 and 19) and portions of the inferior temporal cortex form the association areas. These regions blend with posterior parietal association cortex. Some of the functions of association cortex have been discussed previously.

CLINICAL DISCUSSION: Damage to the area around the calcarine sulcus results in blindness in the affected portion of the visual hemisphere, termed homonymus hemianopsia. If total destruction occurs, such as in a large bleeding accident or large tumor, it can lead to complete blindness in the contralateral visual hemisphere. Although such individuals cannot "see" or identify objects within their visual fields, they still have extracortical visual pathways and can respond to the presence or absence of light. Their pupillary reflex is present and they have a full range of eye movements. This syndrome is referred to as cortical blindness (Aldrich et al., 1987). Lesions that extend into the visual association cortex can result in Anton's syndrome. The individual is cortically blind, but refuses to admit visual loss (Masdeu, 1996).

Simultanagnosia (an ability to see the parts of an image, but an inability to synthesize the whole) can result from damage to the secondary cortex superior to the primary visual cortex. Cortical blindness is not necessarily present in patients with simultanagnosia. The involvement of the medial aspect of the inferior temporo-occipital cortex can result in color agnosia; if bilateral damage occurs in this area, prosopagnosia (loss of recognition of familiar faces) can result (Adams et al., 1997).

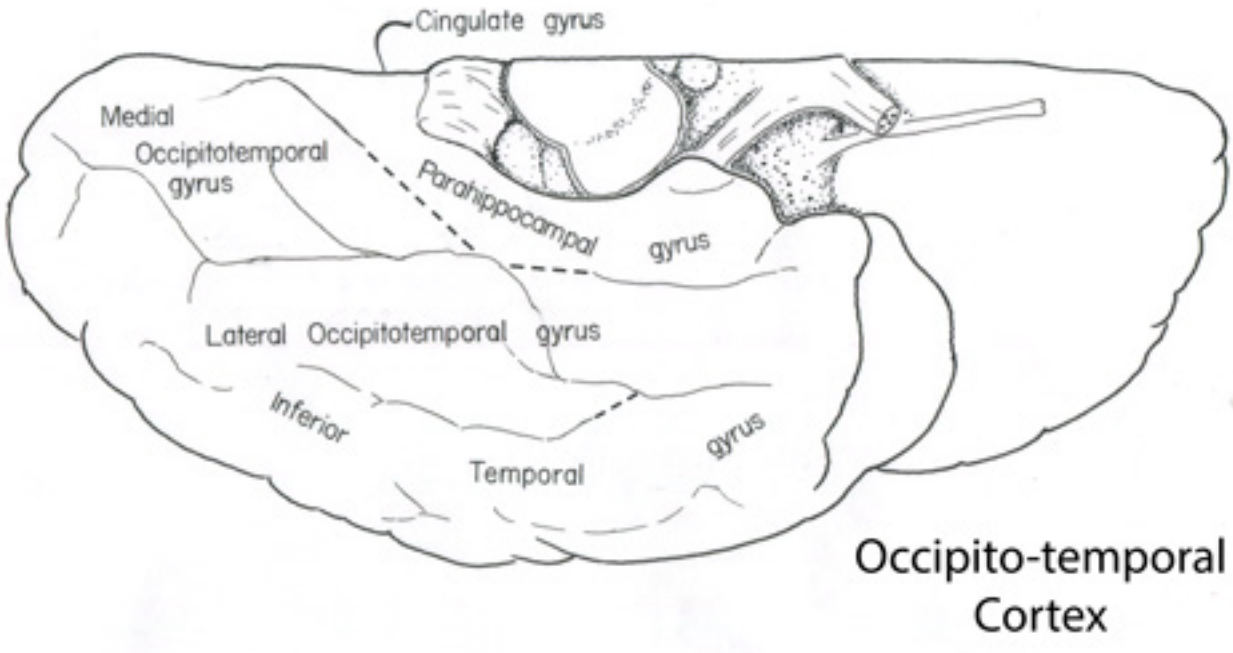


Figure 9-8. This is a ventral view of the brain illustrating the occipitotemporal gyri. The medial occipitotemporal gyrus is also called the lingual gyrus. Some authors call the lateral occipitotemporal gyrus the fusiform gyrus.

INSULA LOBE

If the walls of the lateral fissure are separated or cut away (Figure 9-3), an island of cortex, termed the insula, is seen within. Numerous branches of the middle cerebral artery pass over the surface of the insula lobe as they course through the lateral sulcus. Afferent fibers to the insular cortex arise in the medial geniculate nuclei (auditory and vestibular input), ventroposterior medial nucleus (gustatory and visceral sensory input), parabrachial nucleus of the pons, solitary nucleus of the medulla, and olfactory bulb. Projections from the insular cortex reach the brainstem nuclei with autonomic functions, especially those controlling blood pressure and heart rate. This arrangement favors a role for the insular cortex in the convergence of taste, smell, and visceral feelings to control autonomic functions, such as the cardiovascular system (Shipley and Geinisman, 1984; Ruggiero et al., 1987).

CLINICAL DISCUSSION: Isolated, destructive lesions of the insula in humans are rare. However, irritative lesions have been reported to cause seizures. The precursor for insular lobe seizures can involve gustatory hallucinations, such as a perceived bitter taste (Crosby and Schnitzlein, 1982).

CORPUS CALLOSUM

The longitudinal fissure separates the two cerebral hemispheres. A massive fiber bridge—the corpus callosum—spans the longitudinal fissure, interconnecting the hemispheres (Figure 9-2). Reciprocal mapping occurs between homologous areas of cortex through these commissural connections. Frontal commissural fibers cross in the rostrum of the corpus callosum, parietal commissural fibers cross in the body, and occipital commissural fibers cross in the splenium. The temporal lobes communicate via the anterior commissure passing through the rostral forebrain (see Plates 23 to 25).

The two hemispheres do not function identically, each being capable of some independent thought processes. The localization of specific functions into a restricted hemisphere is called lateralization. The corpus callosum normally helps to unite the activity of the two hemispheres. Sectioning callosal fibers can dissociate the two hemispheres and, literally, produce an individual with two rather distinct brains, a situation termed "split-brain" (Geschwind, 1979; Geschwind and Galaburada, 1985a; Geschwind and Galaburada, 1985b; Geschwind and Galaburada, 1985c; Sergent, 1987; Sperry, 1974).

CLINICAL DISCUSSION: Section of the corpus callosum is done to disconnect the hemispheres in intractable epilepsy. Numerous reviews have summarized the results of these "split-brain" operations (Sperry, 1974; Sperry, 1968). Some split-brain studies can occur naturally; developmental abnormalities leading to partial or complete agenesis of the corpus callosum have been detected in the population using magnetic resonance imaging (Kolodny, 1989). Agenesis occurs in from one to three of every 1000 births and is more predominant in children with additional cerebral malformations (Atlas et al., 1986) or metabolic diseases (Dobyns, 1989). Agenesis or partial genesis of the corpus callosum can appear silent in the patient (Davidson et al., 1985).

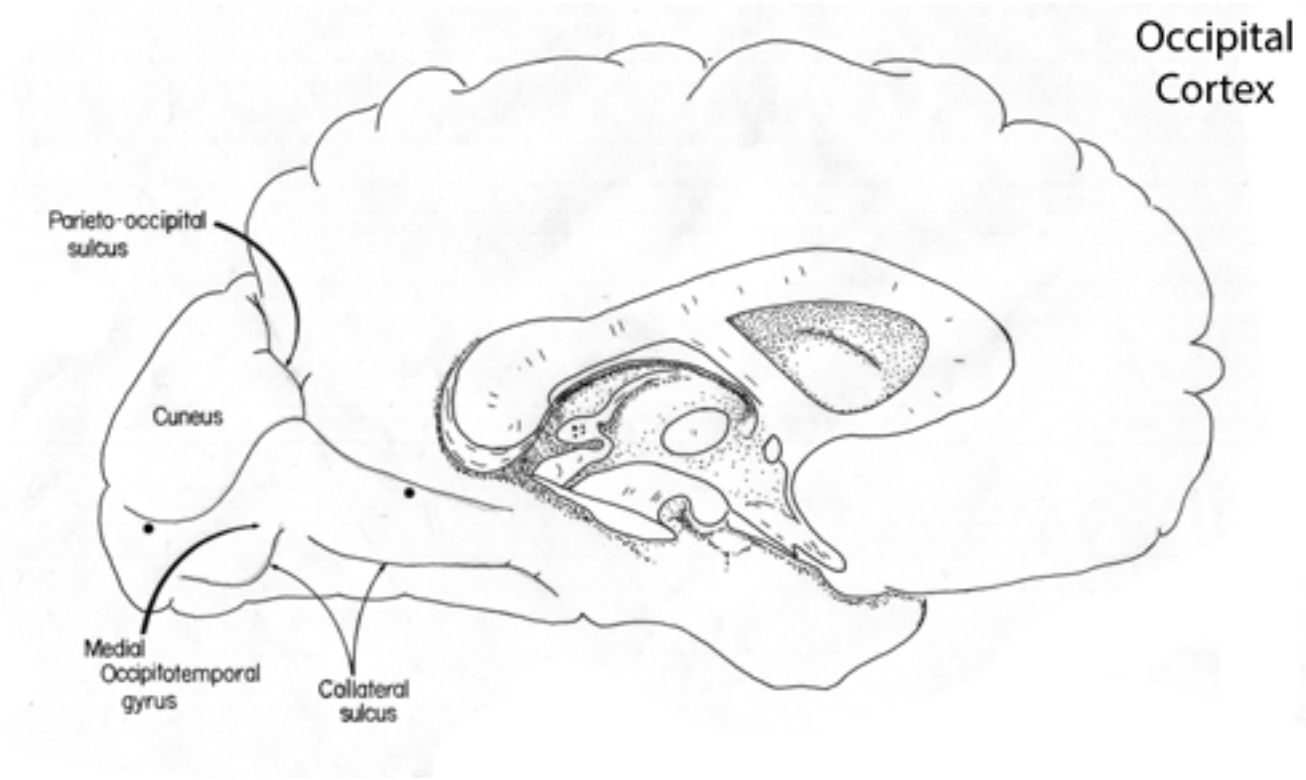


Figure 8-9. This is a medial view of the brain illustrating the general organizations of occipital cortex.

Case Study 9-2

Chief Complaint

A 52-year-old man with paresis of the distal lower extremity, confusion, and aphasia

History of Chief Complaint

This 52-year-old, right-handed male was brought to the emergency room by ambulance after losing consciousness in a restaurant on a Sunday afternoon. Although he maintained vital signs, he remained unconscious for 2 days, after which he began responding to external stimuli. Over a 2-week period he gradually regained consciousness. At this point he was re-examined for evaluation of future course.

Past Medical History

At the time of admission he was a post office employee, married, with three children, all in high school and living at home. His family stated that he did not smoke but admitted that he drank three or four glasses of beer per week. He had been in good health up until the apoplectic episode. His father had died of cerebrovascular disease 10 years before, at the age of 64; his mother was living and in good health.

General Physical Examination

The patient was a well-nourished, well-hydrated male with male-pattern baldness and he appeared his stated age. He was awake and fully cooperative but was disoriented for time and place. He had difficulty recognizing family members and hospital staff. He was overweight and appeared anxious. His optic discs were clear and sharp, and visual acuity was good. The neck was supple, with no bruits or lymphadenopathy. The chest was clear to percussion; the abdomen was soft, with no masses or tenderness. Peripheral pulses were intact at the wrist and ankle. Skin was moist and warm.

Neurologic Examination

Mental Status. The patient was an awake, fully cooperative, but disoriented male. His volitional speech was extremely nonfluent, consisting of several short phrases, such as, "no… no... no... no... no," or "tat... tat… tat." He repeated these phrases many times when attempting to answer questions. He could, however, repeat complicated phrases following the examiner's lead, such as "no ifs, ands, or buts." Yet he could not recite the days of the week or months of the year when asked. Although he could understand simple commands (e.g., "Point to the door."), his comprehension of language was extremely poor. He never understood two- or three-step commands. He could read a few words aloud but could not comprehend what he had read; he could not write or draw even simple figures.

Cranial Nerves. He had a full range of eye movements but tended to keep his eyes positioned to the left when resting. Visual acuity was difficult to test, but he was capable of reading 8-point type. Both pupils were reactive to light, direct and consensual. Hearing could not be tested accurately. Corneal, jaw-jerk, and gag reflexes were intact. There was a mild weakness in the right lower quadrant of his face. The uvula was elevated on the midline, and the tongue protruded on the midline. Snout, grasp, and suck reflexes were not present.

Motor Systems. Strength was diminished on the right, more so in the leg than in the arm. Deep tendon reflexes were elevated on the right compared to the left. A Babinski sign was present on the right, he was incontinent for urine and feces and was visibly upset when this occurred.

Sensorium. The sensorium was difficult to examine because of the patient's poor mental status. Pinprick, temperature, vibratory, and proprioceptive senses appeared intact throughout the body and face, with the exception of some loss in the lower extremity on the right.

Follow-Up

He remained in the hospital for two weeks and was then discharged to a nursing home for critical care. Re-evaluation at 4 months after hospital discharge finds little improvement in comprehension or language capabilities. Gross strength had improved on the right side but deep tendon reflexes remained elevated. His sensorium was still difficult to evaluate due to his poor language and comprehension skills.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision and if so, where in the visual field is the loss? Are there any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function and if so, are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination and if so, are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function and if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem: is the onset of neurologic findings acute or insidious, is the course of the neurologic disease chronically progressive, fluctuant or stable?

7. Based on the presenting signs and symptoms, do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

Cerebral Vasculature

Roots of the Cerebral Vasculature

Arterial branches from the arch of the aorta and the subclavian artery are the major source of vessels supplying cerebral circulation. Anteriorly, the carotid system ascends through the neck to the base of the skull; posteriorly, the vertebral system winds through the transverse processes of the vertebrae to reach the foramen magnum. After entering the cranial vault, the internal carotids bifurcate to form the anterior and middle cerebral arteries, and the vertebral arteries fuse to form the basilar artery. This latter vessel traverses the long axis of the brain stem and subsequently bifurcates in the interpeduncular fossa to form the posterior cerebral arteries. As a result, three paired arterial systems come to lie in close juxtaposition at the base of the brain, surrounding the pituitary stalk (Figure 9-10).

At the base of the brain, the three paired cerebral arteries are joined into an anastomotic circle by small communicating branches (Figure 9-10). The anterior communicating branch unites the two anterior cerebral arteries; the posterior communicating branch joins the middle and posterior cerebral arteries. Finally, the middle and anterior cerebral arteries are united by a common origin from the internal carotid artery. The arterial ring so created is called the circle of Willis; if it is of sufficient size, it can serve to bypass perfusion deficits in any one of the major ascending vessels of the neck.

Anterior Cerebral Artery (ACA)

The anterior cerebral artery (ACA) arises from the internal carotid artery near the optic chiasm (Figure 9-10). The anatomy and radiology of this arterial system is extensively reviewed by Lin and Kricheff (Lin and Kricheff, 1974) and by Moscow (Moscow et al., 1974). This artery turns medially, passing inferior to the medial olfactory stria and superior to the optic tract and giving off the medial striate arteries to the anterior hypothalamus and anterior inferior portion of the striatum. As it approaches the midline, the anterior cerebral arteries are interconnected through the anterior communicating artery, completing the rostral aspect of the circle of Willis. Each anterior cerebral artery enters the longitudinal fissure and arches superiorly and caudally over the rostrum of the corpus callosum.

Once above the corpus callosum, the anterior cerebral artery divides into pericallosal and callosomarginal trunks, which course inferior and superior to the cingulate gyrus, respectively. Each of these trunks gives off cortical branches to supply the walls of the cerebral cortex within the longitudinal fissure, including the anterior cingulate cortex, the medial aspect of frontal and parietal lobes, the anterior corpus callosum, the anterior limb of the internal capsule, and the head of the caudate nucleus (Figure 9-11). Notable among the cortical areas serviced by this artery are the paracentral lobules, which contain motor and sensory representation of the leg and foot, and the supplementary motor cortex, which is involved in the initiation and regulation of voluntary movement and speech.

CLINICAL DISCUSSION: Damage to the anterior cingulate and paracentral distribution of the anterior cerebral artery can present clinically as contralateral paralysis and/or sensory loss in the foot and leg, a Babinski sign, urinary incontinence, gait apraxia, akinetic mutism, transcortical aphasia, and cognitive impairment. If damage occurs to deeper tissue around the internal capsule, undercutting the precentral gyrus, paresis of the upper extremity and facial musculature can result (Bogousslavsky and Regli, 1990). Large lesions of the anterior cerebral artery can affect the frontal eye fields, and the patient may lose volitional control of conjugate eye movement to the contralateral side. In milder cases, the eyes simply drift to the ipsilateral side while resting. Damage to the corpus callosum and/or supplementary motor cortex can produce ideomotor apraxia, alien hand syndrome, and left-handed apraxia and agraphia (Hung and Ryu, 1988).

The incontinence present in anterior cerebral artery occlusion results from damage to the superior frontal and anterior cingulate cortex. As the position of the lesion is shifted anteriorly along the cingulate gyrus, the patients become less

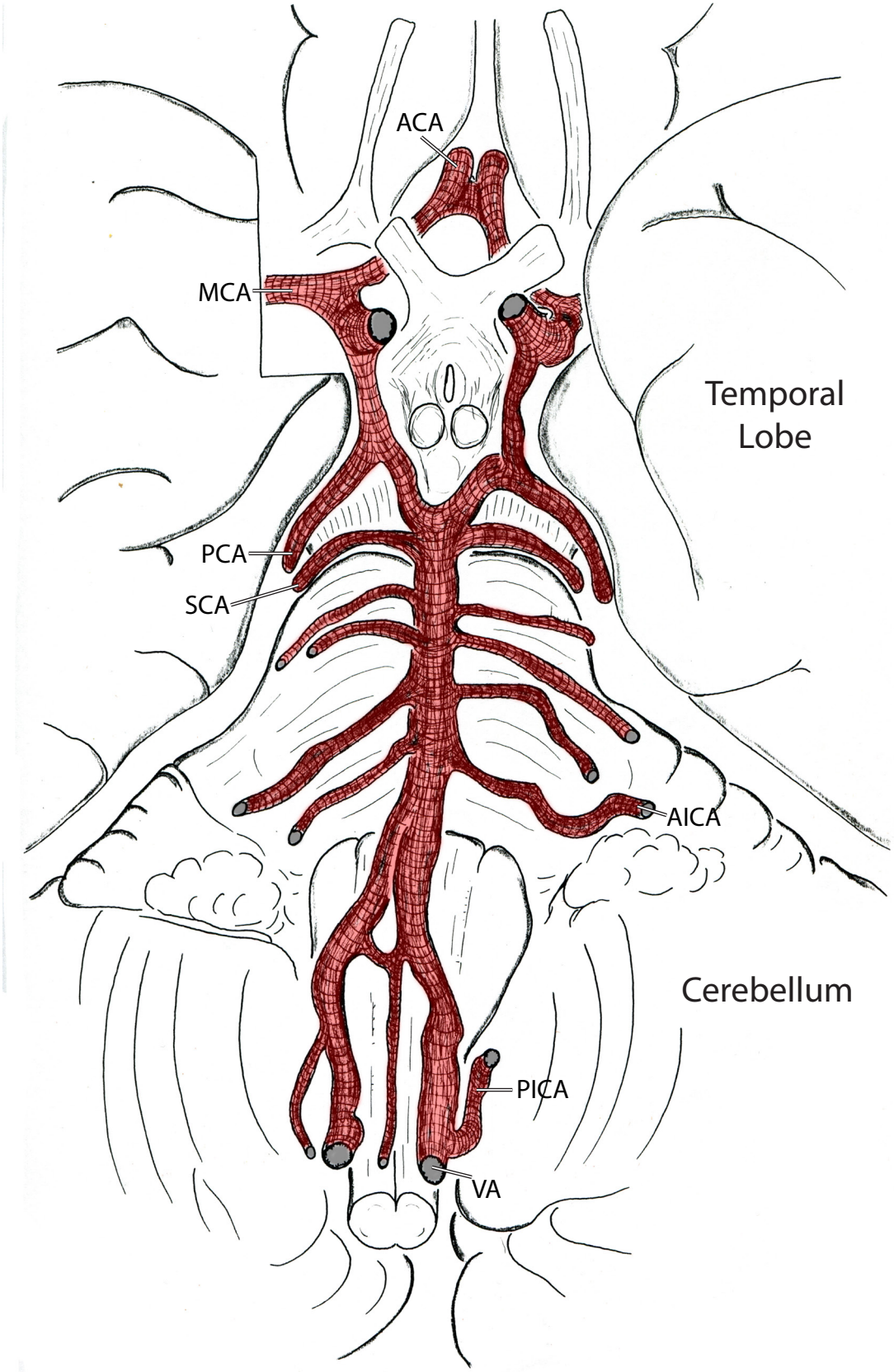


Figure 9-10 A diagram of the circle of Willis as seen from the ventral surface of the brain. (Abb.:ACA, anterior cerebral artery; AICA, anterior inferior cerebellar artery; MCA, middle cerebral artery; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; SCA, superior cerebellar artery; VA, vertebral artery;

concerned with their incontinence (Adams et al., 1997).

A language deficit can result from damage to the anterior cerebral artery. If it involves damage to the medial frontal lobe alone, it is characterized by a loss of spontaneous speech (nonfluent aphasia) in the face of preserved repetition and comprehension and is called transcortical motor aphasia (Rubens and Kertesz, 1983). Damage to the medial parietal lobe results in transcortical sensory aphasia, characterized by fluent but paraphasic spontaneous speech, poor comprehension, and preserved repetition. If both medial frontal and parietal lobes are involved in the lesion, transcortical mixed aphasia can result. Such individuals present with nonfluent speech, poor comprehension, but good repetition (Ross, 1980).

Middle Cerebral Artery (MCA)

The internal carotid ends by bifurcating to form the anterior cerebral and middle cerebral arteries (MCA) (Figure 8-10). The larger of the two branches, the middle cerebral is, in reality, a direct continuation of the internal carotid. It passes upward along the medial aspect of the temporal lobe, winds across the insula, and emerges from the lateral fissure onto the cortical surface. The normal anatomy and radiology of the middle cerebral artery are presented by Ring (Ring, 1974). The branches of the middle cerebral artery spread out to supply the lateral portions of frontal, parietal, and temporal cortex, as well as the extreme anterior border of occipital cortex (Figure 9-12). Anastomoses are established with posterior and anterior cerebral arteries.

The middle cerebral artery can be divided into three regions: a stem or horizontal portion and its penetrating branches, an upper division (ascending frontal branches), and a lower division. The stem passes from the carotid trunk into the insular region; its penetrating branches, the lateral striate arteries, supply caudate, putamen, anterior limb of the internal capsule, and globus pallidus (see Plates 22 to 25). The stem ends by bifurcating into upper and lower divisions. The upper division supplies the middle and inferior frontal gyri as well as the pre- and postcentral gyri. The lower division supplies the superior and inferior parietal lobules as well as the superior and inferior temporal gyri.

CLINICAL DISCUSSION: Defects in the perfusion of the middle cerebral artery are reviewed by Kase (Kase, 1988). Complete occlusion of the middle cerebral arterial stem results in massive damage to the cerebral hemisphere. The patient can present with contralateral hemiplegia of the face, arm, and leg. The whole leg is involved, since damage to the internal capsule undercuts the entire central sulcus. The paralytic side also experiences hemihyperesthesia, homonymous hemianopsia, and conjugate deviation of the eyes into the opposite hemisphere. Individuals with injury look toward the lesioned side because the frontal eye fields are damaged. If the occlusion is on the dominant side, global aphasia with no ability to repeat phrases can be present; if it is on the nondominant side, hemi-inattention, termed neglect, can be present.

Occlusion of the upper division can result in hemiparesis of the upper limbs and face. The lower limb can be spared because of its supply from the anterior cerebral artery. A somatic sensory defect accompanies the paralysis as well as nonfluent aphasia and agraphia (dominant side lesion) or inattention and neglect (nondominant side lesion). Volitional gaze into the contralateral hemisphere can be impaired due to involvement of the frontal eye fields. Occlusion of the lower division is characterized by a visual field defect and fluent aphasia, alexia and agraphia (dominant side lesion) or hemi-neglect syndromes (nondominant side lesion).

Posterior Cerebral Artery (PCA)

The posterior cerebral artery (PCA) arises as the termination of the basilar artery near the interpeduncular fossa (Figure 9-10). The normal anatomy and radiology have been presented by Margolis and colleagues (Margolis et al., 1974). In the ambient cistern, the artery passes laterally around the cerebral peduncles to course in a posterior direction along the medial border of temporal and occipital cortex. Branches of the posterior cerebral artery distribute to the midbrain and caudal thalamus (see Plates 20 and 21) and across the inferior surface of the temporal and occipital lobes (Figure 9-11). The territory supplied by the posterior cerebral artery includes the inferior temporal gyrus, parahippocampal gyrus, hippocampus, medial aspect of superior parietal gyrus, and portions of the occipital lobe. Anastomoses are established with the anterior and middle cerebral arteries.

CLINICAL DISCUSSION: A cardinal sign of damage to the posterior cerebral artery is homonymous hemianopsia, termed cortical blindness (Biller, 1996). If the damage is restricted to the calcarine area, patients can be aware of their visual field defects; however, if the damage involves the occipitotemporal or occipitoparietal association areas, visual neglect can occur although the patients deny loss of sight (Anton's syndrome). Damage to the area around the visual cortex can also result in visual hallucinations, such as perseverations and distortions of color vision.

If the pericallosal branch of the posterior cerebral artery on the dominant side is occluded, the splenium of the corpus callosum as well as part of the deep occipital cortex is affected. As a result, the input of visual information to the supramarginal and angular gyri is diminished. The patient can present with alexia without agraphia (i.e., can write but cannot read what has been written). Infarctions of the pos-

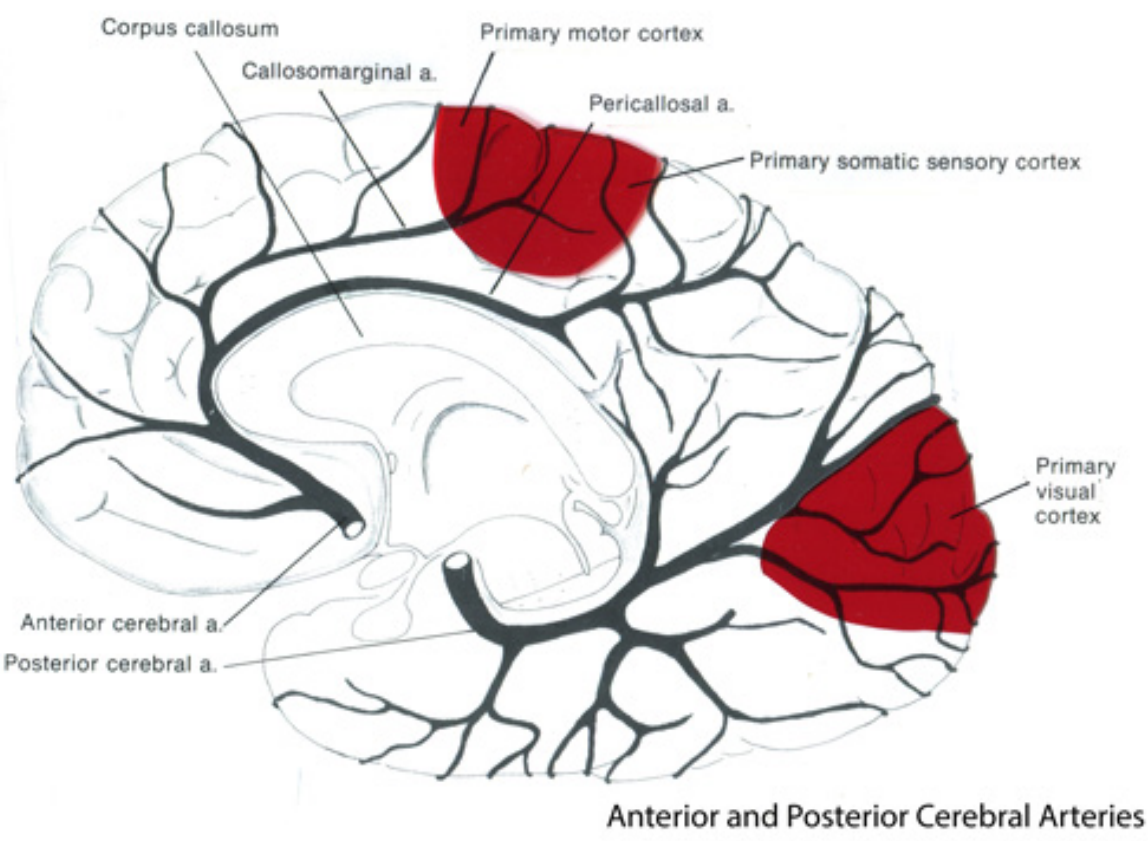


Figure 9-11 A diagram of a midsagittal view of the brain illustrates the distribution of the anterior and posterior cerebral arteries (Modified from Melloni BJ et al., Melloni's illustrated review of human anatomy. Philadelphia: JB Lippincott, 1988).

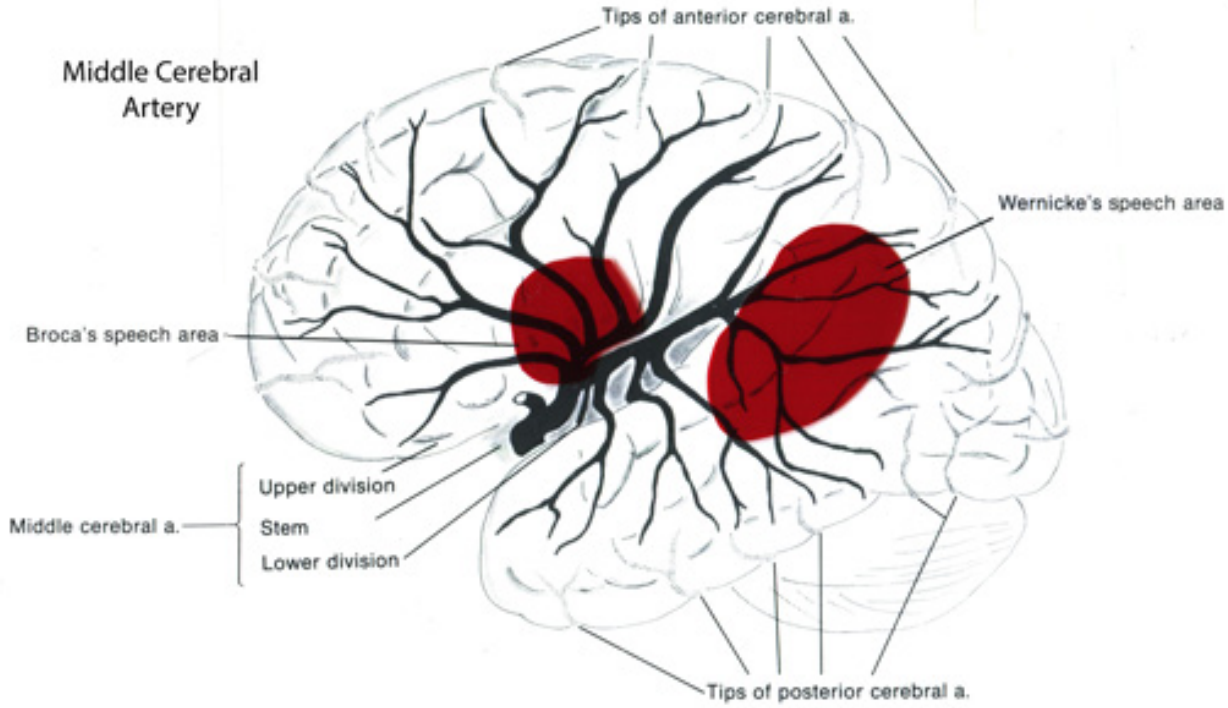


Figure 9-12 A diagram of a lateral view of the brain illustrates the distribution of the middle cerebral artery (Modified from Melloni BJ et al, Melloni's illustrated review of human anatomy. Philadelphia: JB Lippincott, 1988).

terior cerebral artery in the dominant hemisphere can also result in memory defects, transcortical sensory aphasia, or anomic aphasia. Infarction of posterior cerebral artery in the non-dominant hemisphere can result in visual neglect and constructional apraxia (Caplan, 1988).

References

Adams RD, Victor M, Ropper AH (1997) Principles of Neurology. New York: McGraw-Hill Health Professions Division.

Aldrich MS, Alessi AG, Beck RW, Gilman S (1987) Cortical blindness: etiology, diagnosis, and prognosis. Ann Neurol 21: 149-158.

Alexander MP, Fischer RS, Friedman R (1992) Lesion localization in apractic agraphia. Arch Neurol 49: 246-251.

Atlas S, Zimmermanm RA, Bilaniuk LT, Rorke L, Hackney DB, Goldberg HI, Grossman RI (1986) Corpus callosum and limbic sytem: neuroanatomic MR evaluation of developmental anomalies. Radiol 160: 355-362.

Barr ML, Kiernan JA (1993) The Human Nervous System: An Anatomical Viewpoint. Philadelphia: J.B. Lippincott.

Biller J (1996) Vascular syndromes of the cerebrum. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 535-564. Boston: Little, Brown and Company.

Bogousslavsky J, Regli F (1990) Anterior cerebral artery territory infartion in the Lausanne stroke registry. Arch Neurol 47: 144-150.

Caplan LR (1988) Posterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 409-415.

Caplan LR, Kelly M, Kase CS, Hier DB, White JL, Tatemichi T, Mohr J, Price T, Wolf P (1986) Infarcts of the inferior division of the right middle cerebral artery: mirror image of wernicke's aphasia. Neurol 36: 1015-1020.

Changeux J (1986) Neuronal Man. New York: Oxford University Press.

Clopton BM, Winfield JA, Flammino FJ (1974) Tonotopic organization: Review and Analysis. Brain Res 76: 1-20.

Crosby EC, Schnitzlein HN (1982) Comparative Correlative Neuroanatomy of the Vertebrate Telencephalon. New York: MacMillan Pub. Co., Inc.

Damasio AR (1981) The nature of aphasia: signs and syndromes. In: Acquired Aphasia (Sarno MT, ed), pp 51-65. New York: Academic Press, Inc.

Damasio H, Damasio AR (1989) Lesion Analysis in Neuropsychology. New York: Oxford University Press.

Davidson HD, Abraham R, Steiner RE (1985) Agenesis of the corpus callosum: magnetic resonance imaging. Radiol 155: 371-373.

Dobyns WB (1989) Agenesis of the corpus callosum and gyral malformations are frequent manifestation of nonketotic hyperglycinemia. Neurol 39: 817-820.

Freund H-J, Hummelsheim H (1985) Lesions of the premotor cortex in man. Brain 108: 697-733.

Geschwind N (1975) The apraxias: neural mechanisms of disorders of learned movement. Am Sci 63: 188-195.

Geschwind N (1979) Specializations of the human brain. Sci Am 241: 180-199.

Geschwind N, Galaburada AM (1985a) Cerebral localization. Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. Arch Neurol 42: 428-459.

Geschwind N, Galaburada AM (1985b) Cerebral localization. Biological mechanisms, associations, and pathology: II. A hypothesis and a program for research. Arch Neurol 42: 521-552.

Geschwind N, Galaburada AM (1985c) Cerebral localization. Biological mechanisms, associations, and pathology: III. A hypothesis and a program for research. Arch Neurol 42: 634-654.

Henneman E (1980) Motor functions of the cerebral cortex. In: Medical Physiology (Mountcastle VB, ed), pp 859-889. St Louis: The C.V. Mosby Co.

Hung T-P, Ryu S-J (1988) Anterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 339-352.

Kaas JH (1990) Somatosensory system. In: The Human Nervous System (Paxinos G, ed), pp 813-844. San Diego: Academic Press, Inc.

Kandel ER, Schwartz JH, Jessell TM (1991) Principles of Neural Sciences. New York: Elsevier.

Kase CS (1988) Middle cerebral arterial syndromes. Hdbk Clin Neurol 53(9): 353-370.

Kertesz A (1983) The localization of lesions in Wernicke's aphasias. In: Localization in Neuropsychology (Kertesz A, ed), pp 209-230. New York: Academic Press, Inc.

Kolodny EH (1989) Agenesis of the corpus callosum: a marker for inherited metabolic disease? Neurol 39: 847-848.

Levine DN, Sweet E (1983) Localization of lesions in Broca's aphasia. In: Localization in Neuropsychology (Kertesz A, ed), pp 185-208. New York: Academic Press, Inc.

Lhermitte F, Pillon B, Serdaru M (1986) Human autonomy and the frontal lobes. Part I: Imitation and utilization behavior: A neuropsychological study of 75 patients. Ann Neurol 19: 326-334.

Lin JP, Kricheff II (1974) Normal anterior cerebral artery complex.

In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1391-1410. Saint Louis: The C.V. Mosby Company.

Margolis MT, Newton TH, Hoyt WF (1974) The posterior cerebral artery: Gross and roentgenographic anatomy. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1551-1579. Saint Louis: The C.V. Mosby Company.

Masdeu JC (1996) The localization of lesions affecting the cerebral hemispheres. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 449-534. Boston: Little, Brown and Company.

Mesulam M-M (1981) A cortical network for directed attention and unilateral neglect. Ann Neurol 10: 309-325.

Mesulam M-M (1986) Frontal Cortex and Behavior. Ann Neurol 19: 320-325.

Mesulam M-M (1990) Large scale neurocognitive networks and distributed processing for attention, language, and memory. Ann Neurol 28: 597-613.

Moscow NP, Michotey P, Salamon G (1974) Antaomy of the cortical branches of the anterior cerebral artery. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1411-1420. Saint Louis: The C.V. Mosby Company.

Nauta WJH (1971) The problem of the frontal lobe: reinterpretation. Journal of Psychiatric Research 8: 167-187.

Nieuwenhuys R, Voogd J, van Huijzen C (1988) The Human Central Nervous System. Berlin: Springer-Verlag.

Paillard J, Michel F, Stelmach G (1983) Localization without content: a tactile analogue of "blind sight". Arch Neurol 40: 548-551.

Ring AB (1974) Normal middle cerebral artery. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1442-1470. Saint Louis: The C.V. Mosby Company.

Ross ED (1980) Left medial parietal lobe and receptive language functions: mixed transcortical aphasia and left anterior cerebral artery infarction. Neurol 30: 144-151.

Rubens AB, Kertesz A (1983) The localization of lesions in transcortical aphasias. In: Localization in Neuropsychology (Kertesz A, ed), pp 245-268. New York: Academic Press, Inc.

Ruggiero DA, Mraovitch S, Granata AR, Anwar M, Reis DJ (1987) A role of insular cortex in cardiovascular function. J Comp Neurol 257: 189-207.

Sergent J (1987) A new look at the human split brain. Brain 110: 1375-1392.

Shipley MT, Geinisman Y (1984) Anatomical evidence for convergence of olfactory, gustatory, and visceral afferent pathways in mouse cerebral cortex. Brain Res Bull 12: 221-226.

Sperry RW (1968) Mental unity following surgical disconnection of the cerebral hemispheres. Harvey Lectures 62: 293-323.

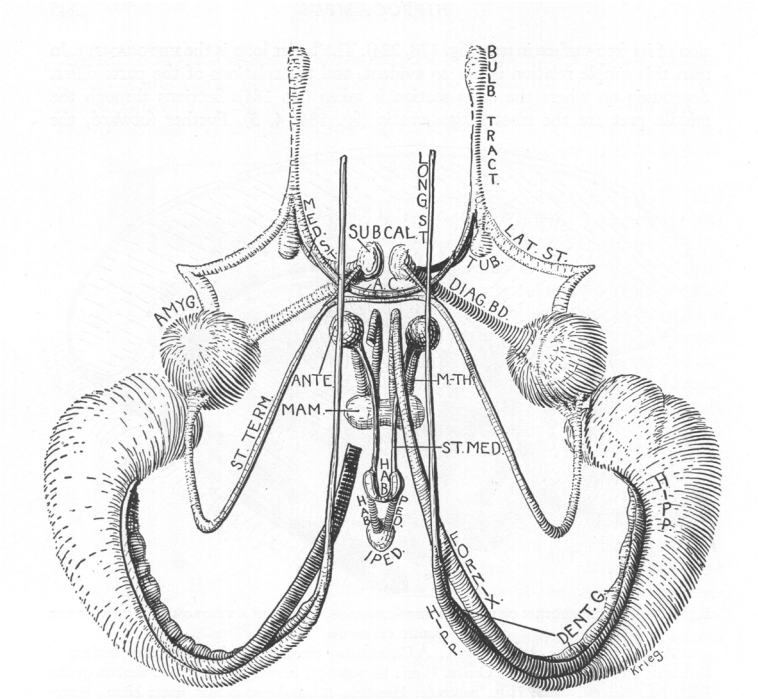
Sperry RW (1974) Lateral specialization in the surgically separated hemispheres. In: The Neurosciences: Third Study Program (Schmitt FO, Worden FG, eds), pp 5-19. Cambridge, MA: The MIT Press.

Watson RT, Fleet WS, Gonzalez-Rothi L, Heilman KM (1986) Apraxia and the supplementary motor area. Arch Neurol 43: 787-792.

Webster WR, Garey LJ (1990) Auditory system. In: The Human Nervous System (Paxinos G, ed), pp 889-944. San Diego: Academic Press, Inc.

Williams PL (1995) Gray's Anatomy: The Anatomical Basis of Medicine and Surgery. Edinburgh: Churchill Livingston.

Chapter 10
The Limbic Lobe



▶ Introduction

The limbic lobe of the cerebrum consists of the cingulate and parahippocampal gyri: two structures that are wrapped around the rostral portion of the brain stem and that form the medial border of the cerebral cortex. Deep to the parahippocampal gyrus are the hippocampus and amygdala. The hippocampus represents the oldest portion of the cerebral cortex (archicortex), and the amygdala is a rostral extension of the tail of the caudate nucleus.

The limbic lobe structures can be considered a neural interface between external and internal environments, receiving converging sensory information at the cerebral cortical level from the five sensory systems representing the extrapersonal world as well as that from the visceral sensory system, which represents the intrapersonal world. This information is funneled through the hippocampus and amygdala and projected on to the hypothalamus, where it can regulate our behavioral responses. Although they are not well understood, these circuitous neural routes through the limbic system modulate the activity of the autonomic nervous system and the endocrine system, and through these two structures, influence the activity of the immune system. The limbic structures also play an important role in various aspects of learning, memory, and emotions.

In this chapter the structure and connections of four components of the limbic lobe - cingulate gyrus, parahippocampal gyrus, hippocampus, and amygdala - will be studied, and their functions will be examined. The vasculature of the limbic lobe will be reviewed and several clinicopathologic cases presented.

GENERAL OBJECTIVES

1. To learn the location, connections, and function of the limbic lobe structures

2. To learn the major neurologic deficits occurring consequent to damage in specific limbic lobe structure

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using a knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before attempting to answer the questions, compile a list of the patient's neurologic signs and symptoms; then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources, such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. Horizontal and coronal sections of the human brain
2. A human brain cut in the midsagittal plane

Chapter Ten Topics:

CASE STUDY 10-1

Chief Complaint

A 38-year-old trauma victim now experiencing loss of consciousness

History of Chief Complaint

A 38-year-old, right-handed, male received a blow to the right side of his skull with the butt of a rifle 6 years ago. At the time of the accident he suffered no syncope or seizures. A subdural hematoma was removed from the right side of the patient. Nine months subsequent to the trauma, he developed seizures. Recently, because of the increased severity of the seizures, his wife brought him to the emergency room at the hospital for examination. They are now seeking consultation for surgery.

Past Medical History

At the time of the examination he was a private with 10 years of service in the army. He had experienced head trauma to the head while on practice maneuvers in the Middle East. He had had several other accident involving automobiles and at least one involving a motorcycle. He had no history of syncope or seizures prior to the traumatic event with the rifle.

Subsequent to being stuck on the head with a rifle butt, he developed seizures characterized by onset of dizziness and followed by an olfactory sensation of foul odor, such as that of vomitus. He then would assume a blank stare and often demonstrate several automatisms, including lip-smacking and rubbing his hands on his shirt. During these periods, he would not respond to questions or statements. He has experienced periods characterized by a sense of light-headedness and mingled thoughts. He occasionally hears voices that give him commands, and he has had periods of automatisms during which he lacked conscious awareness of his acts.

General Physical Examination

At the time of examination, he was an alert, well-hydrated, well-nourished male, oriented for time and place, and appeared his stated age. His body had numerous scars, presumably from previous traumatic injuries. Optic discs were sharp, with no hemorrhagic spots. Visual fields were full to confrontation. Chest was clear to auscultation and percussion. Abdomen was soft, with no masses or tenderness. Blood pressure, pulse, temperature, and respirations were normal.

Neurologic Examination

Mental Status. The patient was alert and oriented to time and place. Knowledge and memory seemed appropriate for his age and occupation. Speech, writing, and reading were intact. He complained of periods when he could not recall events; these times coincided with the seizure events as described by his wife.

Cranial Nerves. His visual fields were full to confrontation, and a full range of eye movements was present. His hearing was normal in both ears. His face had a full range of expression; corneal and jaw-jerk reflexes were intact. His palate and uvula elevated midline; the tongue protruded midline. His shoulders shrugged bilaterally.

Motor Systems. His limb muscles were normotonic with bilaterally symmetric reflexes in all extremities. No weakness, tremor, or dysmetria were present. He exhibited no past pointing or pronator drift.

Sensation. Pinprick, temperature, vibratory, and proprioceptive senses were intact throughout the body and face.

Tests

Interictal EEG studies were normal. Those taken during seizure revealed a predominant right temporal focal involvement.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

CASE STUDY 10-2

Chief Complaint

A 55-year-old man with profound memory loss following cardiovascualr surgery

History of Chief Complaint

This is a 55-year-old, male government worker retired because of medical disability. During coronary surgery he suffered several extended periods of anoxia and has experienced severe neurologic consequences. He is presenting for a checkup, 4 years postsurgery.

Past Medical History

Five years ago, this patient was diagnosed with coronary artery occlusion, and bypass surgery was performed. During recovery, an atrial tear resulted in a significant loss of blood. The patient experienced a 15-minute period of hypoxia. The tear was repaired; however, during this second trip to the operating room, the patient's EEG was flat and his pupils were fixed. The following day, further bleeding required a third trip to the operating room; again his pupils were fixed and the EEG was diminished in amplitude.

Over the next 2 days the patient gradually regained consciousness. He had reduced strength and paresthesia in the left arm. He also demonstrated severe memory loss and confusion with respect to time and place. Prior to the surgical event, he had no history of neurologic signs or symptoms.

General Physical Examination

This was a well-nourished, well-hydrated, obese male who was alert and cooperative and in no acute distress. Carotid auscultation revealed a soft bruit without radiation on the right. Heartbeat was regular; a grade III harsh systolic murmur, auscultated best at the second intercostal space on the right, with an S4 gallop was present. Peripheral pulses were intact. Lungs were clear to auscultation and percussion. The abdomen was soft, without masses, tenderness, rigidity, or rebound. A +2 peripheral, dependent edema was noted in the lower extremities bilaterally. Skin was sallow in appearance, with poor texture and turgor. A well-healed cicatrix of the anterior chest wall extended from the second intercostal space to the diaphragmatic area; a healed 2-cm cicatrix was noted in the left antecubital fossa; and a healed 1-cm cicatrix was located in the left subclavicular area.

Neurologic Examination

Mental Status. The patient was disoriented with respect to time and place and could not describe the reason for his past hospital confinement or recall the history of his illness. However, his speech, naming, reading aloud, and comprehension were all normal for his age. He rapidly forgot information recently expressed to him; he could not recognize any words presented to him 5 minutes previously. He could not recall the names of staff or physicians in either the office or the hospital. Prior to his illness, he had had a strong interest in American history and politics. During the examination

he could recall most of the president's names and supply some details concerning their era, but he could not identify the current president or describe any recent historical events. He frequently relied on his family members to provide any recent descriptions of his life. He did not recall why he was ill or any of the events occurring around the time of his cardiac surgery. No other significant personality changes or cognitive deficits were detectable in the patient.

Cranial Nerves. His visual fields were full to confrontation; fundoscopic examination revealed AV nicking and silver wire changes without exudates, hemorrhages, or papilledema. His hearing was slightly diminished in both ears. A full range of facial expression was present, and the jaw-jerk reflex was normal. Palate and uvula elevated symmetrically, and the tongue protruded on the midline.

Motor Systems. Although the patient had motion in all extremities, strength was dimin¬ished on the left side, with slightly elevated deep tendon reflexes and a Babinski sign. Strength in the left upper extremity was +3/5 and +4/5 in the left lower extremity.

Sensation. Vibratory sense, proprioception, and discriminative touch were diminished but not absent in the left and normal in the right extremities. Paresthesias (tingling sensations) were found involving the patient's left hand and forearm.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION I

LIMBIC LOBE STRUCTURES

CINGULATE CORTEX

The cingulate gyrus (areas 23 and 24 of Brodmann) is best seen on a midsagittal section of a whole brain. This structure stretches along the medial wall of cortex (Figure 10-1) at the base of the longitudinal fissure, in close relationship to the superior surface of the corpus callosum. Rostrally, the cingulate gyrus is continuous, with the inferior frontal cortex, and caudally, with the parahippocampal gyrus through a narrowing called the isthmus. The cingulate and parahippocampal gyri represent the limbic lobe of the cortex and form an annulus (limbus or rim) around the rostral end of the brain stem (Papez, 1937).

The connections of the primate cingulate gyrus are extensive (Baleydier and Mauguiere, 1980). Cortical fibers to the cingulate arise in the association areas, such as prefrontal and posterior parietal. The thalamic fibers to the cingulate cortex arise in the anterior, ventroanterior, and dorsomedial nuclei. Projections from the cingulate gyrus return to the prefrontal and posterior parietal cortex as well as targeting the parahippocampal gyrus. Axons from the parahippocampal gyrus enter the hippocampus proper, from which the hypothalamus and thalamus are innervated. Thalamocortical projections complete a loop back to the cingulate. This recurrent circuit forms a major component of the limbic system (Papez, 1937).

The functions of the cingulate gyrus and related limbic lobe are heteromodal and extremely complex. Some aspects of these functions have been demonstrated by electrical stimulation studies performed in surgery (Baleydier and Mauguiere, 1980) and by positron-emission tomographic studies in human volunteers (Roland, 1992). Alteration in blood pressure, heart and respiratory rate, pupil diameter, and piloerection as well as more complex responses, such as fear, anxiety, and pleasure, have all been observed following stimulation of the cingulate gyrus. Positron-emission tomographic studies of volunteers exposed to painful stimuli have demonstrated that the anterior portion of the cingulate gyrus is the one area of cortex consistently activated in response to nociceptive (painful) stimuli (Roland, 1992).
Based on connectivity, as well as stimulation and ablation studies, a unified description of cingulate cortical function has been developed (Mesulam, 1981). This region of cortex appears to integrate sensory information from association portions of neocortex and the limbic system. By attaching a motivational relevance to stimuli based on the bias set by the intrapersonal and extrapersonal sensorium, cingulate gyrus can direct attention to specific stimuli through its extensive intracortical connections and, through its limbic system output to the hypothalamus, it can also engage the endocrine and autonomic nervous systems in the overall response.

CLINICAL DISCUSSION Damage to the cingulate gyrus can present as akinesia (lack of response), apathy (lack of attention or concern), mutism, incontinence, or indifference to pain. Cingulectomies have been performed to treat patients in intractable pain and with psychotic and neurotic conditions (Adams et al., 1997). A form of contralateral neglect syndrome has also been observed after unilateral lesions of the cingulate gyrus in rhesus monkeys (Watson et al., 1973).

PIRIFORM CORTEX

The piriform cortex is found on the inferior surface of the temporal lobe. From an evolutionary perspective, it is older than the more lateral and superior neocortex, having only three cytologically definable layers, compared to the six layers found in the neocortex. The piriform cortex represents the most inferomedial border of the cerebrum. It is best seen on the inferior surface of the brain, where it covers most of the parahippocampal gyrus (Figure 10-2). As such, the mantle of piriform cortex overlies portions of the hippocampus and amygdala. A distinctive feature of the piriform cortex is that it contains the cortical representation of the olfactory system.

Olfactory Cortex

The olfactory bulb is located at the rostral tip of the olfactory tract and receives primary afferent fibers from bipolar neurons in the portions of the nasal epithelium. As the olfactory tract approaches the ventral forebrain, it divides into medial and lateral striae (Figure 10-2). Between the striae is the anterior perforated substance, a region richly supplied with vasculature. The medial stria crosses the midline to innervate the contralateral olfactory bulb and a small portion of the contralateral olfactory forebrain. The lateral olfactory stria enters the medial aspect of the ipsilateral temporal lobe and its fibers spread out through a portion of the piriform cortex. That portion of piriform cortex receiving axons directly from

neurons in the olfactory bulb is called the primary olfactory cortex. The remainder of the piriform cortex receives projections not from the bulb, but from primary olfactory cortex. Therefore, this region is called the secondary olfactory cortex. The primary olfactory cortex corresponds approximately to the region of the uncus, a protuberance on the medial aspect of the temporal lobe, whereas the secondary olfactory cortex approximates the entorhinal area (Figure 9 2).

CLINICAL DISCUSSION Damage or irritation to the medial aspect of temporal lobe, including the olfactory cortex, can present as complex partial seizures with preceding olfactory hallucinations (Strobos, 1961). Patients experience cacosmia, the sensation of unpleasant or foul odors, especially preceding the onset of the seizure.

Uncus

A large bulge, the uncus, is present on the medial aspect of the temporal lobe. It is created by the almond-shaped nucleus, the amygdala, lying under the surface of the parahippocampal gyrus. A thin veneer of piriform cortex overlies the amygdala. This cortex receives primary olfactory axons from the olfactory bulb; as such, it represents the primary olfactory cortex. Major projections from the primary olfactory cortex reach the amygdala; others reach the secondary olfactory cortex (entorhinal area) as well as possibly the hypothalamus (Price, 1990).

CLINICAL DISCUSSION Unilateral lesions of the uncus are not well documented in the clinical literature; bilateral lesions damage the amygdala and can result in the Kluver-Bucy syndrome. Another clinical significance of the uncus involves its physical location. Expansion of the cerebral hemisphere due to edema or a lesion can push the uncus ventromedially onto the third cranial nerve and brain stem, resulting in third nerve palsy (see Chapter 7).

Entorhinal Area

The entorhinal area (sometimes called the entorhinal cortex) is the visible portion of the parahippocampal gyrus when examined from an inferior view (Figure 10-2). Laterally, it is bordered by the collateral sulcus; the optic tract and brain

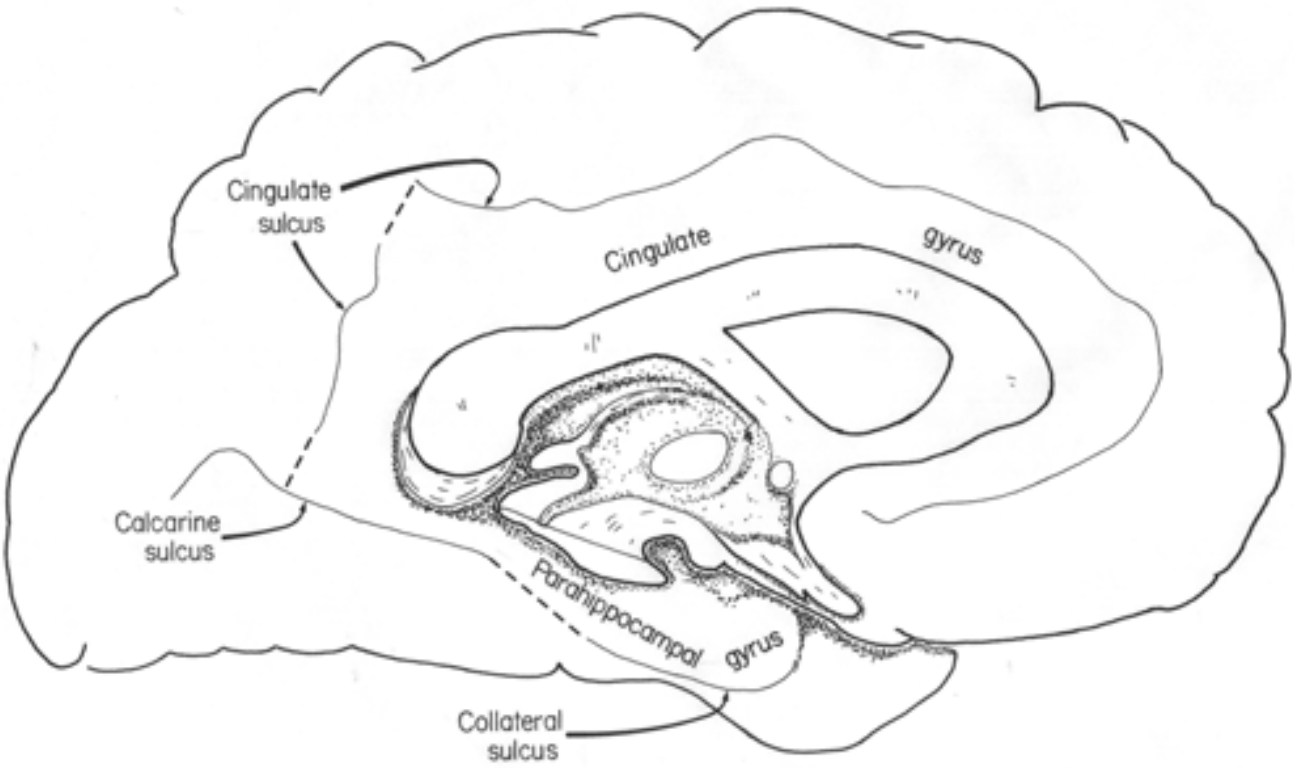


Figure 10-1. Medial view of brain outlining the limbic lobe composed of the cingulate and parahippocampal gyri.

stem form the medial border. A thin veneer of piriform cortex overlies the entorhinal area. It receives information from the olfactory cortex and association areas in frontal, parietal, and temporal cortex and sends information directly to the hippocampus. The entorhinal area is closely tied to the functions of the hippocampus, which involve various forms of memory and emotional behavior.

CLINICAL DISCUSSION Because of their close juxtaposition, damage to or irritation of entorhinal cortex is difficult to distinguish from that of the hippocampus. Consequently they will be considered in the discussion of the hippocampus.

HIPPOCAMPAL FORMATION

The medial aspect of the temporal lobe (parahippocampal gyrus) is folded inward to form the hippocampus. This C-shaped structure lies on the medial aspect of the inferior

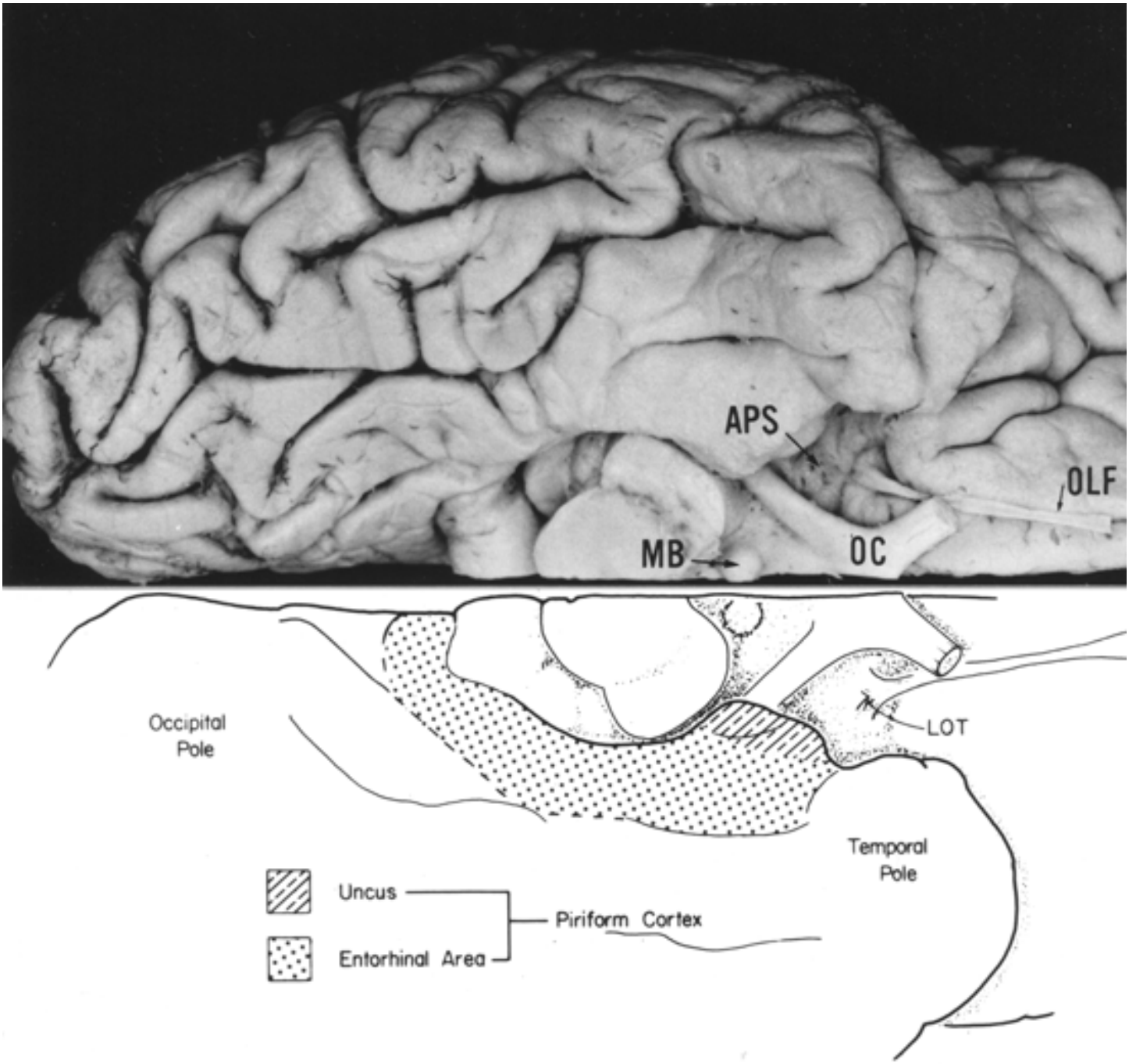


Figure 10-2. This ventral view of the brain illustrates the piriform cortex covering the parahippocampal gyrus. The photograph (above) illustrates the location of the anterior perforated substance (APS), mamillary bodies (MB), optic chiasm (OC), and olfactory tract (OLF). The companion line drawing (below) illustrates the location of the lateral olfactory tract (LOT) and the two regions of the piriform cortex: uncus and entorhinal cortex.

horn of the lateral ventricle and arches around the rostral end of the brain stem. The rostral pole of the hippocampus abuts the amygdala in the temporal lobe; its caudal pole ends in a fiber tract, the fornix. This tract curves superiorly and rostrally to course under the corpus callosum and then descends rostral to the thalamus, finally terminating in the mamillary bodies of the hypothalamus. The fornix contains many afferent and efferent connections of the hippocampus (Amaral and Insausti, 1990).

The hippocampus is a folded sheet of cerebral cortex. It has a trilayered organization, composed of a central layer of pyramidal cells, with sheets of fibers on either side. The pyramidal cell layer is differentiated into four longitudinal stripes called CA1, CA2, CA3, and CA4, with a ridge of small granule cells forming the outer border of CA4. This granule cell layer is termed the dentate gyrus.

The major afferent connections reaching the hippocampus arise in the ipsilateral amygdala, claustrum, septal area, numerous regions of the hypothalamus and thalamus, and the ipsilateral entorhinal cortex. This latter structure receives projections from the major association portions of parietal, frontal, and temporal neocortex. The hippocampus also receives fibers from several chemically defined pathways in the brain stem. Fibers arising in the ventral tegmental nucleus (VTA; see Plate 20) contain dopamine. Those coming from the raphe nuclei (RaNu; see Plate 18) contain serotonin and

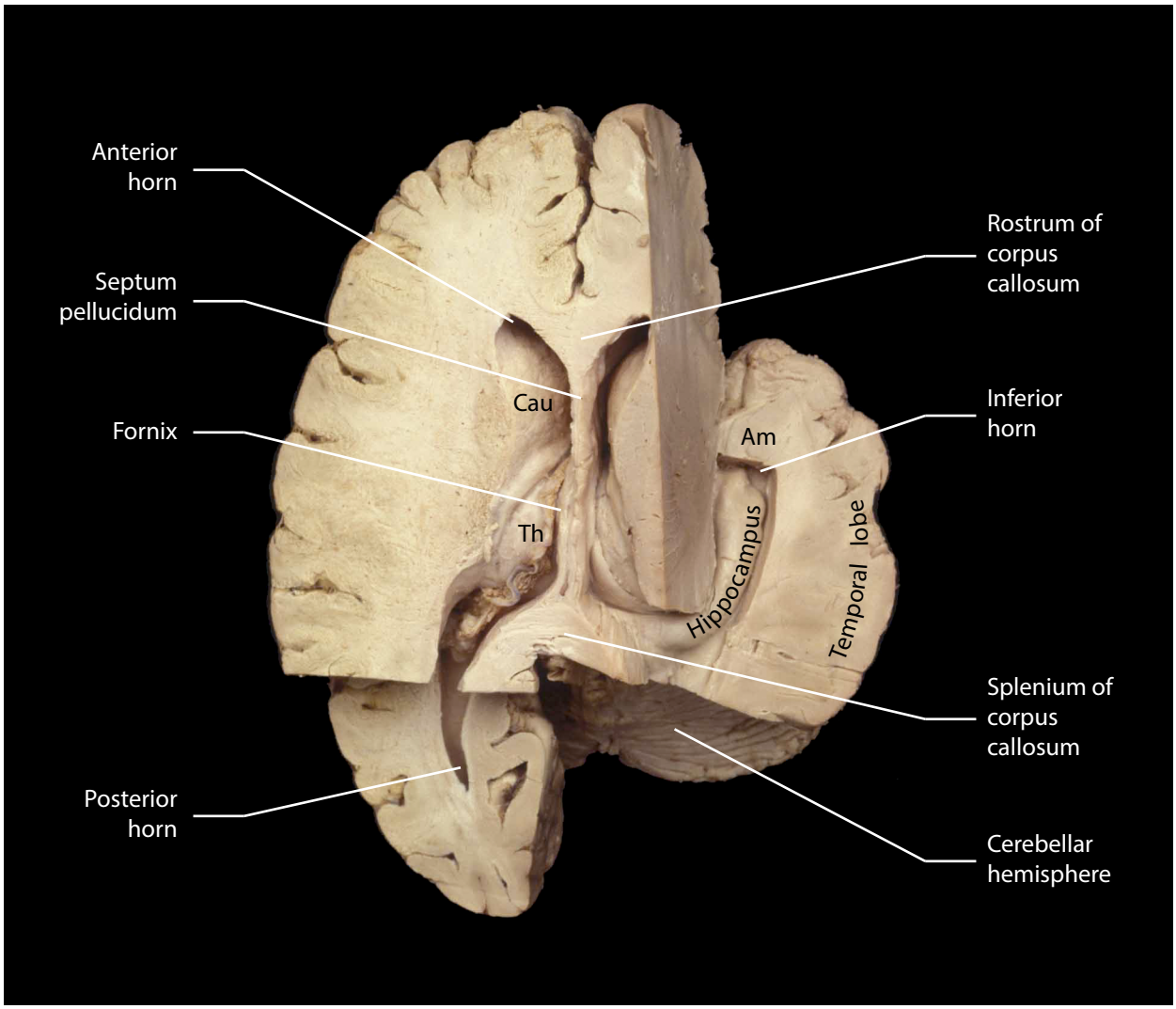


Figure 10-3 A superior view of the brain. An axial section through the cerebrum reveals the anterior horn, body and posterior horn of the lateral ventricular system. A parasagittal section in the right cerebral hemisphere reveals the inferior horn. The hippocampal formation can be seen as a curved mass lying along the medial aspect of the inferior horn. At the rostral end of the hippocampal formation, the amygdala is represented as a mass of gray.

those from the locus coeruleus (LC see Plate 15) release norepinephrine.

The fornix represents a major efferent pathway for the hippocampus (Figure 9 4). Fibers in the fornix innervate the septal area, hypothalamus, and portions of the thalamus. Based on its connections, it appears that the hippocampus assembles sensory information as processed in the neocortex and forms an output to the rostral end of the brain stem.

The hippocampal formation is a target of several cerebral pathologies (Amaral and Insausti, 1990). The region of the hippocampus called CA1, also known as the Sommer sector, is particularly sensitive to anoxia and ischemia (Petito et al., 1987). Loss of cells in this region may play a role in the anterograde amnesia that follows prolonged periods of anoxia, consequent to cardiorespiratory arrest (Zola-Morgan et al., 1986). The most consistent site of cellular degeneration in temporal lobe epilepsy is also in the Sommer sector (CA1). In some cases, the loss of cells from this portion of the hippocampus is quite striking. Finally, extensive loss of neurons and excessive accumulation of neurofibrillary tangles can occur in the CA1 region in Alzheimer's disease.

CLINICAL DISCUSSION The most striking deficit resulting from bilateral damage to the medial aspect of the temporal lobe in humans is amnesia (Petito et al., 1987;Zola-Morgan et al., 1986;Cummings et al., 1984;Penfield and Mathieson, 1974;Scoville and Milner, 1957;Duyckaerts et al., 1985). Memory for events predating the incident is intact (retrograde memory) however, there is limited or no ability to form new memory traces (anterograde amnesia). Restricted lesions in monkeys (Zola-Morgan et al., 1989a) and humans (Zola-Morgan et al., 1986) have demonstrated that these

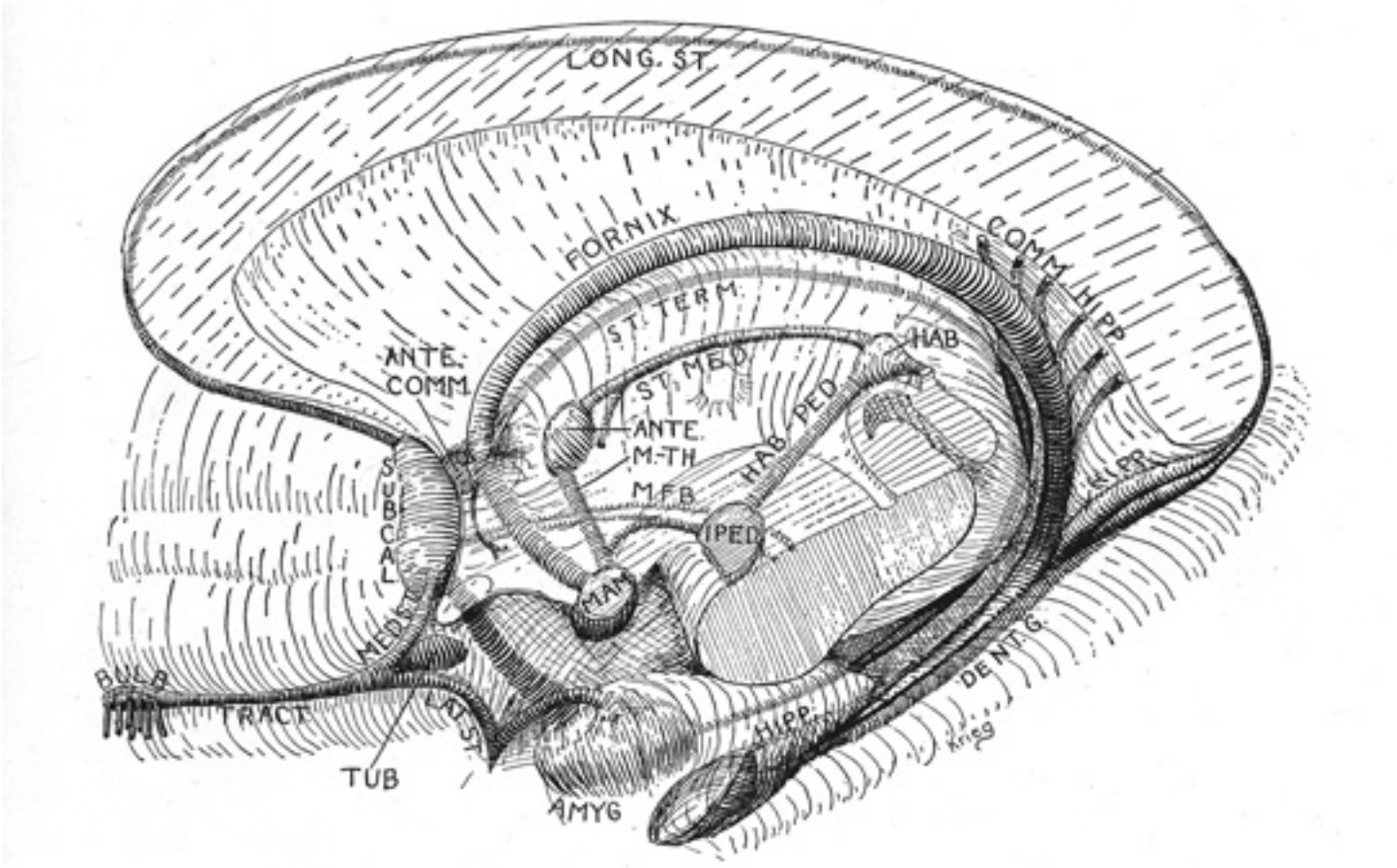


Figure 10-4 A diagram of the hippocampus, fornix, and thalamic nuclei involved in the limbic circuits as seen from the ventromedial surface of the brain. Amyg, amygdala; Ante Comm, AC, anterior commissure; Ante, anterior nucleus of thalamus; Bulb, olfactory bulb; Comm Hipp, hippocampal commissure; DentG, dentate gyrus; Diag Bd, diagonal band; Hab, habenula; Hab-ped, habenulopeduncular tract; Hipp, hippocampus; Iped, interpeduncular nucleus; LatSt, lateral olfactory stria; Long St, longitudinal stria; Mam, mamillary body; MedSt, medial olfactory stria; MFB, medial forebrain bundle; M-th, mamillothalamic tract; StMed, stria medullaris; StTerm, stria terminalis; Subcal, subcallosal gyrus; Tract, olfactory tract; Tub, olfactory tubercle. (Kreig W, Functional neuroanatomy. 2nd ed. Toronto: Blakiston, 1953:345)

memory losses can be obtained by damage to the hippocampus and/or its overlying entorhinal cortex. Pure lesions of the amygdala did not produce these memory deficits (Zola-Morgan et al., 1989b).

Unilateral lesions of the hippocampus also produce memory dysfunctions. However, the specific type of deficits is lateralized. Lesions of the temporal lobe of the dominant side result in language-related memory losses, whereas those of the nondominant temporal lobe present with deficits in retaining nonverbal patterns, such as geometric or tonal patterns (Masdeu, 1996).

Recently, it has been demonstrated that the hippocampal damage resulting from the ischemia of cardiac arrest is delayed by as much as 24 hours postinsult (Petito et al., 1987). This is considerably longer than the time taken for damage to appear in other areas in the brain. The delay time between insult and damage in the hippocampus may offer an opportunity for therapeutic intervention.

AMYGDALA

At the rostral end of the hippocampus, deep to the piriform cortex, is an almond-shaped mass of cells called the amygdala. When it is viewed externally, it forms a bump known as the uncus on the medial aspect of the temporal lobe (Figure 9 3). Some of the afferent connections to the amygdala come from the olfactory cortex. The amygdala also receives sensory information concerning the external environment from the frontal, parietal, and temporal association neocortex as well as viscerosensory information from the nucleus of the solitary tract and the dorsal motor nucleus of the vagus. The major output of the amygdala occurs through the ventral amygdalofugal pathway and the stria terminalis. Using these tracts, projections from the amygdala pass to the prefrontal and premotor cortex, the hypothalamus, the septal area, and the dorsomedial nucleus of the thalamus as well as to many brain stem nuclei, including the dorsal motor nucleus of the vagus.

The amygdala is part of the limbic system circuitry relating the neocortex to the autonomic control portions of the brain. It is involved in modulating neuroendocrine functions and autonomic effector mechanisms. It appears to play a role in complex patterned behavior, such as ingestion, aggression, reproduction, and in the processes of memory and learning (de Olmos, 1990).

CLINICAL DISCUSSION Damage to the medial aspect of the temporal lobe can present as the temporal lobe syndrome of amnesia. The extent to which the amygdala is involved in this amnesia has long been debated. Monkeys receiving isolated lesions of the amygdala performed well on a battery of memory tests (Zola-Morgan et al., 1989b) that were severely compromised in monkeys having isolated lesions of the hippocampus (Zola-Morgan et al., 1989c) or entorhinal cortex (Zola-Morgan et al., 1989a). Although these observations tend to minimize the function of the amygdala, it appears likely that this structure plays other roles in the memory process. Sophisticated behavioral testing of memory loss in primates with lesions carefully restricted to the amygdala demonstrates that the affected component relates to polysensory input. Animals with bilateral amygdaloectomies could make associations dependent on one sensory modality, but faulted in recall associations contingent on input from two or more sensory systems (Mishkin and Appenzeller, 1987). Bilateral damage to the amygdala and surrounding temporal lobe in humans and other primates produces the Kluver-Bucy syndrome. Initially dubbed "psychic blindness," after its more salient sign, the disease involves the following characteristics (Kluver and Bucy, 1937):

- Psychic blindness. Inability to recognize common objects in the face of normal visual fields, in humans this takes the form of visual agnosia (most likely this results from damage to the surrounding temporal lobe).
- Oral tendencies. Most objects encountered are examined by mouth and smell.
- Hypermetamorphosis. A compulsion to attend and react to every visual stimulus, regardless of its significance.
- Emotional changes. A marked diminution of behavior associated with anger or fear; all objects are approached without caution.
- Sexual behavior. A striking increase in the amount of auto-, homo-, and heterosexual behavior
- Dietary habits. Compulsive and indiscriminate eating of any food offered.

This syndrome has been re-created, in part, in a humans following bilateral temporal lobe surgery to alleviate intractable epilepsy (Terzian and Dalle Ore, 1955) Spontaneous expression of Kluver-Bucy syndrome has arisen in patients subsequent to inflammatory or degenerative processes affecting the temporal lobes. In a cohort of 12 patients expressing the syndrome, causative factors included head trauma, Alzheimer's and Pick's disease, and herpes encephalitis (Lilly et al., 1983). Discrete lesions of the temporal cortex or amygdala were capable of producing specific signs of Kluver-Bucy syndrome (Horel et al., 1975). Most of the behavioral signs could be elicited subsequent to amygdaloectomy with the exception of visual agnosia, which is probably developed from damage to the inferior temporal lobe.

Case Study 10-3

Chief Complaint
A 33 year-old man with memory loss and complaining of visual hallucinations

History of the Chief Complaint
A 33-year-old unemployed migrant worker was brought to the emergency room by the police. He had been found wandering the streets and rubbing his nose. He was quite confused and disoriented, complaining of smelling burning odors and seeing large people and trucks in the emergency room. The patient could give no information on his activities for the last 3 hours.

Medical History
The patient denied any recent or past history of trauma, and there were no indications of trauma (bruises, swelling, or discoloration) on his head or body.

General Physical Examination
This was a young man of good physical condition who was confused and disoriented, with noticeable defects in memory. Because of his memory dysfunction, his correct age was not known until obtained at a later date from his last place of employment. His chest was clear to auscultation and palpation. The abdomen was soft, with no masses or tenderness. Lymph nodes were not palpable in axilla or groin. Blood pressure, pulse, temperature, and respirations were normal.

Neurologic Examination
Mental Status. At the time of admission the patient was cooperative, yet confused and disoriented with respect to time and place. He could not state his name or age but could describe and name the farm where he had last worked; otherwise he could supply only a few details of his past life. He had experienced periods of global amnesia during the past 24 hours and described numerous visual and olfactory hallucinations. He was able to follow two- and three-step commands accurately but could not repeat the commands by memory after a delay of 5 minutes. His speech and comprehension of language were appropriate; however, he was unable to read. He could recite the first 10 letters in the alphabet with one or two mistakes. He could write several words such as cat or dog and could copy words, but was unable to read what he had copied. He could do simple one- and two-digit calculations. He was unable to identify colors and could not provide the correct name for many common objects, such as door or window, but he could describe these objects and state their use.

Cranial Nerves. Optic discs were clear, with sharp borders; a pronounced deficit in the right visual field was present. Jaw-jerk and gag reflexes were normal, facial expressions were complete and symmetric, palate and uvula elevated symmetrically, and the tongue protruded on the midline.

Motor Systems. His motor system was intact throughout his body, with normal deep tendon reflexes and no loss of strength.

Sensorium. Pinprick, temperature, vibratory, and proprioceptive sensation were intact throughout his body and face.

Follow-up
The patient was admitted to the hospital for observation. After 24 hours tile visual and olfactory

hallucinations decreased. Two days later he was discharged to a local community shelter for assistance. Examination 2 weeks later revealed that the defect in forming recent memories had cleared; however, he still could not recall events from 24 hours prior to his admission through the end of his first week of discharge. He was capable of supplying his name and some details from his life, but still could not recall his age. He could do simple arithmetic calculations. However, the alexia and a pronounced anomia for visual objects and colors were observed to persist.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

LIMBIC LOBE VASCULATURE

The medial aspect of the temporal lobe borders on a large cistern surrounding the midbrain, called the ambient cistern (Figure 10-1). Coursing around the brain stem within the cistern are several major cerebral vessels, two of which routinely supply penetrating branches to the temporal lobe. These are the anterior choroidal arteries and the posterior cerebral artery.

ANTERIOR CHOROIDAL ARTERY

The anterior choroidal artery arises from the internal carotid artery between the stems of the posterior communicating and anterior cerebral arteries (see Chapter 7). In a few instances (12%), the artery arises from the middle cerebral artery. It supplies the optic tract and lateral aspect of the thalamus (portions of the lateral geniculate nucleus) before penetrating the medial aspect of the temporal lobe to supply the hippocampus, amygdala, and portions of the basal ganglia and internal capsule. Penetrating branches from this artery also reach the midbrain to supply the cerebral peduncle, substantia nigra, and red nucleus. The normal and pathologic anatomy of the anterior choroidal arteries is reviewed by Goldberg (Goldberg, 1974).

CLINICAL DISCUSSION Damage to this artery can present as contralateral hemianesthesia, homonymous hemianopsia, and hemiplegia. The clinical presentation of this picture is

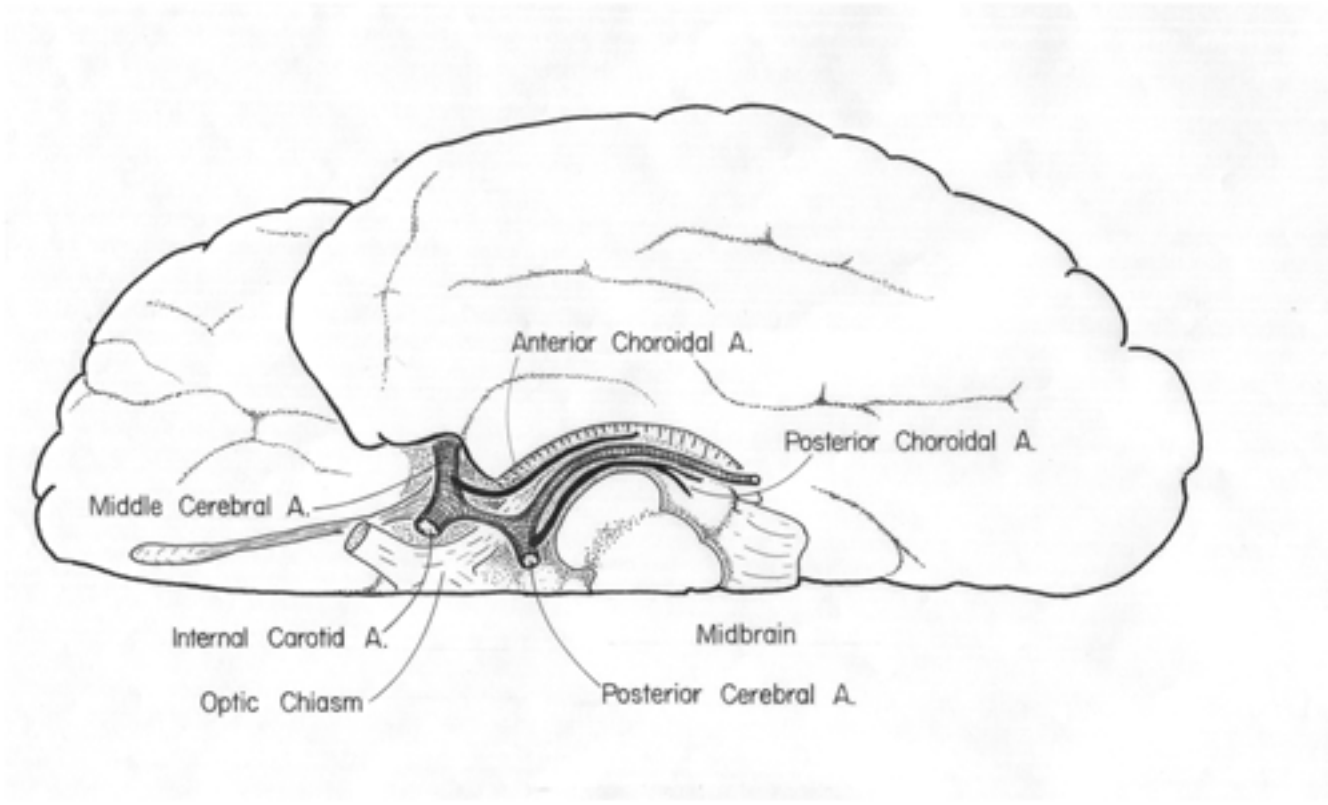


Figure 10-5. Ventral view of the brain illustrates the ambient cistern surrounding the brain stem and its arterial components. The largest artery in the ambient cistern is the posterior cerebral artery.

rare because of the extensive anastomotic network surrounding this artery (Hennerici et al., 1988). The visual dysfunction stems from the branches of the anterior choroidal artery to the lateral geniculate nucleus in the thalamus. The homonymous defect consists of superior and inferior visual field loss with sparing of a horizontal strip through the center of the visual field (Biller, 1996).

POSTERIOR CEREBRAL ARTERY

The posterior cerebral artery arises at the terminus of the basilar artery in the interpeduncular fossa. After passing around the cerebral peduncles, the posterior cerebral sweeps laterally to reach the medial aspect of the temporal lobes. In this passage, it gives off the thalamogeniculate and posterior choroidal arteries supplying the posterolateral thalamus and posterior limb of the internal capsule. Callosal branches of the posterior cerebral artery supply the splenium of the corpus callosum, and cortical branches supply portions of the temporal, occipital, and inferior parietal lobes. Its penetrating branches perfuse the piriform cortex and underlying hippocampus and amygdala. Margolis and colleagues (Margolis et al., 1974) review in detail the normal anatomy and radiology of the posterior cerebral artery; its pathology is reviewed by Newton and colleagues (Newton et al., 1974).

CLINICAL DISCUSSION The deficits resulting from damage to the cortical distribution of the posterior cerebral artery were discussed in Chapter 9. These include contralateral homonymous hemianopsia, visual neglect, visual agnosias, and visual hallucinations.

Damage to penetrating branches of the posterior cerebral artery has a wide range of presentations (Caplan, 1988). These include contralateral hemiplegia (damage to the internal capsule), homonymous hemianopsia (damage to the optic radiations), memory defects (damage to the hippocampus and entorhinal cortex), and visual hallucinations (damage to the secondary visual cortex). If the branches to the splenium of the corpus callosum and surrounding occipital white matter are damaged, the patient can exhibit alexia without agraphia, as well as several forms of anomia (Biller, 1996)

Memory dysfunctions can result from unilateral lesions in the territory of the posterior cerebral artery. An infarction of this artery on the dominant (left) side in a 55-year-old, right-handed man destroyed the medial aspect of the temporal lobe, hippocampus, fornix, splenium of the corpus callosum, and portions of rostral and medial occipital lobe as well as the ventroposterior lateral nuclei in the thalamus. The patient displayed an alexia without agraphia and color anomia, a right hemianopia, a loss of sensory input from the right hand, a transient recent memory loss, and a more protracted but still transient topographic memory loss (Geschwind and Fusillo, 1966).

Reference

Adams RD, Victor M, Ropper AH (1997) Principles of Neurology. New York: McGraw-Hill Health Professions Division.

Amaral DG, Insausti R (1990) Hippocampal formation. In: The Human Nervous System (Paxinos G, ed), pp 711-755. San Diego: Academic Press, Inc.

Baleydier C, Mauguiere F (1980) The duality of the cingulate gyrus in monkey: neuroanatomical study and functional hypothesis. Brain 103: 525-554.

Biller J (1996) Vascular syndromes of the cerebrum. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 535-564. Boston: Little, Brown and Company.

Caplan LR (1988) Posterior cerebral artery syndromes. Hdbk Clin Neurol 53(9): 409-415.

Cummings JL, Tomisyasu U, Read S, Benson F (1984) Amnesia with hippocampal lesions after cardiopulmonary arrest. Neurol 34(5): 679-681.

de Olmos JS (1990) The Amygdaloid Complex. In: The Human Nervous System (Paxinos G, ed), pp 583-710. San Diego: Academic Press, Inc.

Duyckaerts C, Derouesne C, Signoret JL, Gray F, Escourolle R, Castaigne P (1985) Bilateral and limited amygdalohippocampal lesions causing a pure amnesic syndrome. Ann Neurol 18(2): 314-319.

Geschwind N, Fusillo M (1966) Color-naming defects in association with alexia. Arch Neurol 15: 137-146.

Goldberg HI (1974) The anterior choroidal artery. In: Ra-

diology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1628-1658. Saint Louis: The C.V. Mosby Company.

Hennerici M, Aulich A, Freund H-J (1988) Carotid system syndromes. Hdbk Clin Neurol 53(9): 291-337.

Horel JA, Keating EG, Misantone LJ (1975) Partial Kluver-Bucy syndrome produced by destroying temporal neocortex or amygdala. Brain Res 94: 347-359.

Kluver H, Bucy PC (1937) "Psychic blindness" and other symptoms following bilateral temporal lobectomy in Rhesus monkeys. Am J Physiol 119: 352-353.

Lilly R, Cummings JL, Benson F, Frankel M (1983) The human Kluver-Bucy syndrome. Neurol 33: 1141-1145.

Margolis MT, Newton TH, Hoyt WF (1974) The posterior cerebral artery: Gross and roentgenographic anatomy. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1551-1579. Saint Louis: The C.V. Mosby Company.

Masdeu JC (1996) The localization of lesions affecting the cerebral hemispheres. In: Localization in Clinical Neurology (Brazis PW, Masdeu JC, Biller J, eds), pp 449-534. Boston: Little, Brown and Company.

Mesulam M-M (1981) A cortical network for directed attention and unilateral neglect. Ann Neurol 10: 309-325.

Mishkin M, Appenzeller T (1987) The anatomy of memory. Sci Am 256(6): 80-89.

Newton WF, Newton TH, Margolis MT (1974) The posterior cerebral artery: Pathology. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1580-1627. Saint Louis: The C.V. Mosby Company.

Papez JW (1937) A proposed mechanism of emotion. Archives of Neurology and Psychiatry 38: 725-743.

Penfield W, Mathieson G (1974) Memory. Arch Neurol 31: 145-154.

Petito CK, Fledmann E, Pulsinelli WA, Plum F (1987) Delayed hippocampal damage in humans following cardiorespiratory arrest. Neurol 37: 1281-1286.

Price J (1990) Olfactory system. In: The Human Nervous System (Paxinos G, ed), pp 979-998. San Diego: Academic Press Inc.

Roland P (1992) Cortical representation to pain. Trends Neurosci 15: 3-5.

Scoville WB, Milner B (1957) Loss of recent memory after bilateral hippocampal lesions. J Neurol Neurosurg Psychiat 20: 11-21.

Strobos RJ (1961) Mechanisms in temporal lobe seizures. Arch Neurol 5: 36-57.

Terzian H, Dalle Ore G (1955) Syndrome of Kluver and Bucy reproduced in man by bilateral removal of the temporal lobes. Neurol 5: 373-380.

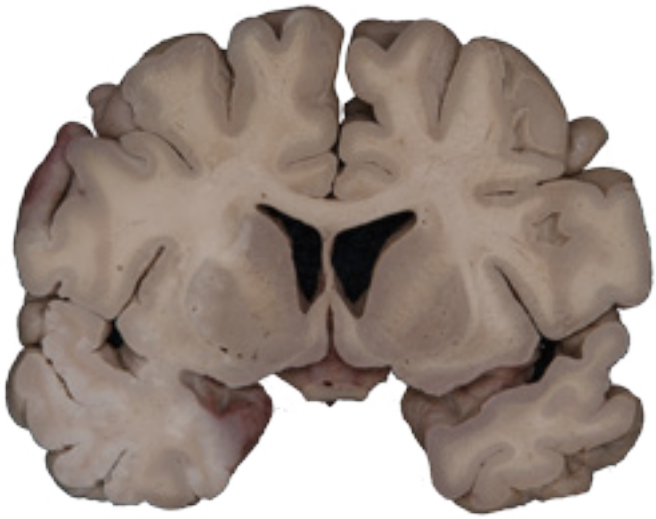
Watson RT, Heilman KM, Cauthen JC, King FA (1973) Neglect after cingulectomy. Neurol 23: 1003-1007.

Zola-Morgan SM, Squire LR, Amaral DG (1986) Human amnesia and the medial temporal lobe region: enduring memory impairment following a bilateral lesion limited to field CA1 of the hippocampus. J Neurosci 6: 2950-2967.

Zola-Morgan SM, Squire LR, Amaral DG (1989b) Lesions of the amygdala that spare adjacent cortical regions do not impair memory or exacerbate the impairment following lesions of the hippocampal formation. J Neurosci 9: 1922-1936.

Zola-Morgan SM, Squire LR, Amaral DG (1989c) Lesions of the hippocampal formation but not lesions of the fornix or the mammillary nuclei produce long-lasting memory inpairment in monkeys. J Neurosci 9: 898-913.

Chapter 11
Basal Ganglia



▶ Introduction

The basal ganglia consist of several interconnected nuclei located deep to the cerebral cortex and rostral, dorsal, and lateral to the thalamus. Rostrally, these nuclei wrap around the anterior limb of the internal capsule; caudally, they form a thin, curved tail extending along the inferior horn of the lateral ventricle into the temporal lobe.

A major source of afferent fibers to the basal ganglia is the cerebral cortex; particularly extensive connections arise in the association areas of the frontal and parietal lobes. Projections from the basal ganglia, directed to thalamus and brain stem, influence the motor control regions of the brain, such as the motor cortex, as well as modulate behavior and cognition through connections with the prefrontal cortex (Alexander et al., 1986;Alexander and Crutcher, 1990). The basal ganglia play a significant role in scaling the intensity of movements, and possibly, the intensity of cognitive responses (Mendez et al., 1989;Laplane et al., 1989). Their blood supply is derived from penetrating branches of the anterior, middle, and posterior cerebral arteries as well as those of the anterior choroidal artery.

In this chapter the individual components of the basal ganglia will be studied, along with the connections and proposed functions. A neural circuit passing through the basal ganglia will be described and an attempt made to relate this circuit to specific neurologic disease processes. The vasculature of the basal forebrain will be studied and several clinicopathologic cases will be presented.

GENERAL OBJECTIVES

1. To learn the locations, connections, and functions of the major nuclei in the basal ganglia

2. To learn the clinically detectable deficits associated with destruction of these nuclei or specific components of their neural circuitry

3. To use the information gathered in the preceding objectives to localize the extent of cerebral damage based on the patient's presenting neurologic signs and symptoms

INSTRUCTIONS

In this chapter you will be presented with one or more clinical case studies. Each study will be followed by a list of questions that can best be answered by using a knowledge of regional and functional neuroanatomy and by referring to outside reading material. Following the questions will be a section devoted to structures from a specific region of the central nervous system. Before attempting to answer the questions, compile a list of the patient's neurologic signs and symptoms, then examine the structures and their functions and study their known clinical deficits. After becoming familiar with the material, reexamine the list of neurologic signs and symptoms and formulate answers to the questions. Be aware that some of the questions can have multiple responses or require information beyond the scope of this manual. It may be necessary to obtain material or advice from additional resources, such as specialty texts, a medical dictionary, or clinical personnel.

MATERIALS

1. Human brains sectioned in the frontal and horizontal planes

2. A human brain cut in the midsagittal plane

Case Study 11-1

Chief Complaint

A 34-year-old male with labile emotions and erratic movements

History of Chief Complaint

This is a 34-year-old, right-handed laborer in a paper and pulp company who was referred to the company physician by his floor supervisor. The company had employed him, in good standing, for 16 years; however, recently his work habits and personality had undergone a progressive change. He had become extremely emotional, yelling at his fellow workers and making unusually rude and sexual comments to the office staff. He had also begun arriving late and frequently got confused on the job, leaving tasks unfinished. In addition, he had begun to move his hands and arms strangely. At first insidious, these random movements now interfered with his work. He appeared clumsy, frequently dropping tools and occasionally stumbling when walking. The supervisor suspected alcoholism and requested the physician's evaluation to determine if it was safe to have him remain at work around heavy industrial equipment.

Family History

At the time of first examination, he was living with his wife and two children, who were 15 and 16 years of age. His mother was alive and in good health. His father had died at age 38 in an accident at the paper company plant 18 years before but had been in good health until that time. The maternal and paternal grandparents were dead. The paternal grandfather had died at 43 years of age; he had not seen a physician but was described by the family as having gone "daffy" and died of the "shakes," which they had attributed to his excessive drinking.

Medical History

The patient had left public school at the age of 18 after completing the 10th grade and obtained a job at the paper company. He had not seen a physician previously, and the only records available were those of the grade school nurse, which were unremarkable. He admitted to a 25-pack-year history of smoking and to having consumed two to three (16 oz.) cans of beer per day.

General Physical Examination

The patient was a well-nourished, well-hydrated, muscular adult male appearing the stated age, with poor hygiene. Head was normocephalic. Funduscopic examination revealed no evidence of exudate, hemorrhage, or papilledema. There was no cervical, supraclavicular, or inguinal lymphadenopathy. The thyroid was positioned on the midline without masses or nodules. He had a regular heart rate and rhythm without gallops or murmurs and carotid pulsations were clear. The lungs were clear to auscultation and percussion. The abdomen was soft, without masses, tenderness, rigidity, or rebound. Peripheral pulses were intact (+2/4) at the radial, femoral, popliteal, dorsales, and tibialis. There was no peripheral edema. Genitalia showed a circumcised penis with testes descended bilaterally. A soft, reducible mass was present in the right inguinal ring. Rectal examination showed sphincter tone intact without fissures, tags, or stenosis. Prostate was grade II without nodules or tenderness, and the stool was guiac negative.

Neurologic Examination

Mental Status. The patient was awake but seemed disoriented with respect to time and place. He was irritable and responded inconsistently to questions. He was able to add and subtract single-digit numbers but could not divide or multiply. He could follow most two-step commands but not three-step commands. Speech, comprehension, and memory were appropriate for his education.

Cranial Nerves. He had a full range of eye movements and complete visual fields. Pupils were equal and reactive to light, both direct and consensual. His hearing was normal in both ears. His facial expressions were full and symmetric. The corneal, jaw-jerk, and gag reflexes were intact. The palate elevated symmetrically and the tongue protruded on the midline. His shoulders elevated symmetrically.

Motor Systems. Strength was 5/5 in the upper and lower extremities; coordination appeared intact but was hard to assess because of the involuntary motion. Tone in the limbs appeared slack, when not in motion. Deep tendon reflexes were +2/4 symmetric in all limbs; however, tendon taps were pendular. A continuous writhing motion was present in his hands and arms. This consisted of jerky, quick motions about the wrist and slower, wandering motions in the arm. He could not stop these motions on command and frequently tried to hide the more obvious ones by combining the motion with other, more purposeful arm movements. He also had jerky movement in his feet and legs that interfered with his gait, causing him to lose balance occasionally and contributing to his drunken appearance. He denied the existence of the involuntary movements, claiming he was nervous about being in a doctor's office. His wife was not sure when the movements began, but claimed that he had been making them for at least 9 months. She also stated that he did not have any involuntary motion when asleep.

Sensation. Cutaneous sensory functions were intact throughout the body; proprioception was intact in all limbs.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patien?

Case Study 11-2

Chief Complaint

A 67-year-old complainting of reduced motion and a tremor

History of Chief Complaint

A 67-year-old, right-handed, retired city worker was brought to you by his wife because of "shaking" and "weakness." His wife reported that not only did his hands shake, but she complained of changes in his personality. She also complained that he had become very slow or "weak" in his movements and often sat motionless with an expressionless face. He had difficulty getting up and moving about the house. She admitted that this had been going on for over a year and was getting worse, but she had resisted seeking treatment since she felt that he had just grown lazy after retirement. He had recently suffered several falls, one of which had resulted in a skin laceration on his forehead. She was seeking a physician at this time because he had started to make "funny noises with his mouth."

Medical History

At the time of examination, the patient had been retired for 2 years; until now he had been in good health except for an appendectomy at age 18. He had three children, who were living independently; none had attended college.

General Physical Examination

This was an alert, cooperative, well hydrated, and well-nourished individual, oriented for place and time and appearing his stated age. He was seated quietly and did not offer much information during the examination, letting his wife provide most of the history. Optic discs were clear with sharp borders. Chest was clear to auscultation and percussion. Blood pressure was normal; peripheral pulses were intact; respirations and temperature were normal. Abdomen was soft to palpation, with no masses or tenderness present. Skin was of normal texture and turgor; a recent skin laceration, 2 cm in length, was present on his forehead.

Neurologic Examination

Mental Status The patient was alert, oriented for time and place, and cooperative. Memory and knowledge were appropriate for his age. Speech was clear and meaningful, but soft and low in volume; his comprehension of language was good. He was capable of writing, but his letters were noticeably reduced in size when compared with a previous sample of 10 years ago provided by his wife.

Cranial Nerves. His range of movement for the extraocular eye muscles was full, and visual fields were complete to confrontation. The corneal, jaw-jerk, and gag reflexes were intact; palate and uvula elevated symmetrically; tongue protruded midline; and shoulder shrug was symmetric. A three-per-second resting tremor was present in the orofacial musculature that diminished on speaking and swallowing or when he opened his mouth. There was a detectable high-frequency hearing loss, more in the right ear than in the left.

Motor Systems. His strength was intact and deep tendon reflexes were normal in all extremities. He had a three-per-second tremor in both upper and lower extremities that was ameliorated with movement and returned upon resting. There was cogwheel rigidity upon passive movement of the limbs. He had no dysmetria or past-pointing present in any extremity. With his arms extended, the tremor diminished and there was no pronator drift. The tremor returned when his arms were relaxed. His gait was slow, with many shuffling steps. Postural reflexes were compromised; if given an abrupt push, he retropulsed, with many short steps and was at risk for falling. The patient could not stand from a seated position in a low, soft-padded chair, but he could, after one or two attempts, rise from a higher chair with a stiffer seat.

Sensation. Discriminative touch and proprioception were intact throughout the body and face.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patien?

Case Study 11-3

Chief Complaint

A 54-year-old woman status post-stroke 9 months ago for which she has a movement disorder and who is now presenting for evaluation

History of Chief Complaint

This was a 54-year-old, right-handed housewife who developed hemiparesis and hemiparesthesia of rapid onset in the right arm and leg 9 months earlier. Subsequently, the paresis and sensory deficit resolved over a 3-month interval; however, an involuntary, flinging motion of the right arm and a writhing, jerky motion of the right leg slowly developed during this time. She is in considerable distress, since the involuntary motions of her extremity disrupted her gait and postural station and thus incapacitated her in her daily routines. She admitted to severe social embarrassment because of the involuntary motion.

Medical History

Her past medical history was positive for hypertension, smoking, and alcohol consumption. Nine months previously, she had suffered a cerebrovascular event that left her with hemiparesis and hemibody sensory

loss on the right side. Language and cognition were not noticeably affected in this event.

General Physical Examination

The patient was an alert, well-hydrated, but underweight female, appearing older then the stated age. Signs of exhaustion and distress were evident, and she was of anxious demeanor. Her optic discs were clear and had sharp borders; visual acuity was normal. Her neck was supple, with no bruits. Her blood pressure, heart rate, and respirations were slightly ele¬vated. Her chest was clear to percussion, and the abdomen was soft, with no masses or tenderness. The remainder of the examination was precluded because of the excessive involuntary limb motion.

Neurologic Examination

Mental Status. This is an alert, oriented, and cooperative female in considerable emotional distress. Language, comprehension, reading, and memory were appropriate.

Cranial Nerve. Testing was complicated by the violence of her involuntary motion in the upper extremity. She had a full range of eye movements, pupils were equal and reactive to light, and accommodation was intact. The corneal and gag reflexes were intact; jaw-jerk was normotensive. Her hearing was equal in both ears. Her tongue protruded on the midline.

Motor Systems. Muscle strength and reflexes were normal in both extremities on the left but were difficult to test definitively on the right because of the continuous and violent involuntary motion. The movement in the upper extremity consisted of violent flinging motions superimposed on a continuous writhing jerky movement. The lower extremity demonstrated the continuous writhing motion with only brief jerks. Occasionally, the jerky motion in the lower extremity became violent. Attempts to reduce the motion in either extremity by physical restraint were unsuccessful. She could move the right extremities on command in between the involuntary motions. Gait was severely compromised by the flinging of the upper extremity. Although she did not experience an embarrassment of postural reflexes, the upper extremity motion was continually pulling her off station. The involuntary movement of the right extremities was ameliorated with sleep but returned upon waking.

Sensation. Vibratory sensation and pinprick were intact on the left; to the extent that it could be tested, both modalities were equivocal on the right.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?
2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?
3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?
4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?
5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?
6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?
7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?
8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?
9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient

▶ DISCUSSION I

BASAL GANGLIA STRUCTURES

The basal ganglia are located deep to the cerebral cortex and surround the rostral border of the internal capsule. They can be divided into three groups of nuclei based on phylogeny; fortunately, these divisions also reflect structural and functional boundaries. The oldest portion is the archistriatum (called the amygdala) and is involved in modulating emotions and memory associations; it has been discussed in Chapter 10. The intermediate-aged portion of the basal ganglia is the paleostriatum (called the globus pallidus) and represents a link between the younger parts of the basal ganglia and the thalamus. The youngest portion is called the neostriatum and is composed of the caudate and putamen; these nuclei receive projections from the ipsilateral cerebral cortex and communicate with the ipsilateral thalamus through the globus pallidus. The paleostriatum and neostriatum are involved in controlling the activity of the somatic motor system as well as cognitive and behavioral systems (Alexander et al., 1986;Alexander and Crutcher, 1990;Mendez et al., 1989;Laplane et al., 1989)

A variety of other terminologies are used for structures in the basal ganglia (Figure 11-1). The caudate nucleus and putamen are referred to as the striatum or dorsal striatum, the globus pallidus is called the pallidum or dorsal pallidum, and the putamen and globus pallidus together are called the lentiform nucleus. Collectively, all these structures are referred to as the corpus striatum.

Several additional structures are often included in the general term basal ganglia because of their intimate connections and interlocking functions. These are the subthalamic nucleus and substantia nigra (Figure 11-2). Each of these forms

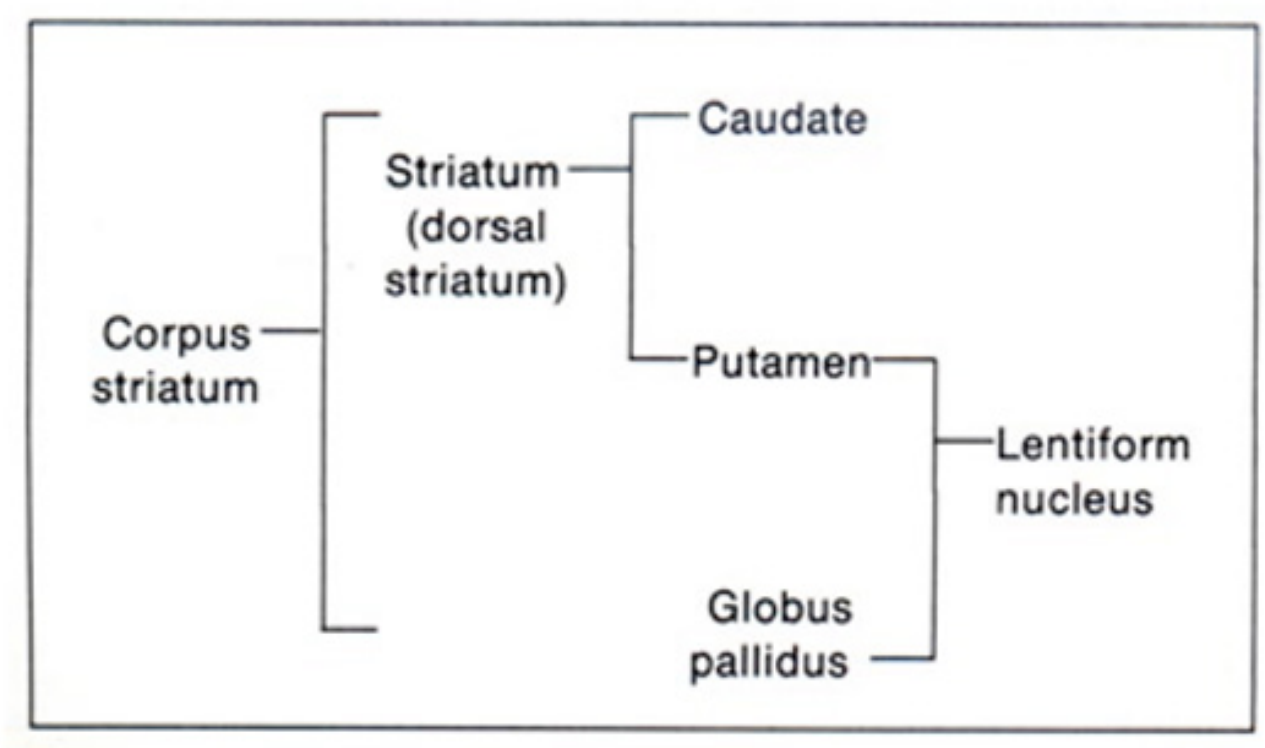


Figure 11-1. A table of terminology used for the corpus striatum.

reciprocal connections with portions of the corpus striatum.

Recently, two other regions in the forebrain have been included in the term basal ganglia (Heimer and Wilson, 1976). The nucleus accumbens, located ventral and medial to the striatum, was recognized as resembling the caudate and putamen in terms of parallel neural connections and neurochemistry; it has thus been named the ventral striatum. For similar reasons, the precommissural septum has been called the ventral pallidum in reference to the globus pallidus, a structure with which it is continuous.

CAUDATE AND PUTAMEN

The caudate nucleus consists of a large, globular head located lateral and anterior to the internal capsule, a tapering body, and a long, thin tail (Figure 11-2). The body of the caudate arches over the thalamus laterally, coursing alongside the body of the lateral ventricle (see Plates 21 to 25) and extends into the temporal lobe as the tail of the caudate. At the rostral pole of the temporal lobe, the tail merges with the amygdala.

The putamen is a disk-shaped nucleus on the lateral border of the basal ganglia (Figure 11-2 and Plates 21 to 25). Medially, it is bounded by the globus pallidus and internal capsule. At its anterior extreme, it is continuous with the head of the caudate nucleus; along its length it is partially separated from the caudate by fascicles of the internal capsule. The striated appearance given these two structures by the penetrating fibers is responsible for their conjoint name, corpus striatum (Figure 11-1).

The caudate and putamen contain very similar neuronal circuits (Alexander and Crutcher, 1990). Both receive glutaminergic fibers from areas in the ipsilateral neocortex. These fibers end on cholinergic and GABAergic neurons. GABAergic fibers from the caudate-putamen innervate the ipsilateral globus pallidus and a closely associated structure, the reticular portion of the substantia nigra. The close association of the caudate and putamen and the parallel organization of their neuronal circuits and neurochemistry explain the often-used term caudoputamen when referencing these structures.

Despite the similarity in neuronal organization, current thought suggests that portions of the caudoputamen play different roles in the activity of the brain. The rostral caudate appears closely related to the prefrontal cortex and is involved in controlling behavioral and cognitive functions (Al-

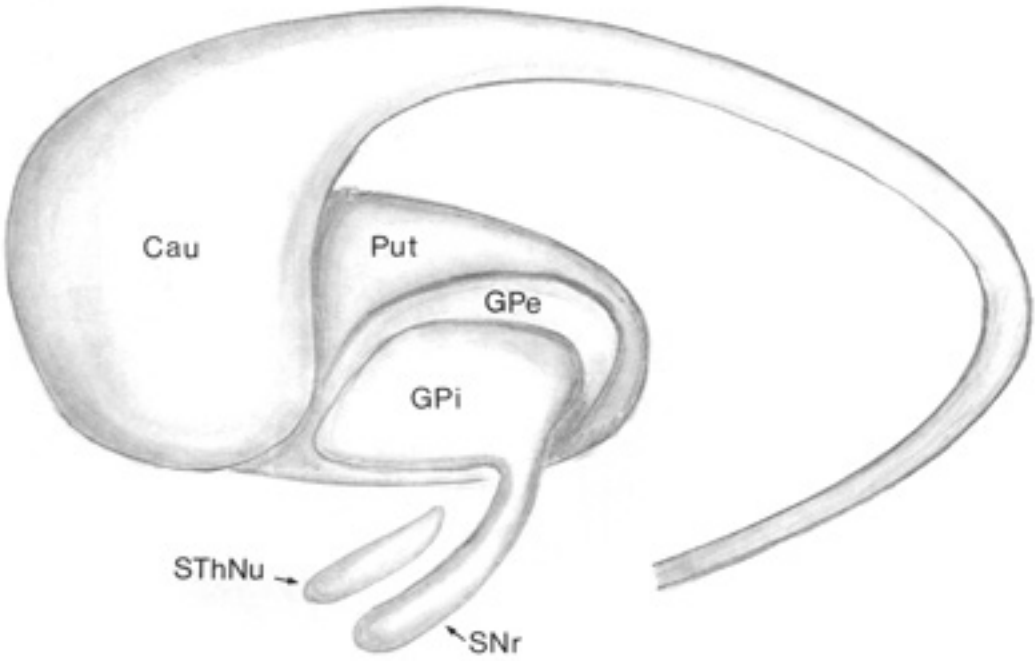


Figure 11-2. Stylized drawing of the medial aspect of the basal ganglia. (Cau, caudate; GPe, external segment of globus pallidus; GPi, internal segment of globus pallidus; Put, putamen; SNr, reticular portion of substantia nigra; SThNu, subthalamic nucleus.)

exander et al., 1986). The putamen is closely related through its connections to premotor and motor cortex and influences the motor operation of distal limb musculature (Liles, 1985).

CLINICAL DISCUSSION Lesions in the caudate or putamen, or degeneration of their neurons can lead to hyperkinetic states of movement such as chorea (a rapid, jerky, aimless, and constant motion of the limbs), athetosis (a slow, sinuous motion of the limbs), and dystonia (slow, sustained, contorting postures). In addition, behavioral and cognitive changes can accompany the loss of normal caudate and putamen output.

The separate functions of portions of the caudate and putamen may be reflected in differing neurologic presentations (Rafal et al., 1984). Lesions restricted to the putamen have resulted in motor dysfunction in the contralateral limbs (Kanazawa, 1986); behavioral defects have been associated with caudate lesions (Mendez et al., 1989). These behavioral defects are characterized by apathy, disinhibition, or a major

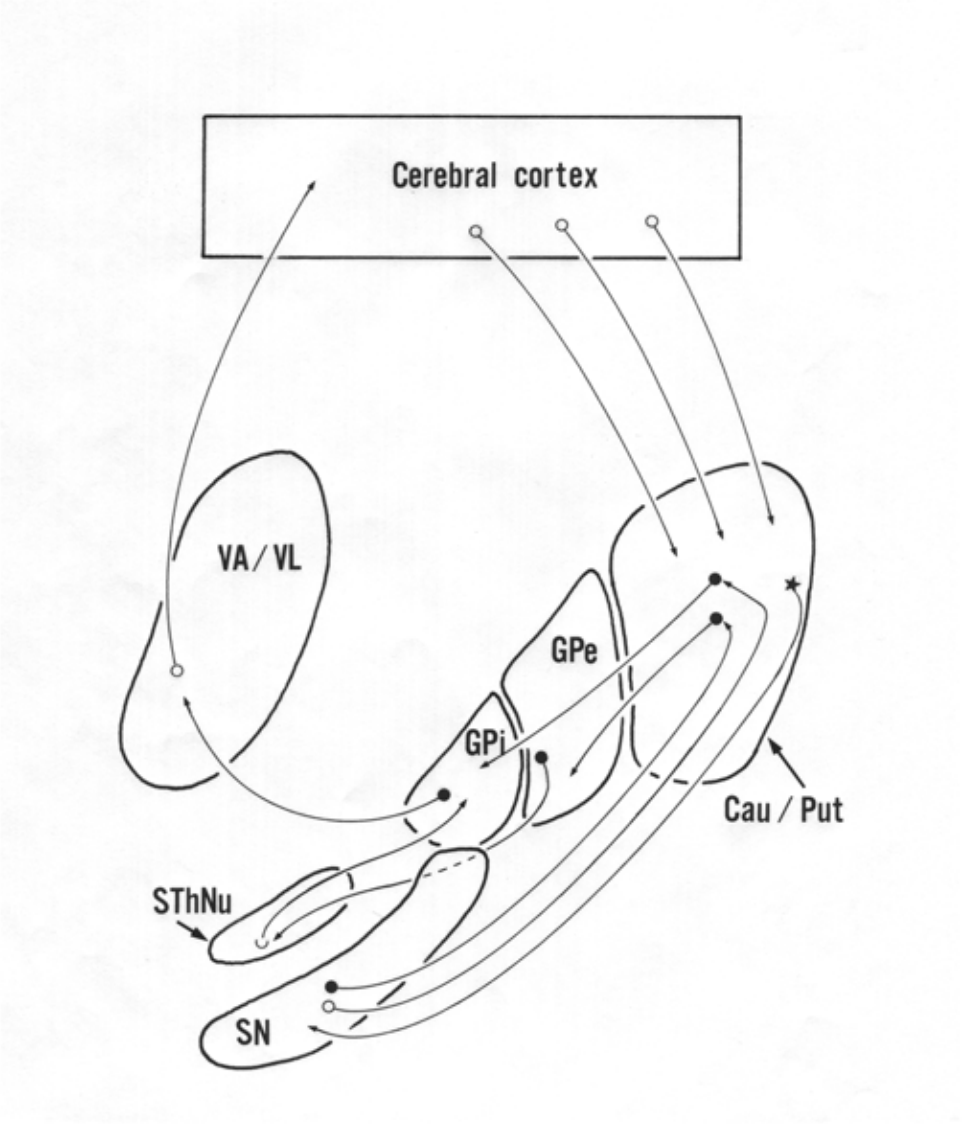


Figure 11-3. The basic organization of connections involving the basal ganglia. The mainstream pathway for motor signals to the spinal cord descends from motor cortex. The basal ganglia and associated pathways appear as a loop starting in the cerebral cortex, passing through the corpus striatum and thalamus, then returning to cerebral cortex. Several side loops through subthalamus and substantia nigra are also present. (Cau, caudate; GPe, external segment of globus pallidus; GPi, internal segment of globus pallidus; Put, putamen; SN, substantia nigra; SThNu, subthalamic nucleus; VA/VL, ventroanterior and ventrolateral nuclei of thalamus.)

affective disturbance.

GLOBUS PALLIDUS

The wedge-shaped nucleus termed globus pallidus, is trapped between the putamen laterally and the internal capsule medially (Figure 11-2 and Plates 22 to 25). A lateral medullary lamina of fibers separates the globus pallidus from the putamen, and a vertically oriented, thin, fibrous sheet, called the medial medullary lamina, divides this nucleus into internal and external segments. The caudal portion of the internal segment is in close association with the reticular portion of the substantia nigra, with which it shares many similarities in neuronal organization.

Both segments of the globus pallidus receive GABAergic projections from the caudate and putamen (Figure 11-3); however, there are intrinsic differences in these projections. The GABAergic fibers to the internal segment also contain a neuropeptide, substance P; those projecting to the external segment contain enkephalin.

The external portion of the globus pallidus has an inhibitory projection onto the ipsilateral subthalamic nucleus that uses GABA as its neurotransmitter. The internal portion has an inhibitory projection, also using GABA as a neurotransmitter, onto several ipsilateral thalamic nuclei. These include ventrolateral and portions of the ventroanterior nuclei (Figure 10 3), centromedian nucleus, and dorsomedial nucleus.

The GABAergic/substance-P-containing fibers between corpus striatum and internal segment are part of a direct pathway through the basal ganglia (Alexander and Crutcher, 1990) involving the striatum, internal segment of globus pallidus, and thalamus, which will be described later. The GABAergic/enkephalin-containing neurons between corpus striatum and external segment are part of an indirect pathway through the basal ganglia. This latter pathway involves striatum, external segment of globus pallidus, subthalamic nucleus, internal segment of globus pallidus, and thalamus. The organization and function of these connections will be presented in the section on neuronal circuits.

CLINICAL DISCUSSION Lesions in portions of the globus pallidus lead to a profound hypokinesia, somewhat similar to Parkinsonian rigidity, but without the associated tremor. Stereotaxically placed lesions in the globus pallidus have been used by neurosurgeons to ameliorate unwanted body motions (Jellinger, 1968). Profound rigidity and catatonic posture is also associated with severe degeneration of the globus pallidus as seen in anoxic states such as carbon dioxide or carbon disulfide intoxication, respiratory failure, and pure nitrogen inhalation (Jellinger, 1986).

SUBTHALAMIC NUCLEUS

The subthalamic nucleus is a thin, elongated wedge of gray matter located medial to the globus pallidus and ventral to the thalamus (Figure 11-2 and Figure 11-3; Plates 21 and 22). Laterally, it is bounded by the internal capsule and medially, by the lenticular fasciculus. It receives inhibitory (GABAergic) fibers from the external portion of the globus pallidus and sends excitatory (glutaminergic) projections to the internal segment of the globus pallidus. Thus, the subthalamic nucleus provides a source of excitation to the internal segment of the globus pallidus that can be modulated by the external segment. The significance of this arrangement will be discussed in the section on neuronal circuits.

CLINICAL DISCUSSION Lesions of the subthalamic nucleus result in ballistic motions on the side contralateral to the lesion. Lateralized ballistic motions are referred to as hemiballistic and are defined as a violent, flinging, uncontrolled movement of the limb. The most common cause of these lesions is cerebrovascular accidents (Fahn, 1989). Lesion of the subthalamic nucleus in a primate with experimentally induced parkinsonian symptoms can ameliorate the motor disturbances (Bergman et al., 1990).

SUBSTANTIA NIGRA

The substantia nigra is located in the midbrain but extends rostrally to lie in close association with the globus pallidus (Figure 11-2 and Figure 11-3; Plates 19 to 21). Ventrolaterally, it is bounded by the cerebral peduncle, and dorsomedially, by the red nucleus. The substantia nigra is divided into two segments: the pars compacta and pars reticulata. The neurons of the compact portion contain melanin, a by-product of the production of dopamine. Axons from these cells innervate the ipsilateral caudate and putamen, forming the nigrostriatal pathway. The pars reticululata shares similarities in its neural circuits with that of the internal portion of the globus pallidus. In fact, the pars reticulata is thought to represent a caudal extension of the globus pallidus.

CLINICAL DISCUSSION Destruction of the dopamine-containing cells in the pars compacta of the substantia nigra can result in parkinsonian signs and symptoms on the contralateral half of the body. Bilateral degeneration of the dopamine-producing cells can result in bilateral expression of parkinsonism.

Recently, certain synthetic heroins, sold as street drugs, have been demonstrated to be neurotoxic to the dopamine cells of the substantia nigra (Ballard et al., 1985). Attention was directed to these compounds when young adults in northern California developed profound parkinsonism after using the synthetic heroin. The active ingredient in the street drug is a neurotoxin named 1-methyl-4-phenyl-,2,3,6-tetrahydropyridine(MPTP). This compound is currently being used to

induce a Parkinson model system for study in primates.

NUCLEUS ACCUMBENS

The nucleus accumbens is located in the small area bounded by the base of the septum, the ventral aspect of the internal capsule, and the third ventricle. It is continuous dorsally with the caudate and putamen. It is called the ventral striatum, since it has close parallels with the dorsal striatum in neurochemistry and connectivity. The nucleus accumbens receives cortical projections from the cingulate and temporal gyri and from the piriform lobe. It has projections to the precommissural septum as well as other regions of the brain. Increased activity in the nucleus accumbens has been detected in the craving phase of patients addicted to cocaine (Breiter et al., 1997).

PRECOMMISSURAL SEPTUM

Several named cell groups are located in the vicinity of the

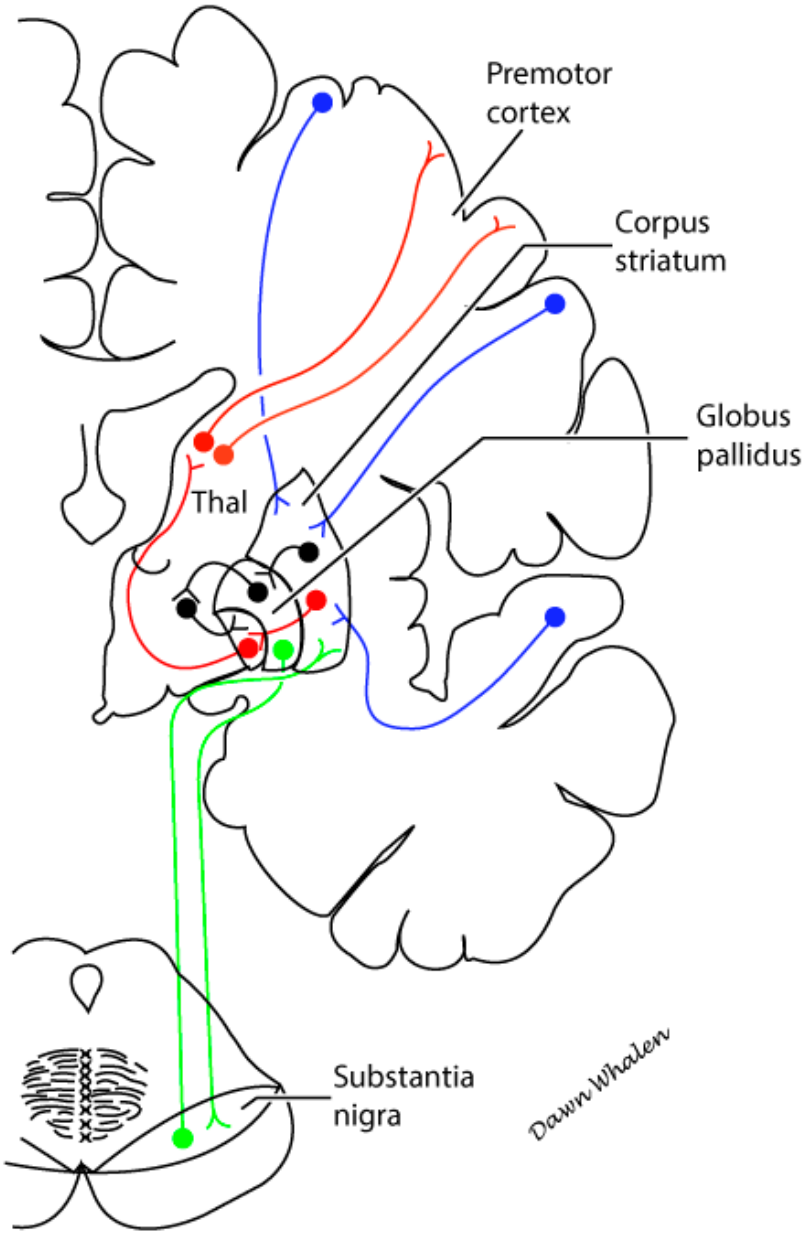


Figure 11-4. A diagram of the major afferent and efferent fiber tracts of the globus pallidus. (Barr ML, Kiernan JA. The human nervous system: an anatomical viewpoint. Philadelphia: JB Lippincott, 1988:213)

anterior commissure. Ventrally, this area is continuous with the internal segment of the globus pallidus, with which it shares a similar neurochemistry and parallel connectivity. In reference to these relationships, the precommissural nuclei are collectively referred to as the ventral pallidum. Projections to the ventral pallidum arise in the ipsilateral ventral striatum (nucleus accumbens). Its efferent axons reach the ipsilateral dorsomedial nucleus of the thalamus. Thus, the ventral pallidum, like its dorsal counterpart, the globus pallidus, is a gateway from portions of the striatum to the thalamus.

CONNECTIONS OF THE BASAL GANGLIA

The connections of the nuclei within the basal ganglia are very complex. However, an appreciation of their arrangement is necessary to understand their function in the motor system, as well as the pathophysiology of numerous disease states affecting the motor system.

AFFERENT PROJECTIONS TO THE BASAL GANGLIA

There are three main sources of projections to the basal ganglia: neocortex, thalamus, and brain stem.

Corticostriate Fibers

The caudate and putamen receive glutaminergic fibers from most of the ipsilateral neocortex (Figure 11-3 and Figure 11-4). These projections are arranged in an orderly fashion creating a cortical map laid out over caudate and putamen (corpus striatum). The premotor cortex and supplementary motor cortex are represented in the putamen while prefrontal and posterior parietal cortex project to the caudate (Alexander et al., 1986) Through these projections, the striatum is informed of activity in most portions of the neocortex.

Thalamostriate Fibers

The intralaminar nuclei of the thalamus project axons to the ipsilateral striatum. Many of the ascending somatic sensory pathways that pass through thalamus to the neocortex give off collateral fibers to the intralaminar nuclei. In addition, these nuclei receive projections from various regions of the brain stem reticular formation that are privy to ascending fibers from the spinal cord. Consequently, through direct (spino-intralaminar) and indirect (spino-reticular-intralaminar) projections, caudate and putamen are informed of external events affecting the somatic sensory system.

Brain Stem Afferents

The striatum receives diffuse projections of fibers from several areas of the brain stem. Some of these projections have been identified based on their neuropharmacology. The midbrain raphe nuclei provide serotinergic axons to striatum; the substantia nigra provides dopaminergic axons. These nigrostriatal axons will be discussed later in the text.

INTERNAL CONNECTIONS OF THE BASAL GANGLIA

The internal connections of the basal ganglia can be divided into two groups. The first group is composed of pathways that connect the striatum to the ipsilateral globus pallidus; the second includes a series of reciprocal loops between the striatopallidal complex and the substantia nigra and the subthalamic nucleus.

Striatopallidal Connections

The striatum, which receives fibers from neocortex and thalamic intralaminar nuclei, projects axons to the globus pallidus (Figure 11-3). The striatopallidal fibers are GABAergic and provide an inhibitory influence on both the internal and external portion of the globus pallidus. These fibers are arranged in a topographic array; thus, globus pallidus receives a map of striatal neuronal activity. A distinctive feature helps to separate GABAergic neurons that project to the internal segment from those that project to the external segment of the globus pallidus. Those with axons terminating in the internal segment contain the neuropeptide substance P, as well as GABA. Those terminating in the external segment produce (co-localize) enkephalin with GABA. These two cell populations represent two separate pathways for the flow of information out of the basal ganglia; a direct path involving the GABA/substance P fibers and an indirect pathway involving the GABA/enkephalinergic cells.

Striatonigral and Pallidonigral Fibers

The substantia nigra receives axons from the striatum (striatonigral) and globus pallidus (pallidonigral). At this writing, it is known that the striatonigral fibers produce neuropeptides, but the chemistry of the pallidonigral fibers remains largely unknown (Graybiel, 1990).

Nigrostriatal Fibers

Dopaminergic neurons in the compact portion of the substantia nigra give rise to an axonal projection to the corpus striatum called nigrostriatal fibers (Figure 11-5). Recent evidence suggests that these axons inhibit those striatal neurons projecting to the external segment of globus pallidus (the GABA/enkephalin fibers of the indirect pathway) while exciting those striatal neurons projecting to the internal segment (the GABA/substance P fibers of the direct pathway). Thus, the nigrostriatal fibers can shift the balance between the direct and indirect pathways to favor that of the direct (Alexander et al., 1986).

Subthalamopallidal and Pallidosubthalamic Fibers

The subthalamic nucleus forms reciprocal connections with the globus pallidus (Figure 11-5). The pallidosubthalamic fibers, producing GABA, originate in the external segment of the globus pallidus, while subthalamopallidal fibers, producing glutamate, terminate in the internal segment of the globus pallidus (Graybiel, 1990). This arrangement is consid-

ered part of the indirect pathway through the basal ganglia circuit (Alexander and Crutcher, 1990).

EFFERENT CONNECTIONS OF THE BASAL GANGLIA

There are two major efferent pathways from the basal ganglia: projections to the ipsilateral thalamus, which then influence the neocortex, and projections to the tegmentum of the midbrain, which influence motor nuclei in the brain stem.

Pallidothalamic Fibers

In humans, the largest output from the basal ganglia is directed to ventrolateral, ventroanterior, and centromedian nuclei of the thalamus; subsequently, these nuclei influence portions of motor, premotor, supplementary motor, and prefrontal cortex. The thalamic projections arise in the internal segment of the globus pallidus. Two pathways are used to reach the thalamus from the internal segment (Figure 11-4 and Figure 11-5). Some fibers pass under the inferior border of the internal capsule and then curve superiorly to enter the ventroanterior thalamus. This pathway is called the ansa lenticularis (Plates 23 to 25; Figure 11-4). The second pathway involves fibers that pass directly through the internal capsule and enter the ventrolateral thalamus. This latter fiber bundle is termed the lenticular fasciculus (Plates 22 and 23; Figure 11-4). Both pathways come into juxtaposition at the medial border of the zona incerta and, in this region, are called the thalamic fasciculus (see Chapter 8). In general the pallidothalamic projections produce GABA and have an inhibitory influence on the neurons of the thalamus.

Pallidotegmental Fibers

In addition to the thalamic fibers, the globus pallidus sends axons into the brain stem. These fibers leave the globus pallidus with those of the lenticular fasciculus; however, instead of curving superiorly into the thalamus, they turn inferiorly and pass into the midbrain, terminating in the nucleus tegmenti pedunculopontis (Figure 11-4). This latter structure is a large nucleus in the midbrain tegmentum that is wrapped around the dorsolateral border of the decussation of the superior cerebellar peduncle. From the tegmental nucleus, projections pass to the brain stem region involved in motor control (vestibular and reticular formation areas). Using the pallidotegmental connection, the basal ganglia mediate control over brain stem motor function. Although this connection is important in the control of motor pathways for nonprimate species, it has been overshadowed by the pallidothalamic fibers in primates.

NEURONAL CIRCUITS IN THE BASAL GANGLIA

Although the basal ganglia may seem like a plethora of interconnected structures, there is an underlying fundamental pattern for the passage of information through these nuclei. Parallel connections passing through the basal ganglia circuitry represents each of the structure's various functions (Figure 11-5). These parallel connections pass through differing portions of striatum, pallidum, and thalamus.

A generic neural circuit will be described for these pathways through the basal ganglia, and four specific examples will be provided. The significance of these parallel circuits is that they share the same neurochemistry (as described for the generic circuit) and therefore can be expected to have related responses to fluctuation in neurotransmitter levels and to degenerative neuronal pathologies.

GENERIC CIRCUIT

The generic circuit is organized as a large loop, beginning in the cerebral cortex and passing through the corpus striatum, thalamus, and back to cerebral cortex (Figure 11-3 and Figure 11-5). Two separate routes, direct and indirect, are used in the passage of information through the corpus striatum.

The generic neuronal circuit for the basal ganglia is illustrated in Figure 11-5. It begins with glutaminergic (excitatory) fibers projecting from cerebral cortex to striatum. Two essentially antagonistic pathways leave the striatum to reach the internal segment of the globus pallidus. The direct pathway involves GABAergic/substance-P-containing fibers that directly innervate the internal segment of the pallidum. The indirect pathway features a loop passing from striatum to external pallidal segment, to subthalamus, and finally, on to the internal pallidal segment. In this latter pathway, striatal GABAergic/enkephalinergic fibers provide an inhibitory innervation to the external segment of the pallidum. In turn, GABAergic fibers from the external segment provide an inhibitory innervation to the subthalamic nucleus. The indirect pathway ends with an excitatory, glutaminergic projection from the subthalamic nucleus to the internal segment of the globus pallidus. Significantly, both pathways converge, with opposing effects, on the internal pallidal segment. Thus, a balance is struck in the internal segment between the inhibitory influence of the direct pathway and the excitatory influence of the indirect pathway. The outcome is a dynamic modulation of the pallidothalamic pathways.

GABAergic neurons of the internal segment project axons through the ansa lenticularis or the lenticular fasciculus to reach the thalamus. These axons exert an inhibitory influence on the thalamic targets. From the thalamus, projections are returned to the cerebral cortex using glutaminergic fibers; thus, the major thalamic relay nuclei to neocortex provide an excitatory input. The thalamocortical circuit, which consists of reciprocal connections between these two structures, demonstrates rapid, oscillating neuronal activity. It is through the GABAergic fibers of the globus pallidus that the

high activity of the thalamocortical circuit is partially controlled.

A significant feature of the tandem circuit through the corpus striatum is that the inhibitory output of the internal segment of the pallidum is controlled by the balance between the direct pathway (inhibitory) and the indirect pathway (excitatory). The output of the internal segment controls the activity of thalamus and, subsequently, portions of cerebral cortex. Both direct and indirect pathways are influenced by the nigrostriatal (dopaminergic) axons; however, there is a differential effect. Within the striatum, dopamine fibers inhibit the GABAergic neurons of the indirect pathway while exciting those of the direct pathway. Thus, the substantia nigra can modulate the balance between these two pathways.

In summary, the two pathways of the striatum have an antagonistic effect on the output of the internal segment and, acting through the thalamus, differentially modulate this neural activity of cerebral cortex. According to the model, increased activity in the direct pathway or decreased activity in the indirect pathway will result in diminished output of the internal segment. Since the internal segment is inhibitory to thalamus, the result is a disinhibition of thalamus, which is then free to send more activity to cortex; as such, the patient experiences a hyperactive state. The reverse situation occurs when the activity of the direct pathway is decreased or that of the indirect pathway is increased. The internal segment becomes more active and consequently supplies more inhibition to the thalamus, which then supplies less excitation to

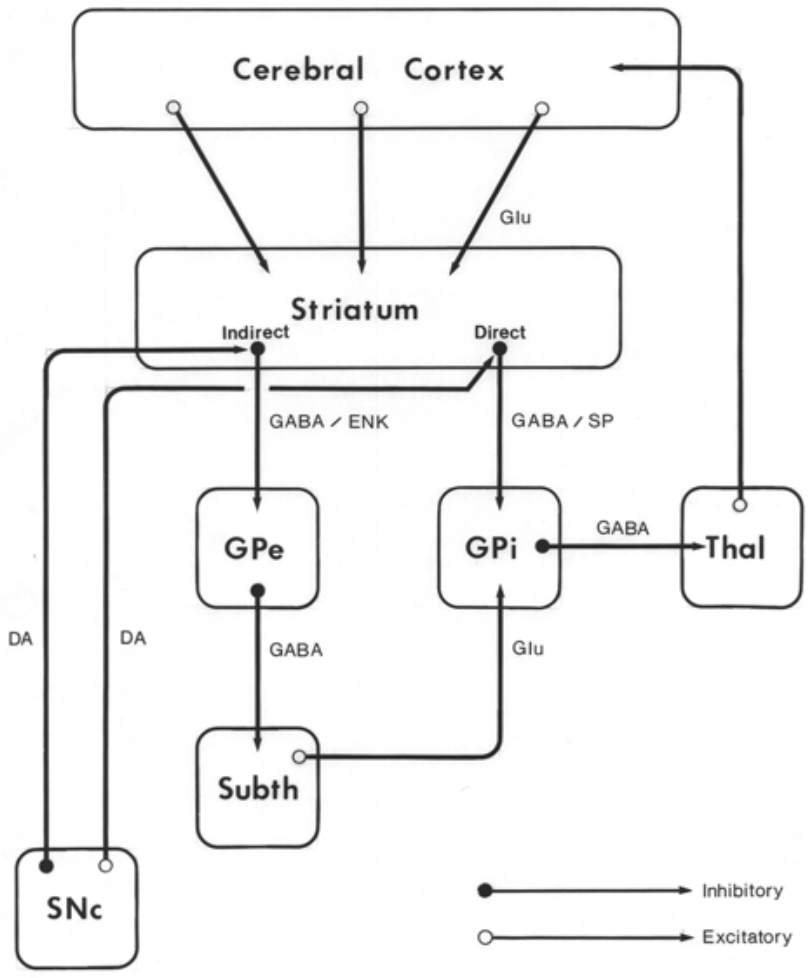


Figure 11-5. A schematic diagram of a generic neuronal circuit involving the basal ganglia. Open circles are excitatory neurons; closed circles are inhibitory. (Modified from Alexander GF, Crutcher MD. Functional architecture of basal ganglia circuits: neural substrates of parallel processing. Trends Neurosci 1990; 13:266-271)

the cerebral cortex. Thus the patient experiences hypoactivity. The cortico-striatao-palladial fibers represent a powerful control on the explosive, feed-forward oscillating neural activity of the thalamocortical circuits. Through this method, the basal ganglia exerts a strong influence on the activity of the neocortex.

MOTOR CIRCUIT

The motor form of the generic basal ganglia circuit is illustrated in Figure 11-6. The corticostriatal projections arise in the somatic sensory, supplementary, premotor, and motor cortex; their striatal termination is in the putamen. The thalamic target for these projections is the ventrolateral nucleus, which then projects back to supplementary motor cortex.

CLINICAL DISCUSSION Using the model for neuronal organization provided, it is possible to reexamine the signs and symptoms of movement disorder consequent to lesions that involve basal ganglia damage. Loss of the dopaminergic fibers from the substantia nigra will lower the activity of

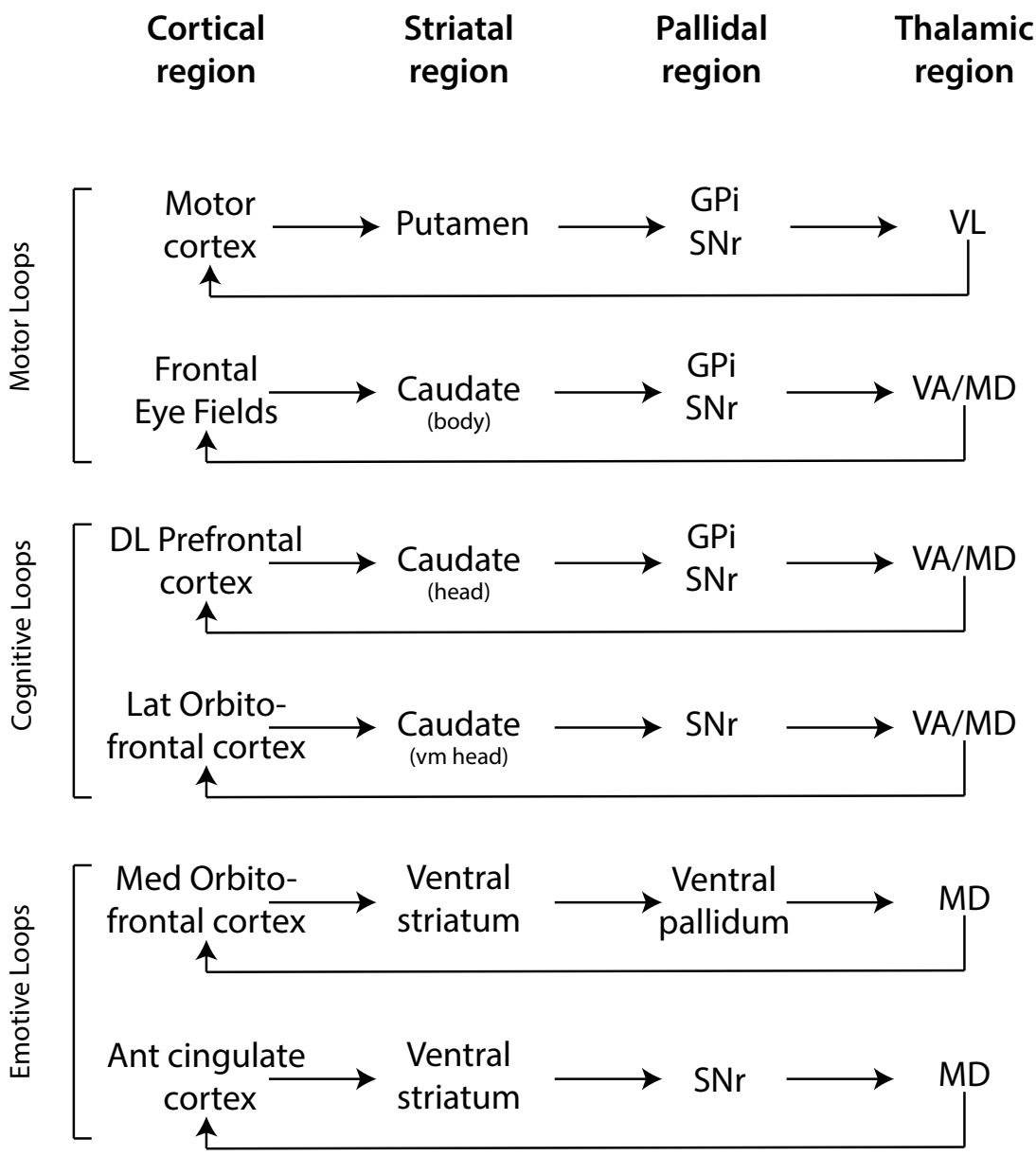


Figure 11.6. Table illustrates the various circuits passing through the corpus striatum (MD, dorsomedial thalamic nucleus; GPi, internal segment of globus pallidus; SNr, pars reticulata of substantia nigra; VA, ventroanterior thalamic nucleus; VL, ventrolateral thalamic nucleus.) Note that the ventral striatum contains the nucleus accumbens and the ventral pallidum contains the substantia innominata. (Modified from Alexander GE, DeLong MR, Strick PI. Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Ann Rev Neurosci 1986;9-357)

the direct pathway and increase (through disinhibition) the activity of the indirect pathway. The net result is that the internal segment provides a stronger inhibition of thalamus. This could contribute to the bradykinetic state experienced by Parkinson's patients.

Degeneration of the GABAergic/enkephalinergic neurons of the striatum, such as occurs in Huntington's chorea, decreases the outflow from striatum to the external segments of the pallidum, diminishing activity in the indirect pathway. The balance is tipped in favor of the direct pathway, and consequently, the internal segment of globus pallidus expresses decreased inhibition on the thalamocortical unit. The thalamus, minus its palladial inhibition, is allowed to operate at a higher level of activity, and the cerebral cortex receives more information. This could account for the hyperkinetic state experienced by Huntington's patients.

A rigid form of Huntington's chorea has been described. The patient presents with bradykinesia instead of chorea, limb rigidity with cogwheeling on passive movement, and a masked face. Although initially this presents similar to Parkinson's disease, it is due to degeneration of the corpus striatum and can occur in families with Huntington's disease. Recently, it has been demonstrated that GABAnergic projections from the striatum to both internal and external segments of the globus pallidus, have degenerated in the rigid form of Huntington's (Albin et al., 1990). Putting this observation into the circuit diagram of the basal ganglia (Figure 11-5), one can conclude that the internal segment is receiving only excitatory input from the subthalamic nucleus. Consequently, it is strongly inhibiting the thalamus, and the patient experiences bradykinesia similar to the situation in Parkinson's disease.

Cerebrovascular accidents that damage the subthalamic nucleus on one side would be expected to remove the excitation from that structure to the internal segment of the pallidum (decrease activity in the indirect pathway). As a consequence, the internal segment would not be able to inhibit the thalamocortical unit; thus, the thalamus would release too much activity to the cerebral cortex. The hyperkinetic state experienced by the patient would be confined to the contralateral side of the body. This mechanism could explain the hemiballistic motion expressed by patients subsequent to vascular lesions of the subthalamic nucleus.

OCULOMOTOR CIRCUIT

A specific circuit in the basal ganglia is related to control of eye movement (Alexander et al., 1986), called the oculomotor circuit (Figure 11-6). The corticostriatal fibers arise in the posterior parietal and prefrontal cortex and the frontal eye fields; they terminate in the body of the caudate. The ventroanterior and dorsomedial thalamic nuclei receive the pallidothalamic fibers from the internal segment of the globus pallidus. Thalamocortical projections are directed back to the frontal eye fields. This circuit functions to control the movement of the extraocular eye muscles.

ASSOCIATION CIRCUIT

The basal ganglia contains a neural circuit capable of modulating the activity of some of the association areas of the cerebral cortex (Figure 11-6). Called the association circuit, it appears to function in modulating cognitive and behavioral processes (Alexander et al., 1986). The corticostriatal projections arise in the prefrontal, premotor, and posterior parietal cortex and terminate in the head of the caudate nucleus. The thalamic targets of this circuit are the ventroanterior and dorsomedial nuclei, two structures that project to the prefrontal cortex.

CLINICAL DISCUSSION In a recent study, the case histories of a cohort of 18 patients with identifiable lesions confined to the caudate nucleus were examined (Caplan et al., 1990). Several of the patients had no detectable motor signs, others experienced hemiparesis that was transient. The most notable defects involved behavioral and cognitive dysfunction such as abulia, restlessness, hyperactivity, neglect (contralateral), language abnormalities, and poor memory. These findings support the contention that the basal ganglia circuit passing through the caudate is involved in scaling behavioral and cognitive functions in much the same way that the putamenal circuit scales motor activity.

LIMBIC CIRCUIT

A circuit through the basal ganglia also involves components of the limbic system (Figure 11-6; see Chapter 10). The cortical sources of projections to the striatum are cingulate gyrus, piriform lobe, and portions of the temporal gyri. The striatal target for these projections is nucleus accumbens (ventral striatum). The pallidal target of projections from the accumbens is the precommissural septal area (ventral pallidum) extending caudally into parts of the internal segment of globus pallidus. The thalamic area involved in this circuit is a portion of the dorsomedial nucleus, which has the cingulate gyrus as its cortical target, thus completing the circuit.

Case Study 11-4

Chief Complaint

A 75-year-old man with a history of a postural movement disorder subsequent to a cerebrovascular accident who presents for evaluation

History of Chief Complaint

This was a 75-year-old, right-handed male with tonic posturing motions of the left upper extremity that developed subsequent to a resolving spastic paralysis. He presented for an annual checkup, 2 years following a cerebrovascular event.

Medical History

He was a Jewish scholar who emigrated from eastern Poland to the United States after World War II. He had been in good health until 2 years before, when he suffered a cerebrovascular accident of rapid onset that left him with spastic paralysis and sensory paresthesia in the left extremities. At that time his strength in the left limbs was 2/5 and his deep tendon reflexes were elevated at +4/4. No language or cognitive deficit was recorded at the time of the first presentation.

General Physical Examination

This was an alert, oriented, and cooperative man. He was well nourished and well hydrated and appeared his stated age. He had male-pattern baldness. His optic discs were clear with sharp borders. Visual acuity was normal with his glasses. His neck was supple; a slight bruit was present over the right carotid. His chest was clear to percussion and abdomen was soft to palpation, with no tenderness or masses. His heart rate, blood pressure, and respirations were physiologic. His peripheral pulses were intact at the wrists and ankles. His skin was warm and moist, with good turgor.

Neurologic Examination

Mental Status. He was alert, oriented for time and place, and cooperative. He gave a precise history. Memory was appropriate; speech, writing, and reading (English, Polish, and Hebrew) were intact. He could list all the presidents in order and recite passages from the Torah verbatim.

Cranial Nerves. He had a full range of eye movements and visual fields were intact. His hearing was significantly diminished, especially for the high frequencies, more so in the right ear than in the left. The corneal and jaw-jerk reflexes were intact; facial expression was symmetric and appropriate to the situation. The gag reflex was intact; palate, uvula, and tongue were symmetric in position. He had slightly diminished sensation to vibratory sense on the left side of his face.

Motor Systems. Strength was 5/5, and deep tendon reflexes were +2/4 for both extremities on the right. Strength was mildly reduced (4/5) for the upper limb on the left, and deep tendon reflexes were slightly elevated (+3/4). The lower limb on the left had reduced strength (3/5) and increased deep tendon reflexes (+3/4). An involuntary, posturing movement was present in the left limbs that had not been detected in his first presentation, poststroke. In the upper limb the movement consisted of slow, writhing postural changes, including pronounced flexion of the wrist, and phalangeal-metacarpal joints. With the upper limbs held horizontally extended, the left limb wandered in position continuously. Occasional sudden, jerky movements of the upper limb occurred. The lower left limb displayed slow postural movements that interfered with his gait. The movement disorder was somewhat masked by the more pronounced residual paralysis in the lower left limb. The involuntary motion ceased when the patient slept, returning when he awoke. Past-pointing and dysmetria were not present on either side. Pronator drift did not appear to be present, but this was difficult to evaluate on the left side because of the wandering motion in the upper limb. With the upper limbs extended anteriorly and held in a fixed position, a 10-Hz tremor was present in the right arm, but not in the left. This movement in the right limb was ameliorated when the arm was relaxed to the

adducted portion. The tremor could be seen in his writing, particularly if he held his hand off of the paper's surface as he wrote.

Sensation Response to pinprick, vibratory stimuli, and position sense was normal on the right side of his body and only slightly reduced on the left side.

QUESTIONS

1. Has the patient experienced any changes in consciousness or cognition, language function or spatial recognition, personality or emotional behavior, or any loss in memory?

2. Does the patient exhibit any loss of vision, and if so, where in the visual field is the loss? Are their any visual hallucinations present in this patient?

3. Are there any changes in cranial nerve function, if so are they signs of suprasegmental or segmental level defects?

4. Are there any changes in motor function such as reflexes, muscle tone, movement, or coordination, if so are they signs of suprasegmental or segmental level defects?

5. Are there any changes in sensory function, if so, what levels of the body have experienced this change?

6. What is the clinical temporal profile of this patient's neurologic problem acute or chronic, progressive or stable?

7. Based on the presenting signs and symptoms do you think the distribution of the neurologic pathology is focal, multifocal or diffuse?

8. Based on the answers to these questions develop a differential diagnosis of the patient's neurological problem?

9. If the origin of the pathology is vascular, what arterial supply is most likely involved with the lesion in this patient?

▶ DISCUSSION II

BASAL GANGLIA VASCULATURE

The basal ganglia and internal capsule receive a complex blood supply derived from several sources that ultimately originate from the anterior circulation. Two major suppliers of the corpus striatum, the medial and lateral striate vessels, arise from the proximal portions of the anterior and middle cerebral arteries. These vessels frequently are the source of intraparenchymal hemorrhages such as is shown in Figure 11-7. The third source, the anterior choroidal artery, is derived directly from the internal carotids (Gillilan, 1968). Given the intense anastomosis of vessels in the basal ganglia, it is not yet possible to associate specific signs and symptoms of neurologic damage and specified vessels.

MEDIAL STRIATE VESSELS

The internal carotid artery ascends to the level of the basal forebrain, where it bifurcates into the anterior and middle cerebral arteries. The proximal portions of these arteries present a horizontal surface coursing directly inferior to the anterior perforated substance (Figure 11-8). It is from the dorsal surface of this vessel that the medial striate arteries arise. They are derived from the proximal stem of both the anterior and the middle cerebral artery (Figure 11-8). The ventral side of the proximal portion of the anterior cerebral artery gives rise to short branches that perfuse the optic nerve, chiasm, and tracts (Figure 11-8).

The medial striate arteries consist of three to six vascular channels penetrating the basal forebrain (Leeds, 1974). Most are quite small and only reach the external segment of the globus pallidus. One large vessel stands out in radiographs, the recurrent artery of Heubner (AHb in Figure 11-8), which usually arises from the anterior cerebral artery, courses laterally and then superiorly to reach the anteromedial aspect of the head of the caudate, anterior portion of the putamen, globus pallidus, and a portion of the anterior limb of the internal capsule (Figure 11-8).

LATERAL STRIATE VESSELS

These vessels arise from the proximal segment of the middle cerebral artery (Leeds, 1974). After entering the forebrain these vessel make a long, graceful arc, curving from inferolateral to superomedial across the corpus striatum (Figure 11-8). They supply substantia innominata, putamen, and globus pallidus as well as the anterior and posterior limb of the internal capsule. Anteriorly, these vessels anastomose with the medial striate vessels; posteriorly, they anastomose with the anterior choroidal artery.

ANTERIOR CHOROIDAL ARTERY

The anterior choroidal arterial tree arises from the internal carotid in most cases, but it can spring off of the middle cerebral artery as well. As the anterior choroidal winds its way around the cerebral peduncle in the ambient cistern (see Chapter 8), it gives off penetrating branches into the base of the cerebrum. These branches reach the posterior portion of the globus pallidus, putamen, and genu of the internal capsule. The anatomy and pathology of the anterior choroidal artery is reviewed by Goldberg (Goldberg, 1974).

CLINICAL DISCUSSION Vascular lesions of the basal ganglia have varying presentations, depending on the portion of the structure damaged. Unfortunately, lesion location and symptomatology have not been well correlated to date. Small infarctions confined to the caudate and/or putamen can present with choreiform motion (Goldblatt et al., 1974;Saris, 1983), behavior and cognitive dysfunction (Caplan et al., 1990). Focal dystonia has been reported as a presenting complaint in a lacunar infarction confined to the lenticular nucieus (Russo, 1983). Hemidystonia can result from vascular lesions in the caudate nucleus, lentiform nucleus (partic-

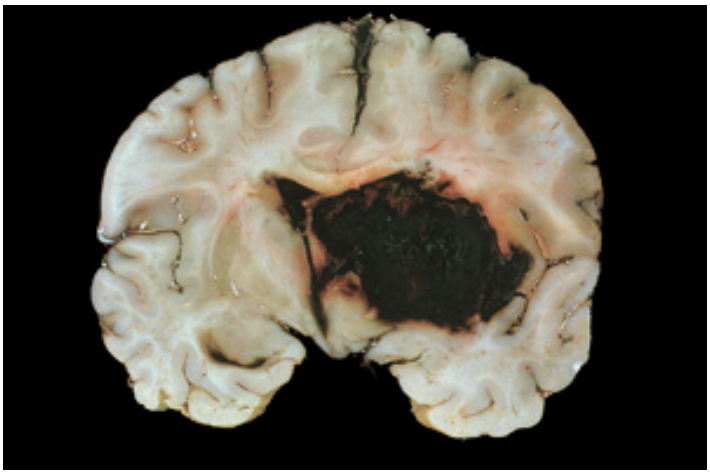


Figure 11-7 This is a coronal view taken through the basal ganglia of the brain of an individual who died from a large intraparenchymal hemorrhage involving one or more of the striate arteries. Figure taken from: H. Okazaki and B. W. Scheithuer. Atlas of Neuropathology, New York:Gower Medical Publishing, 1988.

ularly the putamen), or thalamus (Marsden et al., 1985). Hemiballism and hemichorea have occurred in a patient with a small lesions in the putamen (Kase et al., 1981).

Lesions that extend into the internal capsule can present with an initial pure hemiparesthesia or pure hemiparesis that subsequently resolves into a movement disorder. The initial hemiplegia masks the movement disorder, but as the plegia resolves the involuntary motions are expressed. These are called posthemiplegic movement disorders. A frequent movement disorder to follow lesions of the internal capsule is athetosis, a slow, writhing series of postural adjustments. It most likely represents interruption of the pallidothalamic fibers as they pass through the capsule. Dysarthria can also accompany involvement of the internal capsule in the lesion (Kase, 1988).

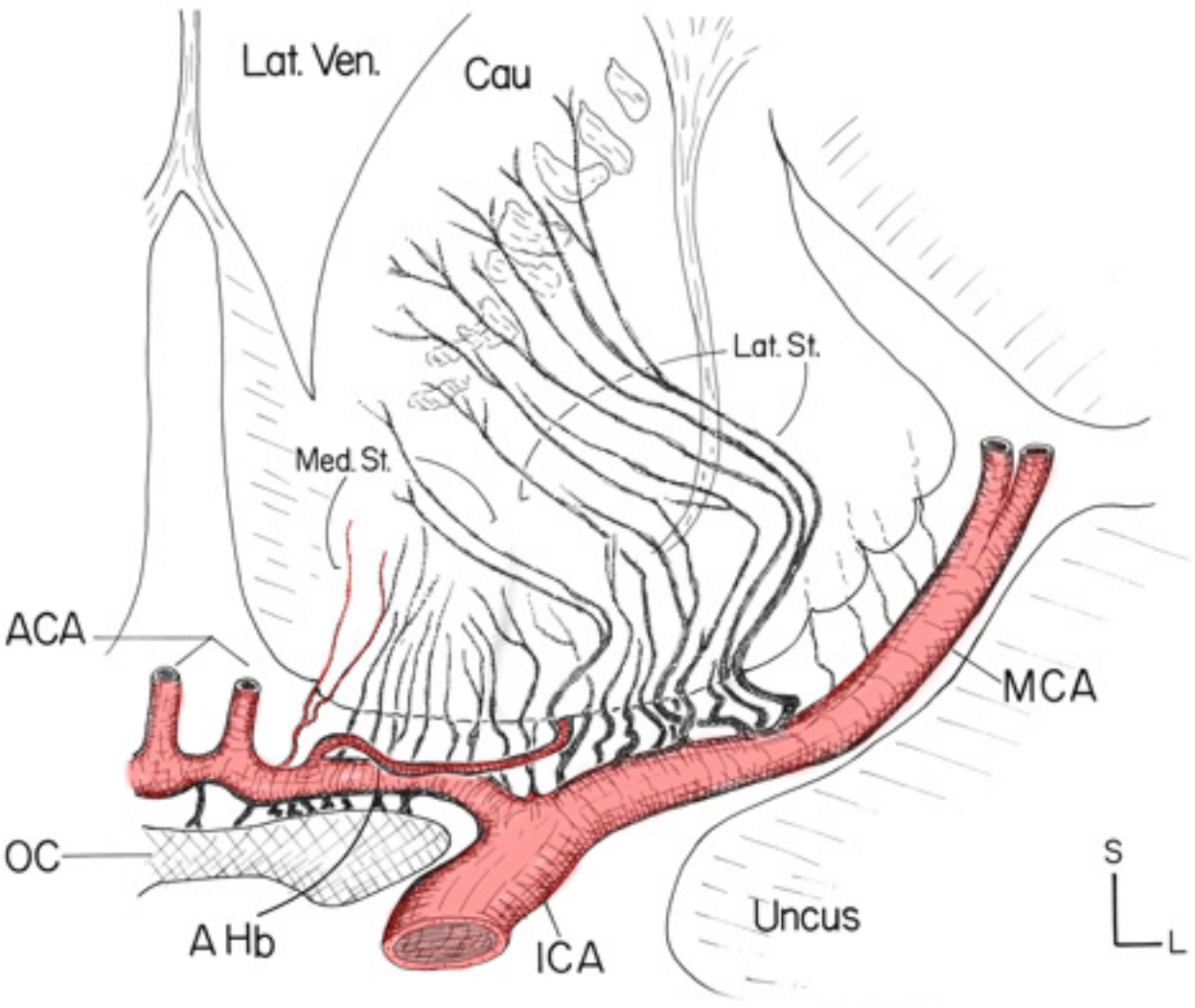


Figure 11-8 Diagram of a coronal section through the head of the caudate nucleus illustrates the medial and lateral striate arteries. The medial striate arteries enter the brain through an area called the anterior perforated substance. (ACA, anterior cerebral arteries; AHb, Heubner's artery; Cau, caudate nucleus; ICA, internal carotid artery; L, lateral; Lat.St., lateral striate arteries; Lat.Ven., lateral ventricles, anterior horn; MCA, middle cerebral artery; Med. St., medial striate arteries; MCA, middle cerebral artery; OC, optic chiasm; S, superior.) (Modified from Seeger W. Atlas of topographical anatomy of the brain and surrounding structures. New York: Springer-Verlag, 1978)

Reference

Albin RL, Reiner A, Anderson KD, Penney JB, Young AB (1990) Striatal and nigral neuron subpopulations in rigid Huntington's disease: implications for the functional anatomy of chorea and rigidity-akinesia. Ann Neurol 27: 357-365.

Alexander GE, DeLong MR, Strick PL (1986) Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Ann Rev Neurosci 9: 357-381.

Alexander GF, Crutcher MD (1990) Functional architecture of basal ganglia circuits: neural substrates of parallel processing. Trends Neurosci 13: 266-271.

Ballard PA, Tetrud JW, Langston JW (1985) Permanent human parkinsonism due to 1-methyl-4-phenyl-1,2,3,6- tetrahydropyridine (MPTP): seven cases. Neurol 35: 949-956.
Bergman H, Wichmann T, DeLong MR (1990) Reversal of experimental parkinsonism by lesions of the subthalamic nucleus. Sci 249: 1436-1438.

Breiter HC, Gollub RL, Weisskoff RM, Kennedy DN, Makris N, Berke JD, Goodman JM, Kantor HL, Gastfriend DR, Riorden JP, Mathew RT, Rosen BR, Hyman SE (1997) Acute effects of cocaine on human brain activity and emotion. Neuron 19: 591-611.

Caplan LR, Schmahmann JD, Kase CS, Feldmann E, Baquis G, Greenberg JP, Gorelick PB, Helgason C, Hier DB (1990) Caudate infarcts. Arch Neurol 47: 133-143.

Fahn S (1989) Huntington disease and other forms of chorea. In: Merritt's Textbook of Neurology (Rowland LP, ed), pp 647-652. Phil.: Lea & Febiger.

Gillilan LA (1968) The arterial and venous blood supplies to the forebrain (including the internal capsule) of primates. Neurol 18: 653-670.

Goldberg HI (1974) The anterior choroidal artery. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1628-1658. Saint Louis: The C.V. Mosby Company.

Goldblatt D, Markesbery WR, Reeves AG (1974) Recurrent hemichorea following striatal lesions. Arch Neurol 31: 51-54.

Graybiel AM (1990) Neurotransmitters and neuromodulators in the basal ganglia. Trends Neurosci 13: 244-254.

Heimer L, Wilson RD (1976) The subcortical projections of the allocortex. Similarities in the neural associations of the hippocampus, the piriform cortex, and neocortex. In: Golgi Centential Symposium: Prespectives in Neurology (Santini M, ed), pp 177-193. New York: Raven Press.

Jellinger K (1968) Degenerations and exogenous lesions of the pallidum and striatum. Hdbk Clin Neurol 6: 631-693.

Jellinger K (1986) Exogenous lesions of the pallidum. Hdbk Clin Neurol 49(5): 465-491.

Kanazawa I (1986) Clinical pathophysiology of basal ganglia disease. Hdbk Clin Neurol 49(5): 65-85.
Kase CS (1988) Middle cerebral arterial syndromes. Hdbk Clin Neurol 53(9): 353-370.

Kase CS, Maulsby G, deJuan E, Mohr JP (1981) Hemichorea- hemiballism and lacunar infarction in the basal ganglia. Neurol 31: 452-545.

Laplane D, Levasseur M, Pillon B, Dubois B, Baulac M, Mazoyer B, Tran Dinh SA, Danze F, Baron JC (1989) Obsessive-compulsive and other behavioural changes with bilateral basal ganglia lesions a neuropsychological, magnetic resonance imaging and positron tomography study. Brain 112: 699-725.

Leeds NE (1974) The striate (lenticulostriate) arteries and the artery of Heubner. In: Radiology of the skull and brain: Angiography (Newton TH, Potts DG, eds), pp 1527-1539. Saint Louis: The C.V. Mosby Company.
Liles SL (1985) Activity of neurons in putamen during active and passive movements of wrist. J Neurophysiol 53: 217-236.

Marsden CD, Obeso JA, Zarranz JJ, Lang AE (1985) The anatomical basis of symptomatic hemidystonia. Brain 108: 463-483.

Mendez MF, Adams NL, Lweandowski KS (1989) Neurobehavioral changes associated with caudate lesions. Neurol 39: 349-354.

Okazaki, H. and B. W. Scheithuer. Atlas of Neuropathology, New York:Gower Medical Publishing, 1988.

Rafal RD, Posner MI, Walker JA, Friedrich FJ (1984) Cognition and the basal ganglia. Brain 107: 1083-1094.

Russo LS (1983) Focal dystonia and lacunar infarction of the basal ganglia. Arch Neurol 40: 61-62.

Saris S (1983) Chorea caused by caudate infarction. Arch Neurol 40: 590-591.

Appendix
Spinal Cord & Brainstem
Atlas

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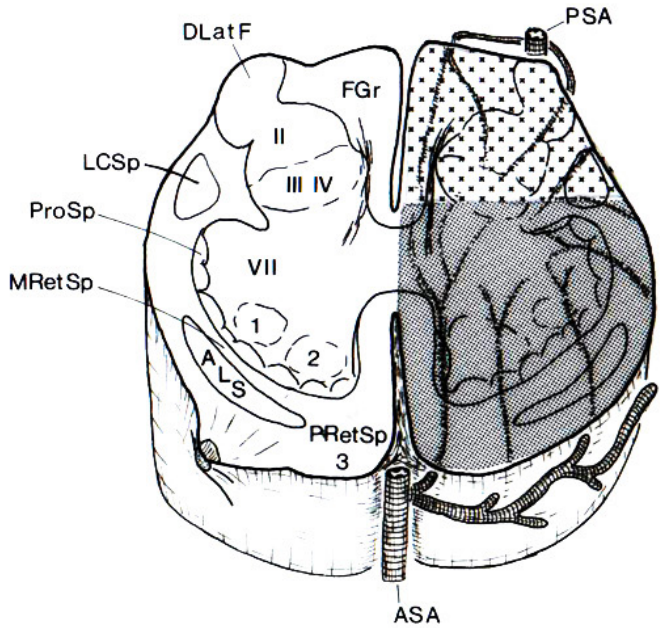
Abbreviations

List of Abbreviations used in Atlas Plates

IXn	Glossopharyngeal Nerve
AbdNr	Abducens Nerve
AbdNu	Abducens Nucleus
AccNu	Accessory Nucleus
AchA	Anterior Choroidal Artery
ACom	Anterior Commissure
ACSp	Anterior Corticospinal Tract
AICA	Anterior Inferior Cerebellar Artery
ALS	Anterolateral System
AmyNu	Amygdaloid Nucleus
AN	Anterior Nucleus
AnLen	Ansa Lenticularis
ARadA	Anterior Spinal Artery
ArcNu	Arcuate Nucleus
ASA	Anterior Spinal Artery
AVC	Arterial Vasocorona
BA	Basilar Artery
BasNu	Basal Nucleus
BrBA	Paramedian Branches of the Basilar Artery
BrIC	Brachium of the Inferior Colliculus
CA	Collicular Artery
Cau	Caudate
CC	Crus Cerebri
CeAq	Cerebral Aqueduct
CeGy	Central Gray
CM	Centromedian Nucleus
CoNu	Cochlear Nucleus
CoNuF	Corticonuclear Fibers
CoPF	Corticopontine Fibers
CSNu	Chief Trigeminal Sensory Nucleus
CST	Corticospinal Tract
CThT	Cerebellothalamic Tract
CTT	Central Tegmental Tract
CunNu	Cuneiform Nucleus
DAONu	Dorsal Accessory Olivary Nucleus
decML	Decussation of the Medial Lemniscus
decPy	Decussation of the Pyramdal Tract
decSCP	Decussation of the Superior Cerebellar Peduncle
DLatF	Dorsolateral Funiculus
DLF	Dorsal Longitudinal Fasciculus
DM	Dorsomedial Nucleus
DMNu	Dorsal Motor Nucleus
DorNu	Dorsal Nucleus of Clarke
DSCT	Dorsal Spinocerebellar Tract
DTTr	Dorsal Trigeminothalamic tract
EML	External Medullary Lamina
FacNr	Facial Nerve
FacNu	Facial Nucleus
FCu	Fasciculus Cuneatus
FGr	Fasciculus Gracilis
Fx	Fornix
GPe	Globus Pallidus, External segment
GPi	Globus Pallidus, Internal Segment
Hab	Habenular Nucleus
HPTr	Habenulopeduncular Tract
HyNr	Radiations of Hypoglossal Nerve
HyNu	Hypoglossal Nucleus
HyTh	Hypothalamus
IAF	internal Arcuate Fibers
IC	Inferior Colliculus
ICP	Inferior Cerebellar Peduncle
IML	Internal Medullary Lamina
IntCap	internal Capsule
InThP	Inferior Thalamic Peduncle
IONu	Inferior Olivary Nucleus
IPF	Interpeduncular Fossa
IPNu	Interpeduncular Nucleus
ISNu	Inferior Salivatory Nucleus
ISNu	Inferior Salivatory Nucleus
LatCen,IH	Lateral Ventricle, Inferior Horn
LatVen, B	Lateral Ventricle, Body
LCNu	Lateral Cuneate Nucleus
LCSP	Lateral Corticospinal Tract
LD	Laterodorsal Nucleus
LenFas	Lenticular Fasiculus
LGB	Lateral Geniculate Body
LL	Lateral Lemniscus
LLNu	Nuclei of the Lateral Lemniscus
LMNu	Lateral Motor Nucleus
LoCer	Locus Coeruleus
LP	Lateral Posterior Nucleus
LRNu	Lateral Reticular Nucleus
LStBr	lenticulostriate branches
LVestSp	Lateral Vestibulospinal Tract
LVNu	Lateral Vestibulospinal Nucleus
MAONu	Medial Accessory Olivary Nucleus
MB	Mammillary Bodies
MCP	Medial Cerebellar Peduncle
MesNu&Tr	Mesencephalic Trigeminal Nucleus & Tract
MesTr	Mesencephalic Trigeminal tract
MGB	Medial Geniculate Body
MI	Mass Intermedia
MidRetF	Midbrain Reticular Formation
ML	Medial Lemniscus
MLF	Median Longitudinal Fasciculus
MMNu	Medial Motor Nucleus
MRetF	Medullary Reticular Formation
MRetSp	Medullary Reticulospinal Tract
MSO	Medial Superior Olivary Nucleus
MTTr	Mamillothalamic Tract
MVNu	Medial Vestibular Nucleus
NuAm	Nucleus Ambiguus
NuCu	Nucleus Cuneatus
NuGr	Nucleus Gracilis
NuPp	Nucleus Prepositus
OcNr	Radiations of the Oculomotor Nerve
OcNu	Oculomotor Nucleus
OpRad	Optic Radiations
OpTr	Optic tract
PBNu	Pontobulbar Nucleus
PCA	Posterior Cerebral Artery
PCeF	Pontocerebellar Fibers
PChA	Posterior Choroidal Artery
PICA	Posterior Inferior Cerebellar Artery
PmBr	Paramedian Branches
PMChA	Posteromedial Choroidal Artery
PoCom	Posterior Commissure
PonNu	Pontine Nuclei
PONu	Principal Inferior Olivary Nucleus
PPRF	Paramedian Pontine Reticular Formation
PreTec	Pretectal Nuclei
PRetF	Pontine Reticular Formation
PRetSp	Pontine Reticulospinal tract
ProSp	Propriospinal Tract
PSA	Posterior Spinal Artery
Pul	Pulvinar Nucleus
Put	Putamen
Py	Pyramidal Tract
RaNu	Raphe Nucleus
RetSp	Reticulospinal Tract
RINMLF	Rostral Interstitial Nucleus of the MLF
RuSp	Rubrospinal Tract
SagNu	Nucleus Sagulum
SC	Superior Colliculus
SCA	Superior Cerebellar Artery
SCP	Superior Cerebellar Peduncle
SN	Substantia Nigra
SolNu	Solitary Nucleus
SolTr	Solitary Tract
SONu	Superior Olivary Nucleus
SpTNu	Spinal Trigeminal Nucleus
SpTNu,g	Spinal Trigeminal Nucleus, pars gelatinosia
SPTNu,m	Spinal Trigeminal Nucleus, pars magnocellularis
SpTT	Spinal Trigeminal Tract
SpVNu	Spinal Vestibular Nucleus
SSNu	Superior Salivatory Nucleus
SThNu	Subthalamic Nucleus
StMed	Stria Medullaris
StTer	Stria Terminalis
SVNu	Superior Vestibular Nucleus
TecSP	Tectospinal Tract
ThFas	Thalamic Fasciculus
ThGA	Thalamogeniculate Artery
ThRetNu	Thalamic Reticular Nucleus
TrapB	Trapezoid Body
TriMoNu	Trigeminal Motor Nucleus
TriNr	Radiation of the Trigeminal Nerve
TroNr	Radiations of the Trochlear Nerve
TroNu	Trochlear Nucleus
TuThBr	Tuberothalamic Branches
VA	Vertebral Artery
VANu	Ventroanterior Nucleus
VCNr	Vestibulocochlear Nerve
VCNu	Ventral Cochlear Nucleus
VesSp	Vestibulospinal Tract
VL	Ventrolateral Nucleus
VPL	Ventroposterior Lateral Nucleus
VPM	Ventroposterior Medial Nucleus
VSCT	Ventral Spinocerebellar Tract
VTA	Ventral Tegmental Area
VTTr	Ventral Trigeminothalamic Tract
VWCom	Ventral White Commissure
Zi	Zona Incerta



1 LMNu
2 MMNu
3 LVestSp

Plate 01

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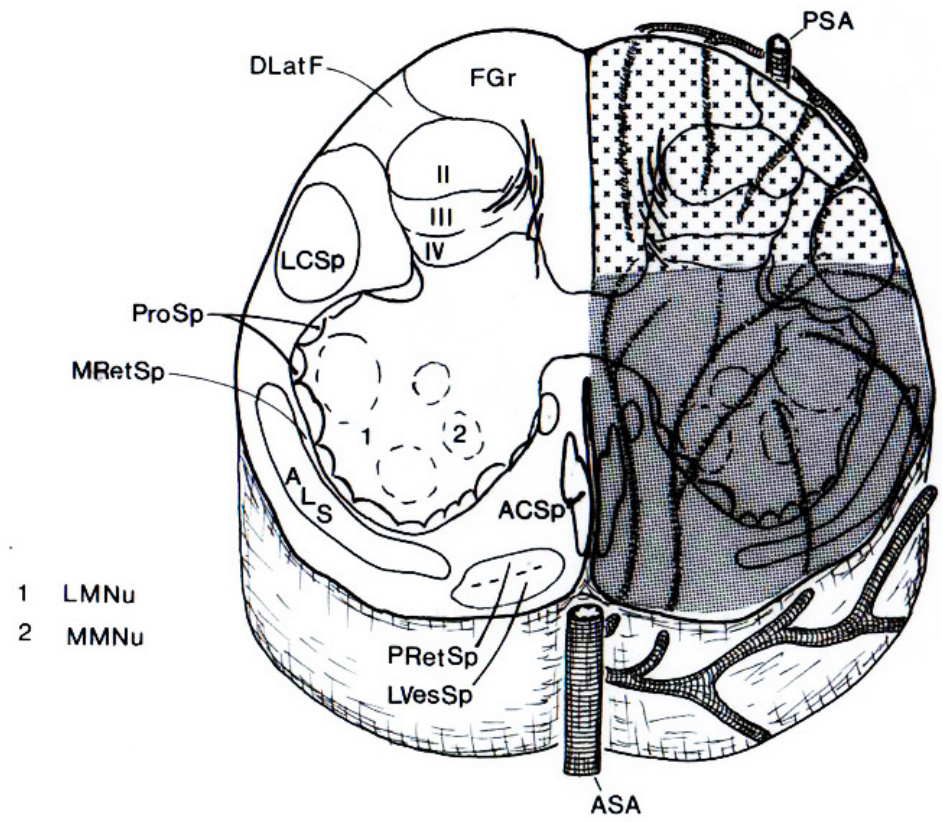

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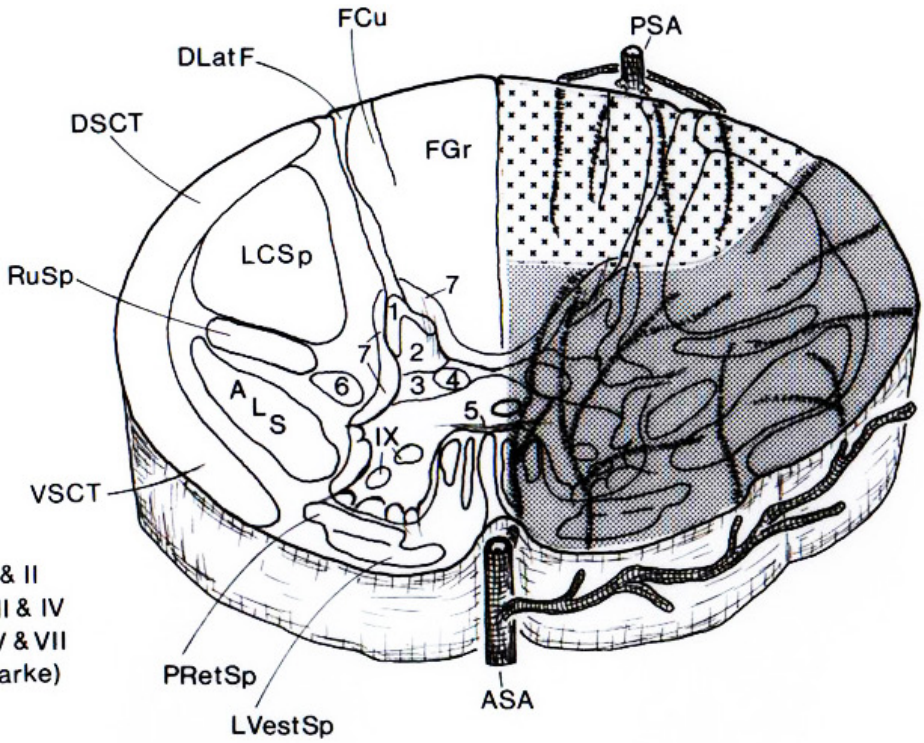

1 Laminae I & II
2 Laminae III & IV
3 Lamina V & VII
4 Dor Nu (Clarke)
5 VWCom
6 MRetSp
7 ProSp

Plate 03

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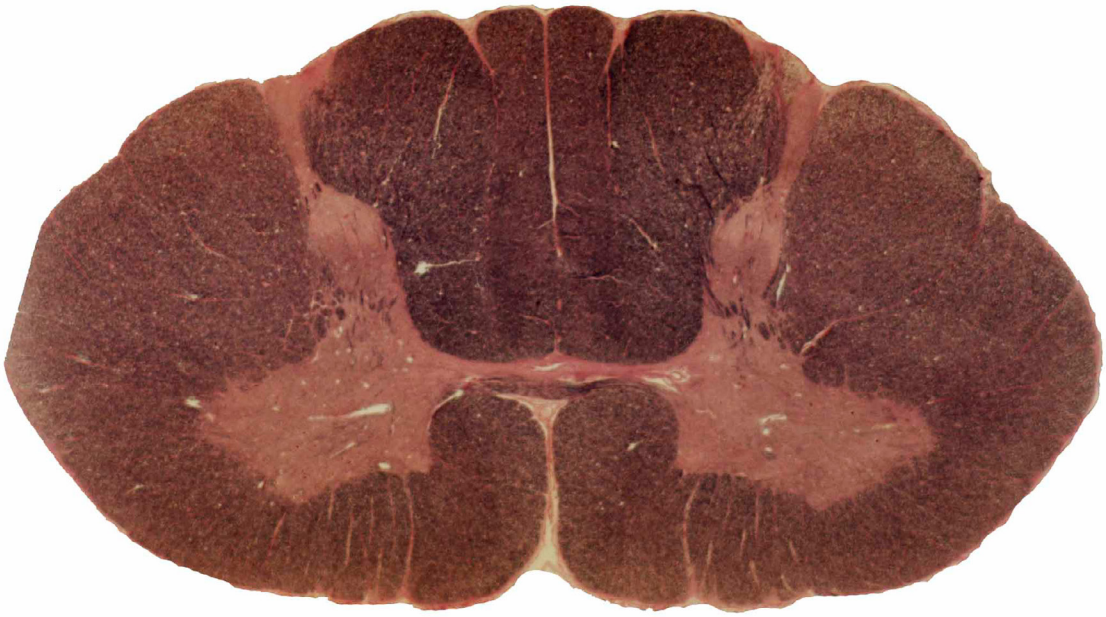

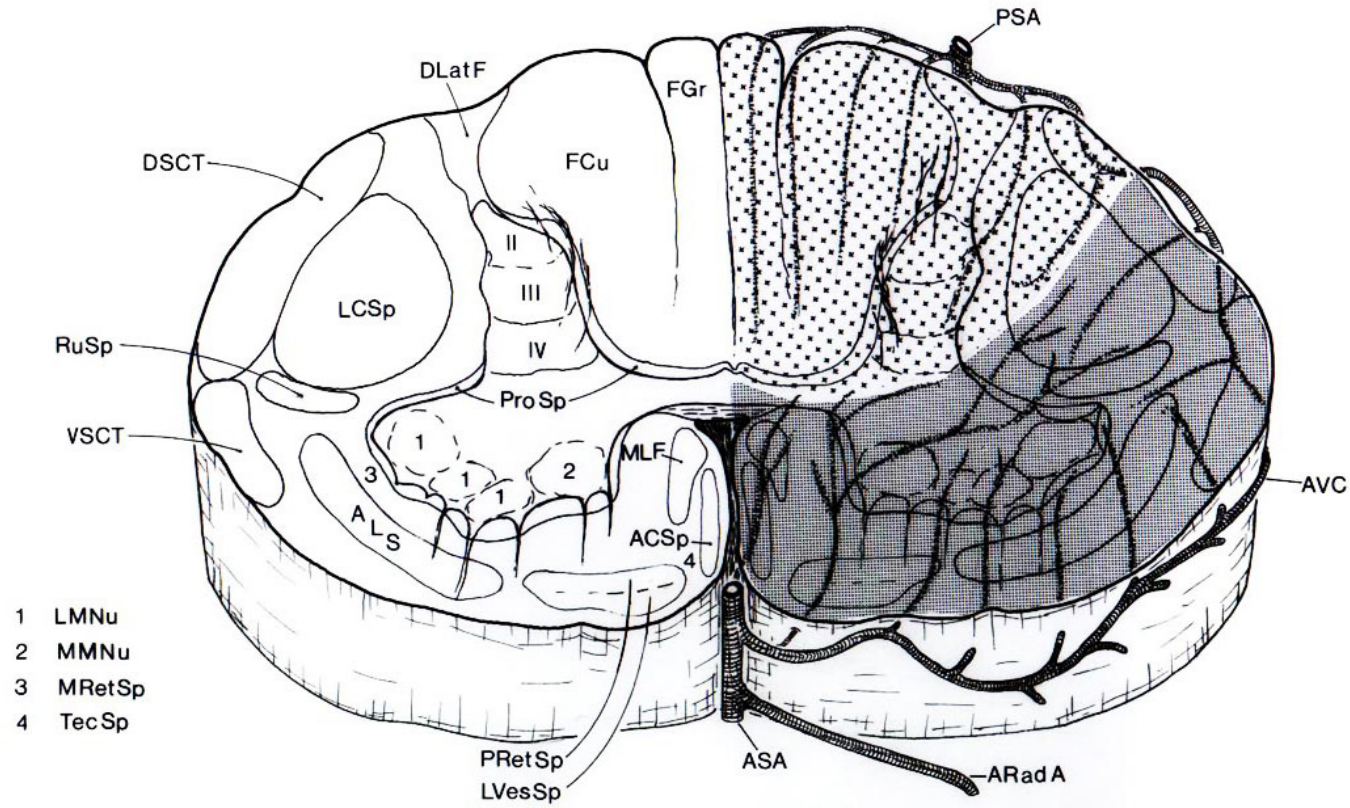

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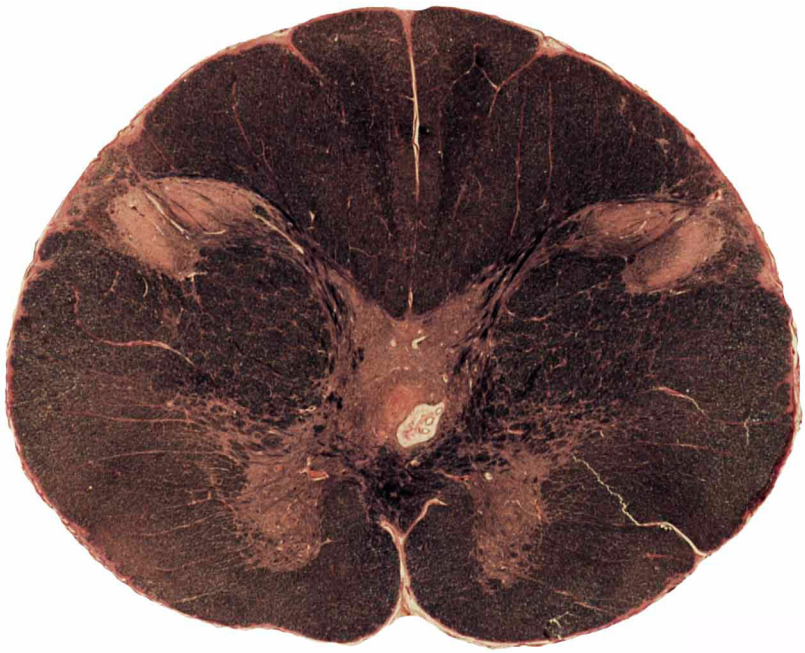

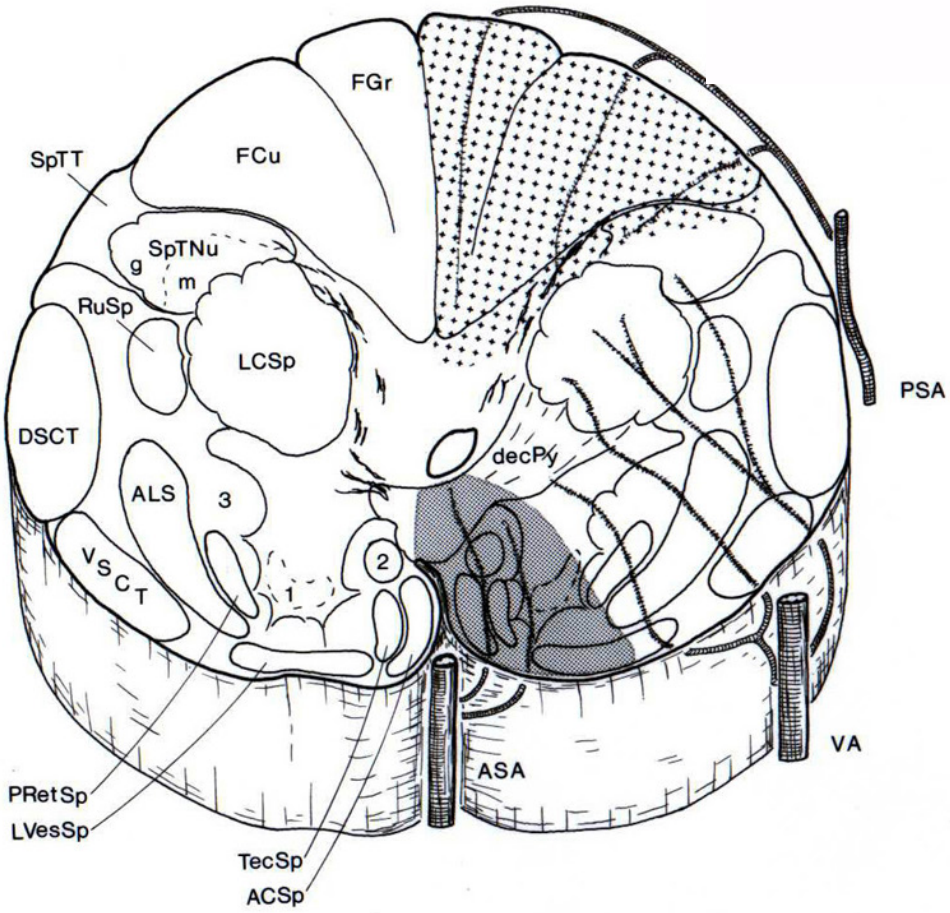

Acc Nu
MLF
MRetSp

Plate 05

Abbreviations

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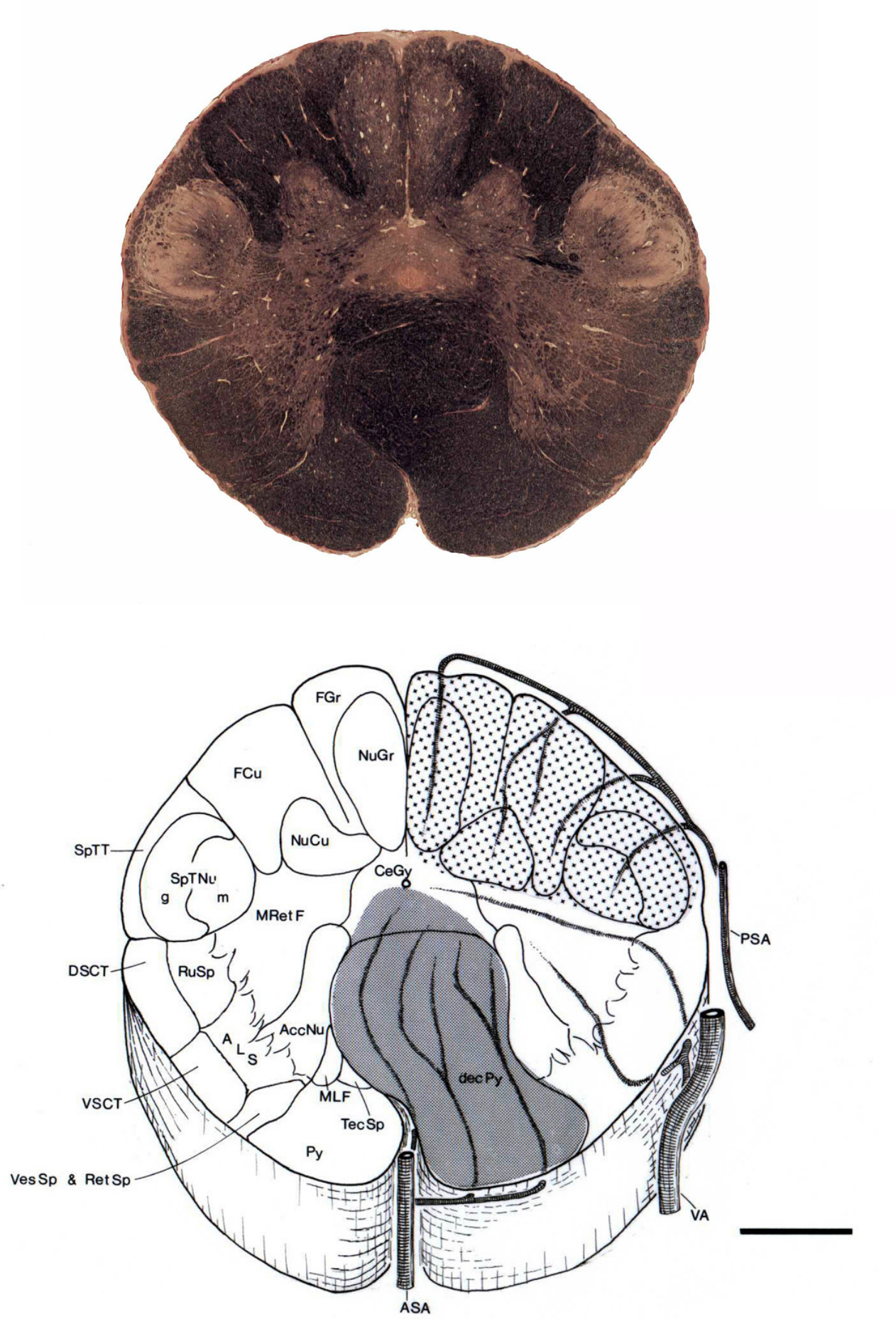

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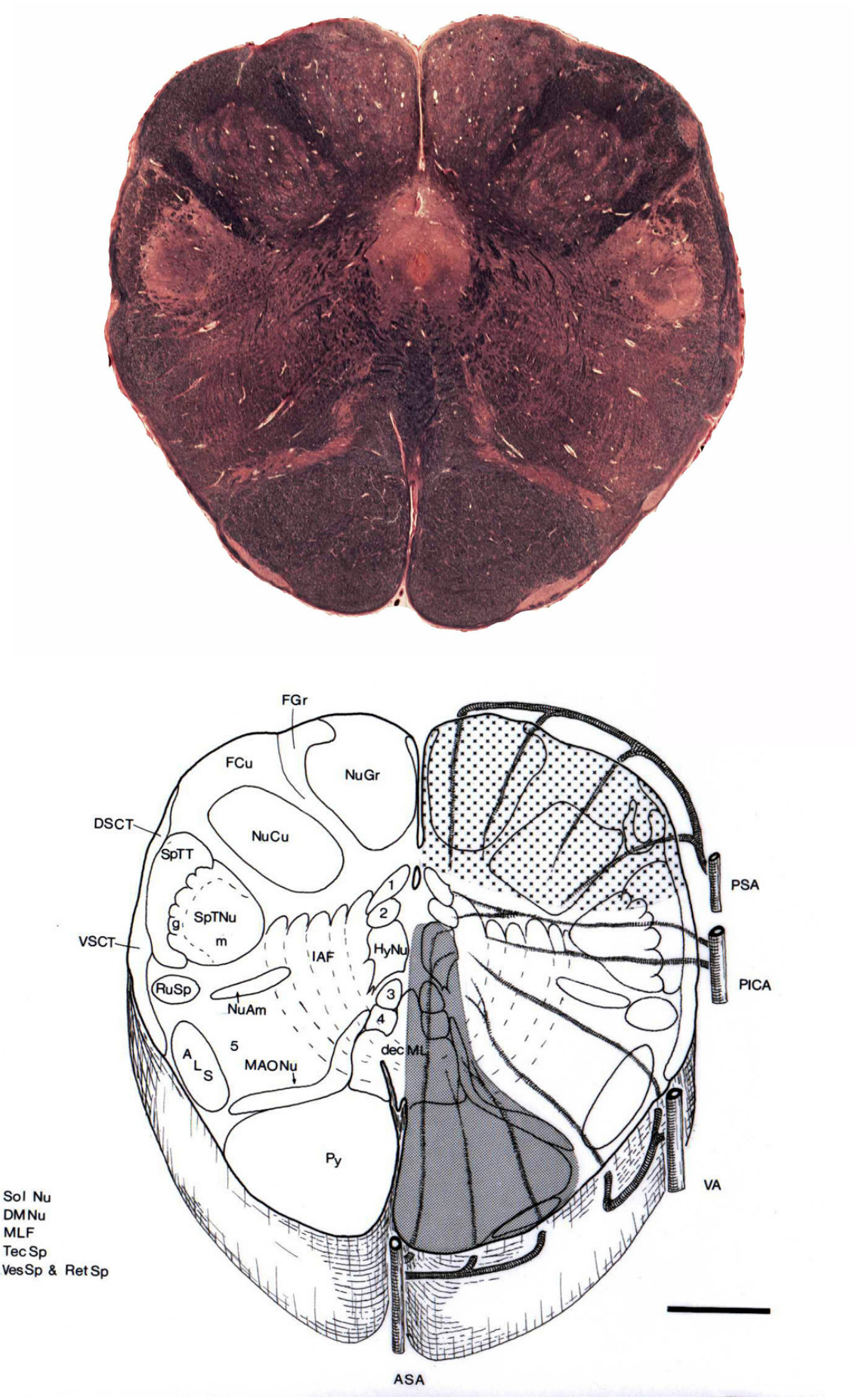

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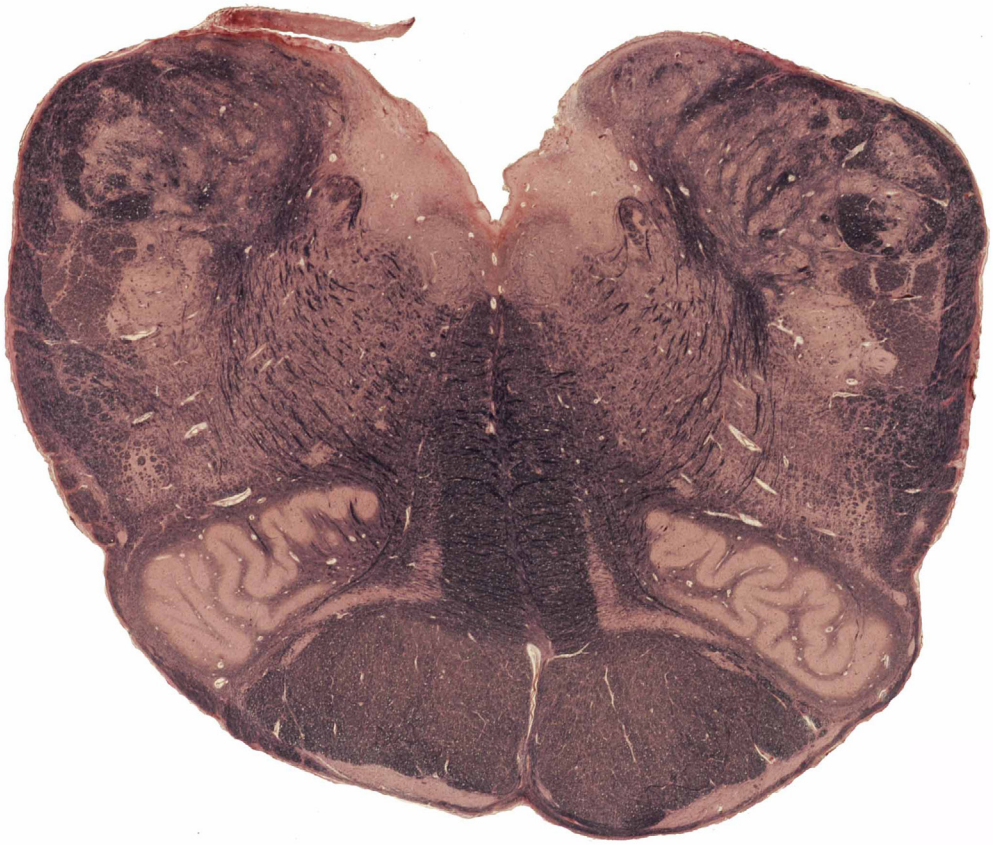

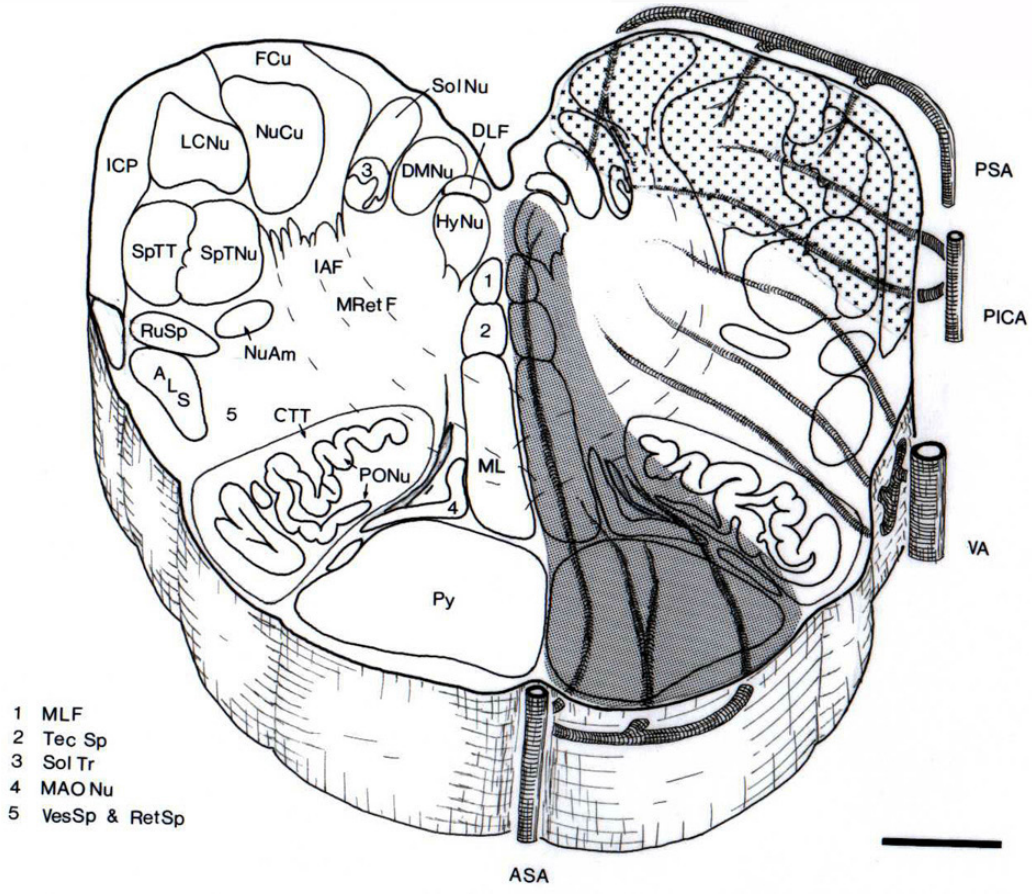

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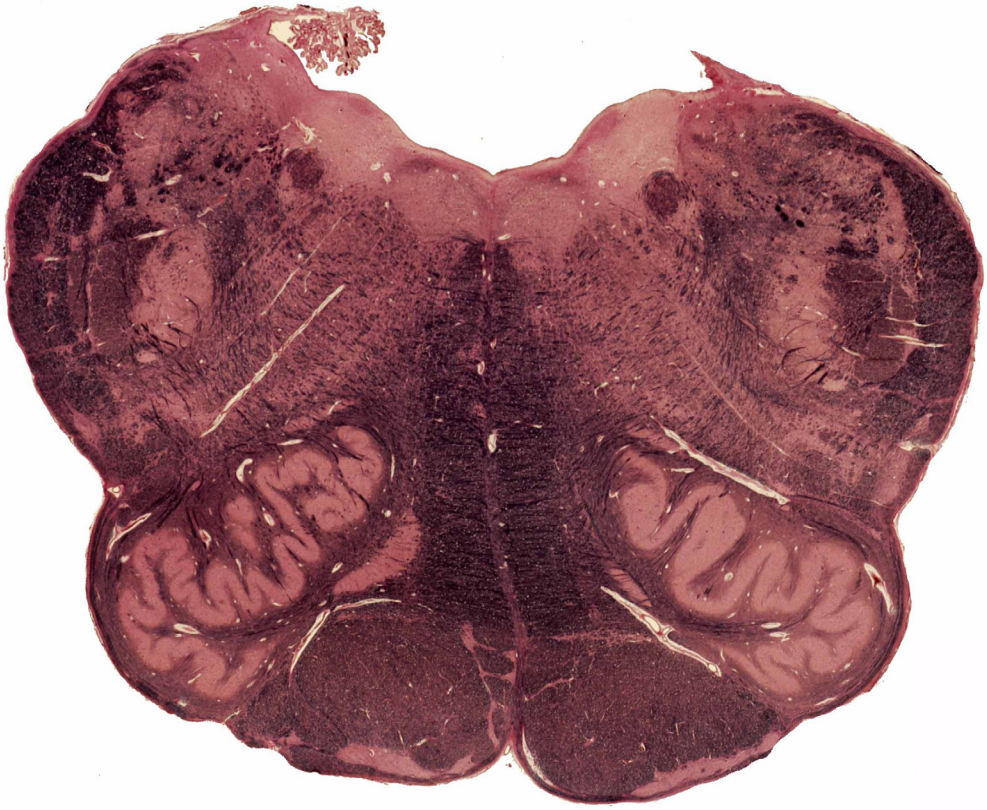

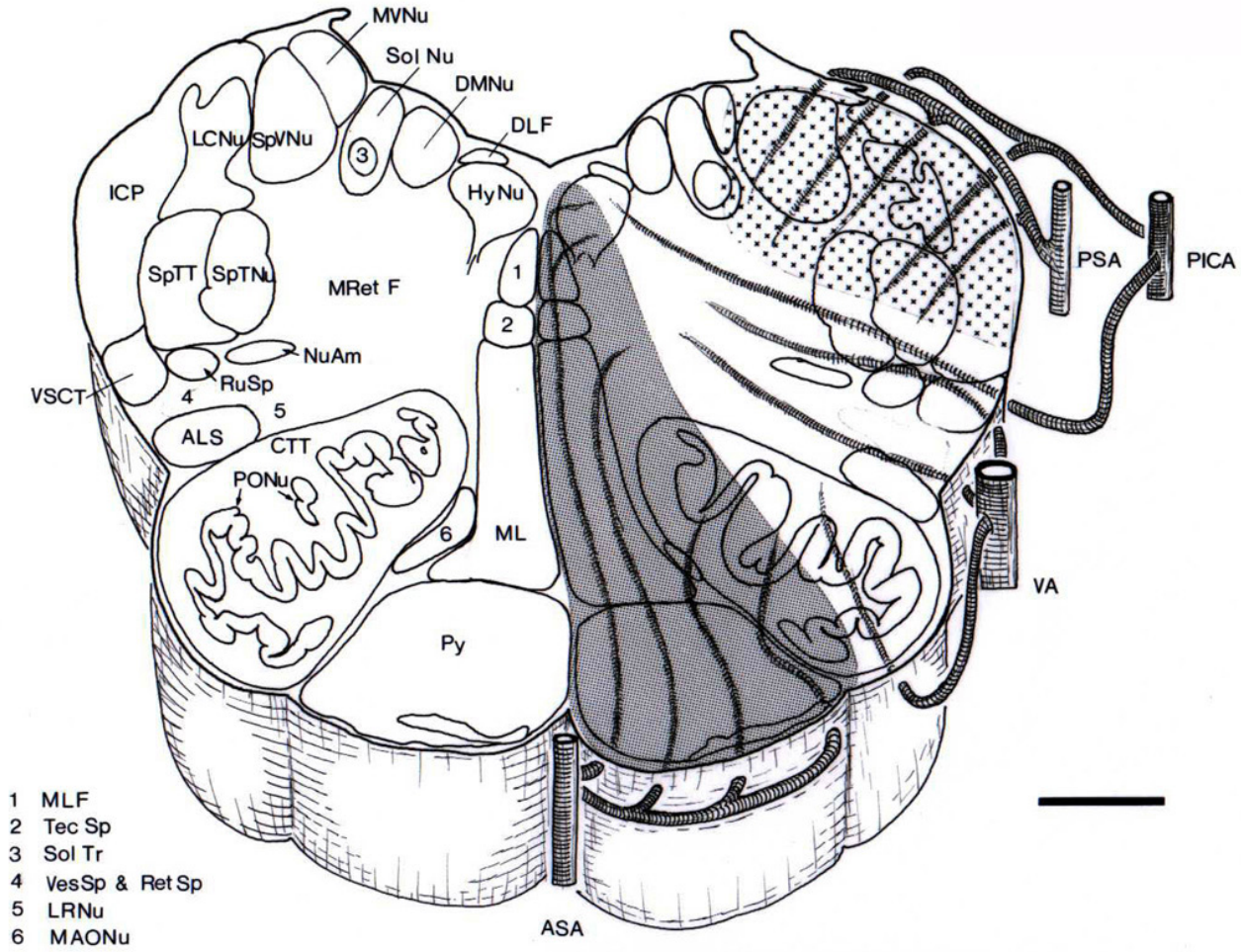

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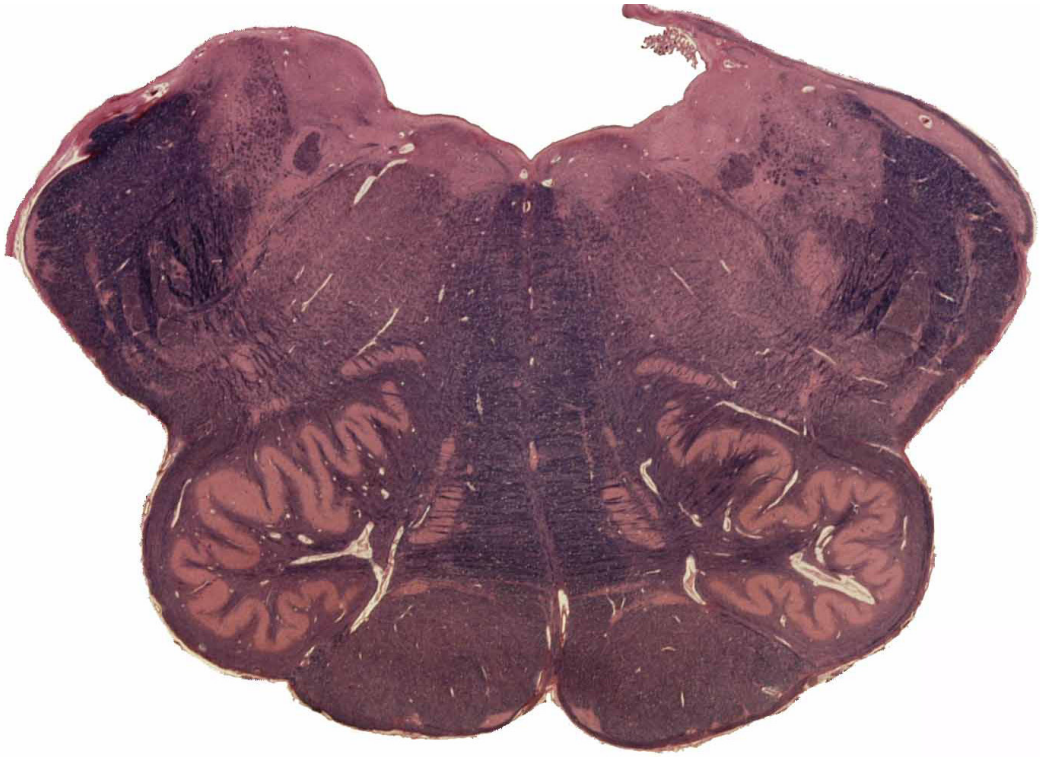

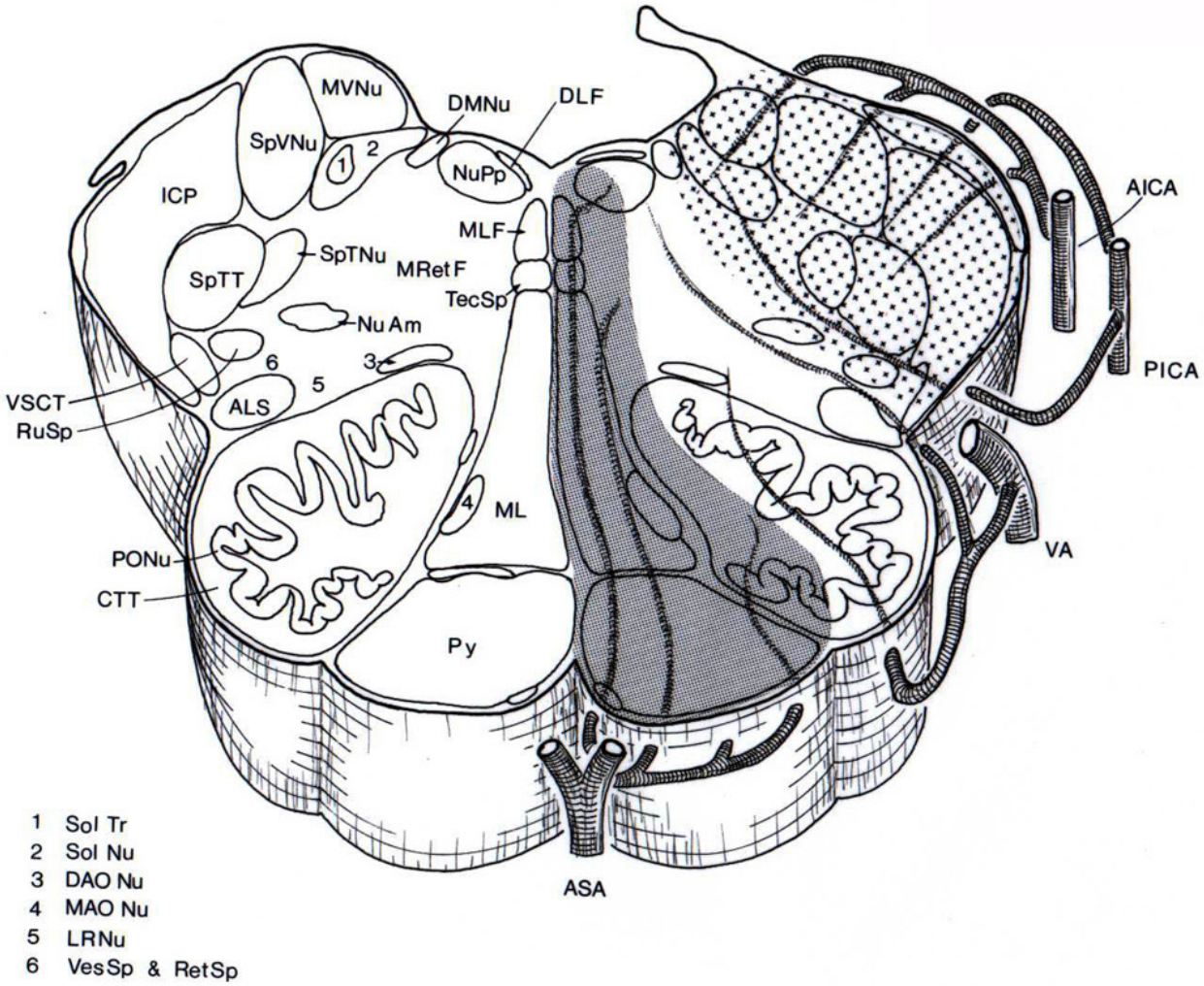

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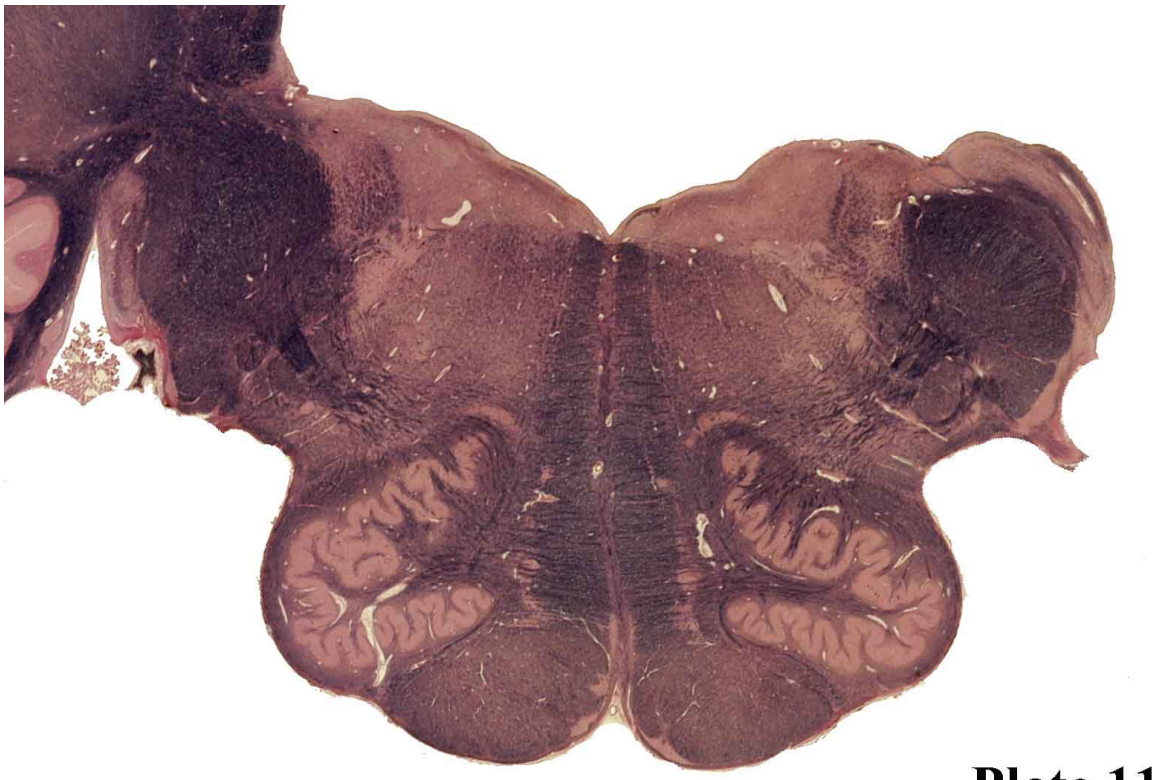

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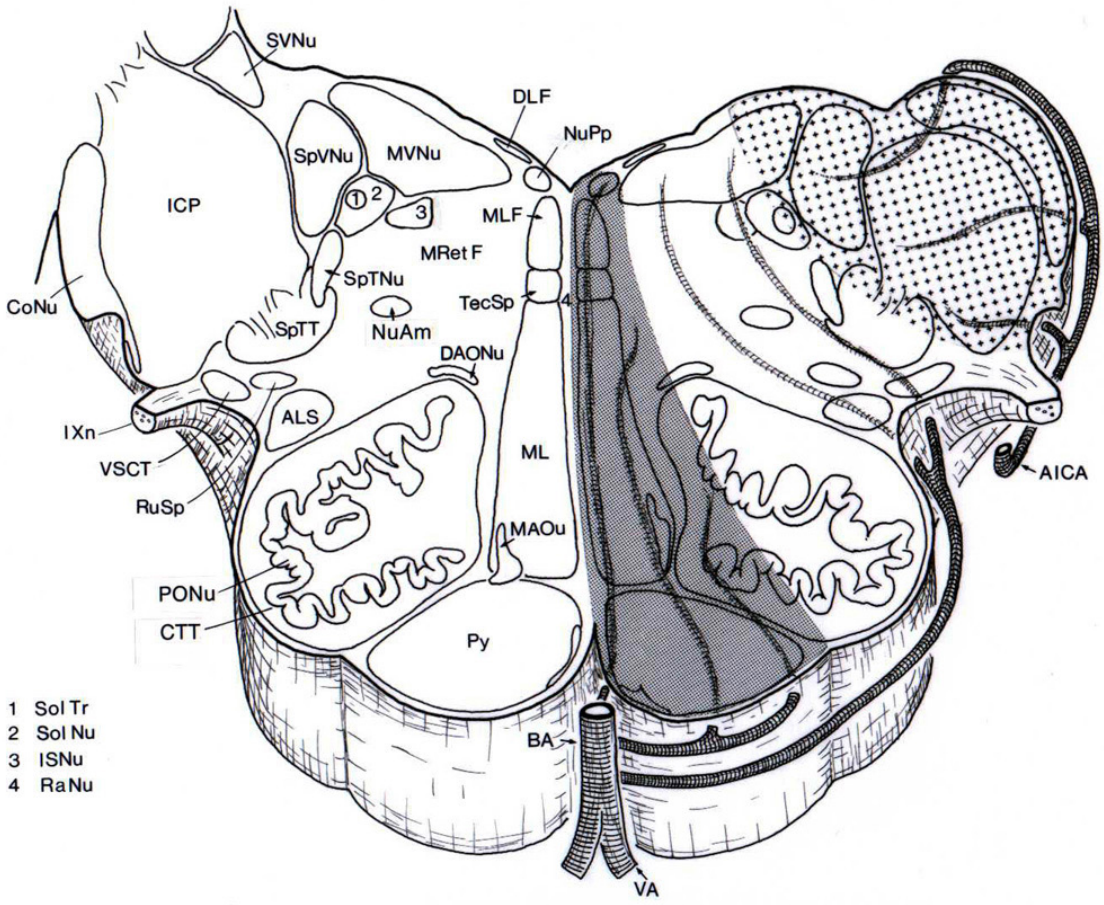

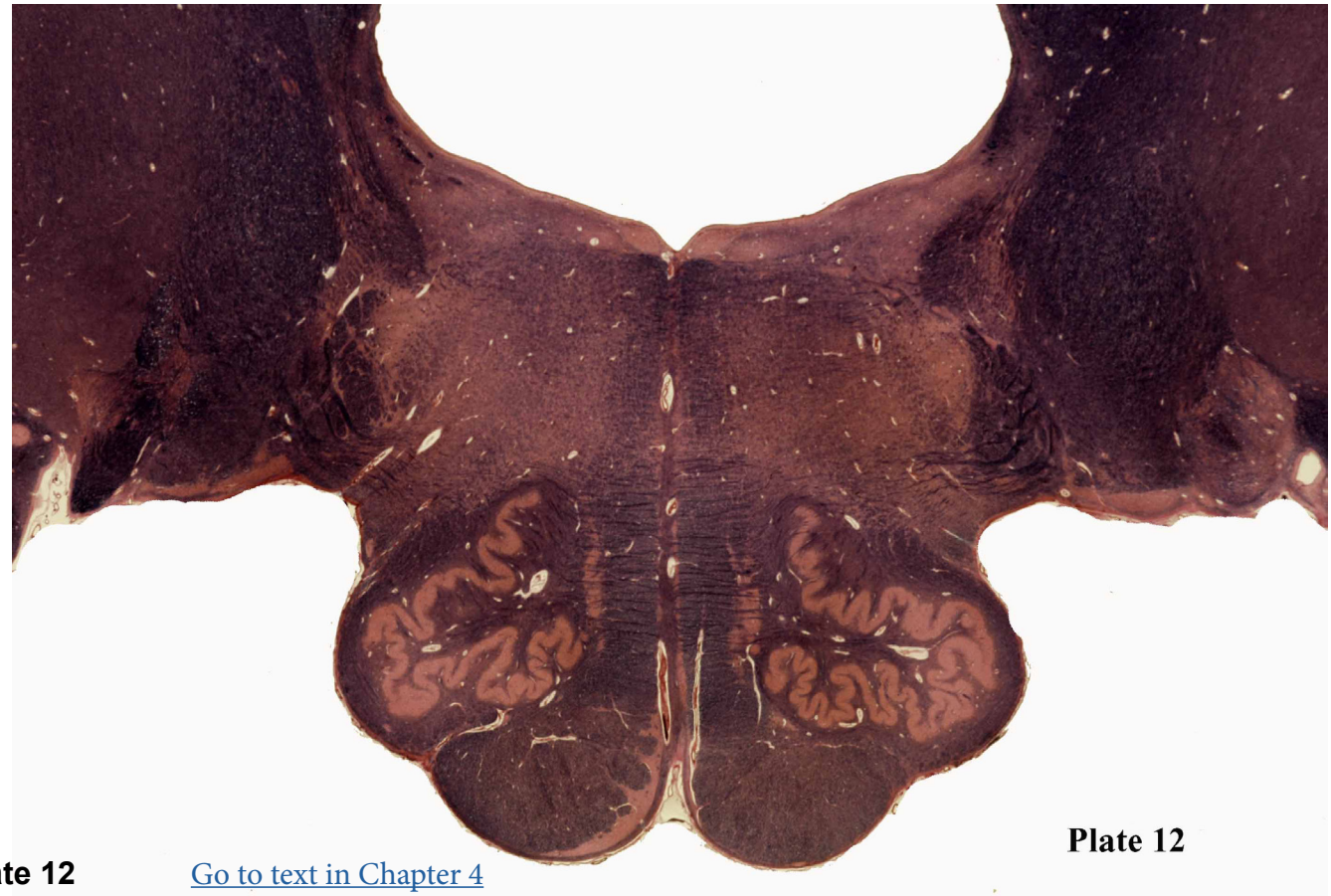

Plate 12

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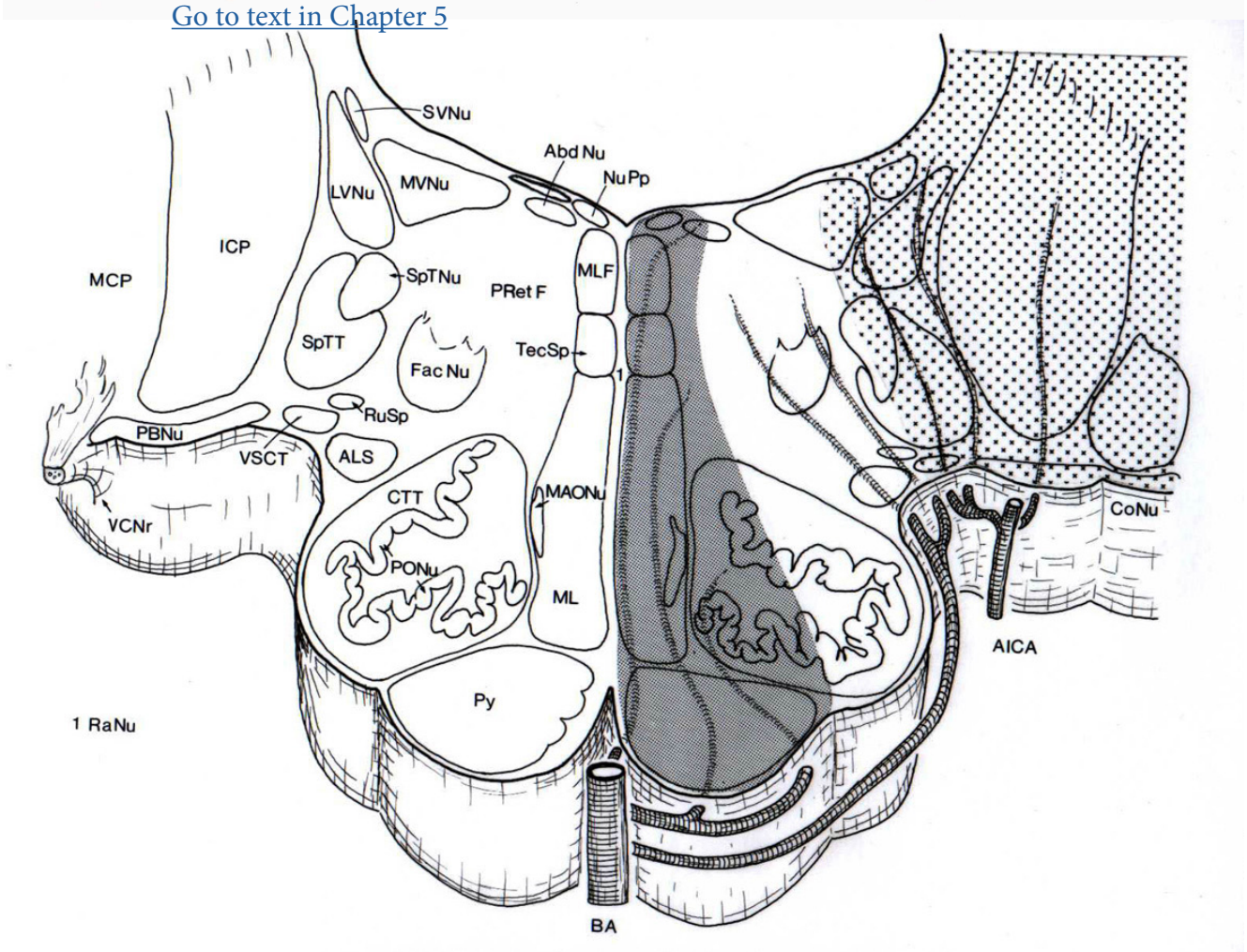

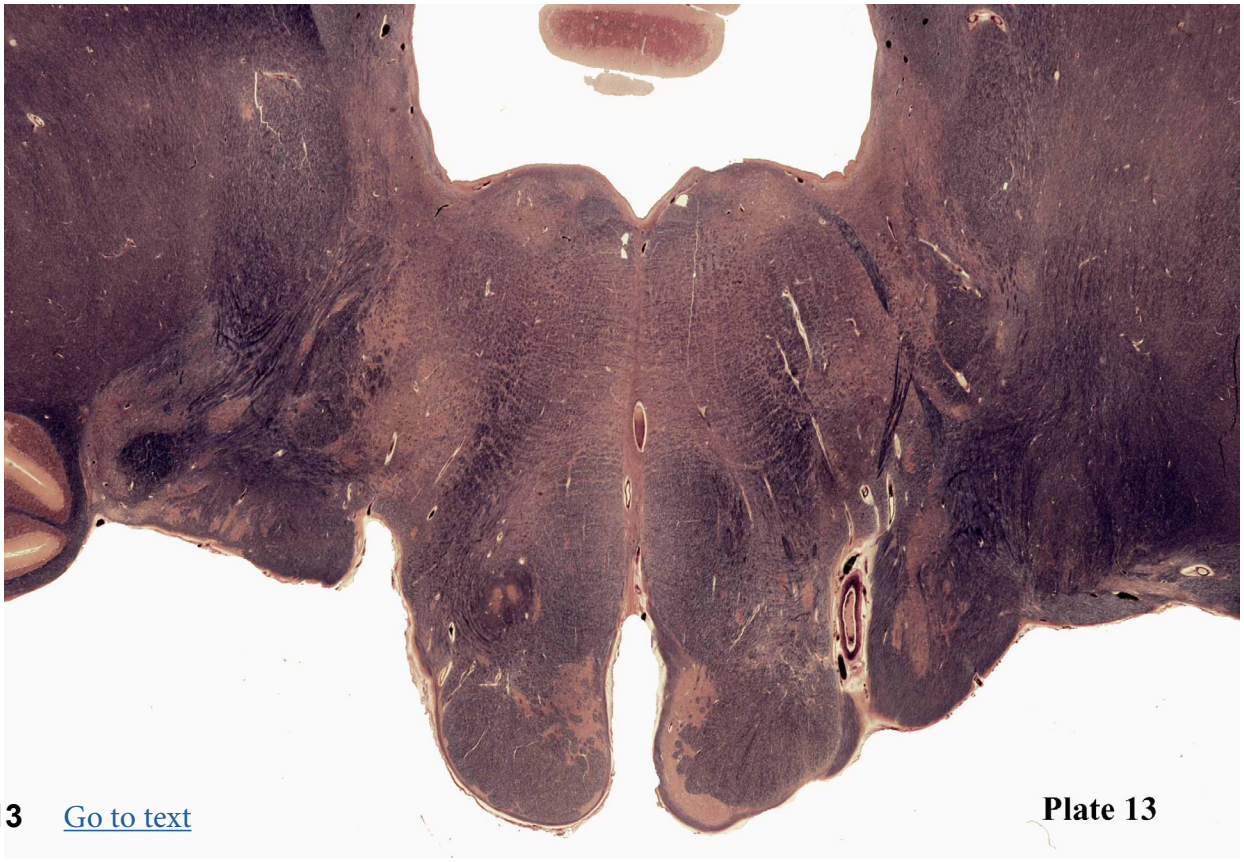

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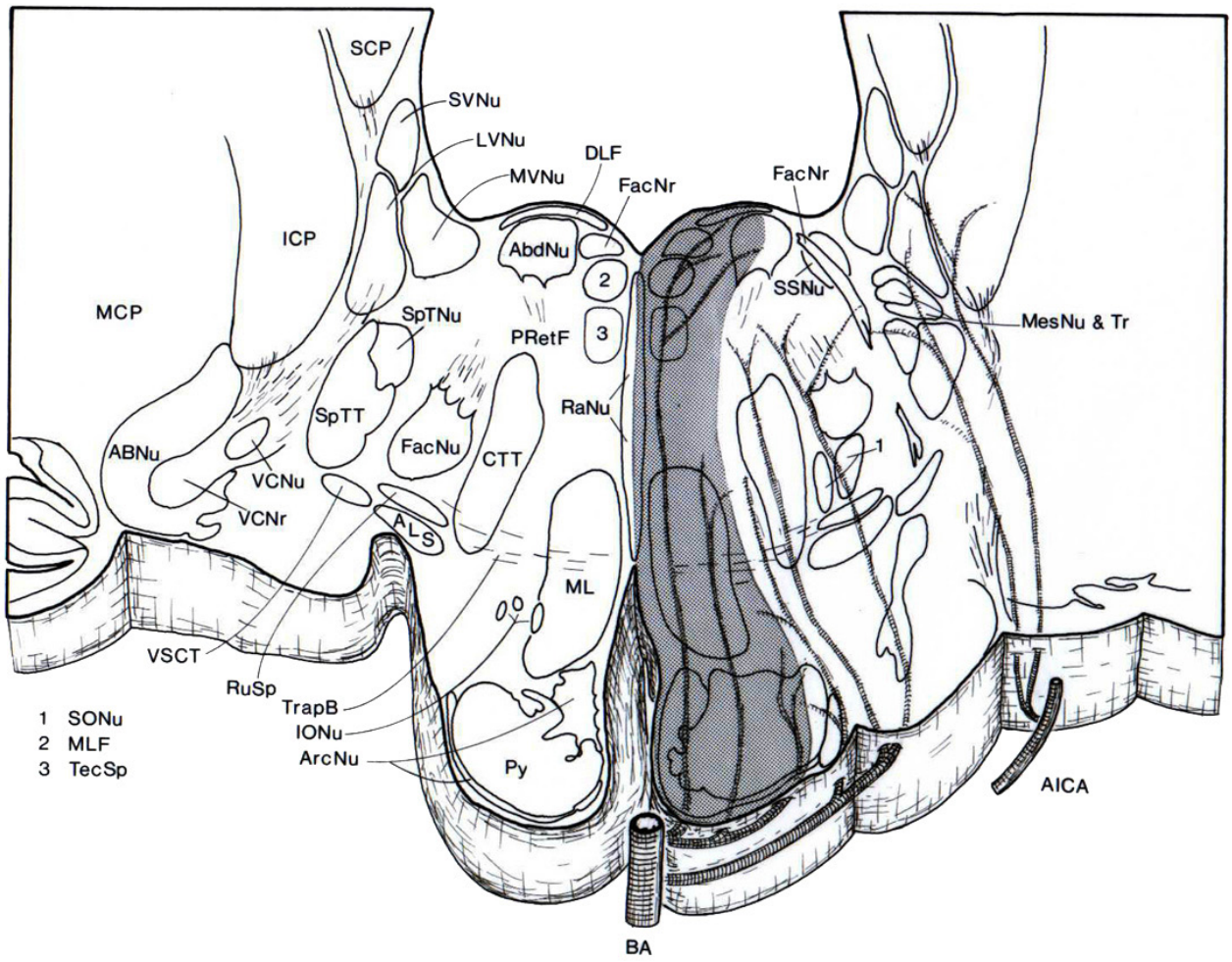

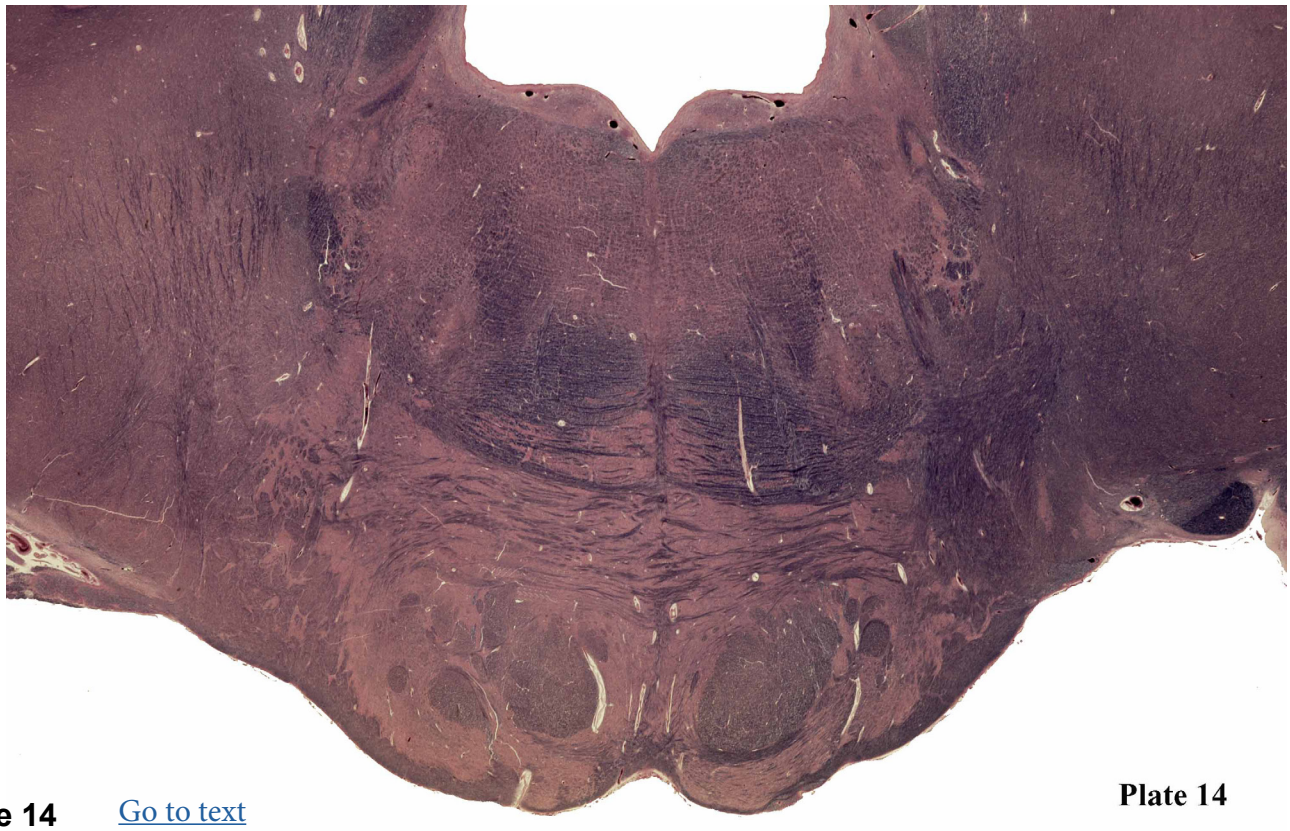

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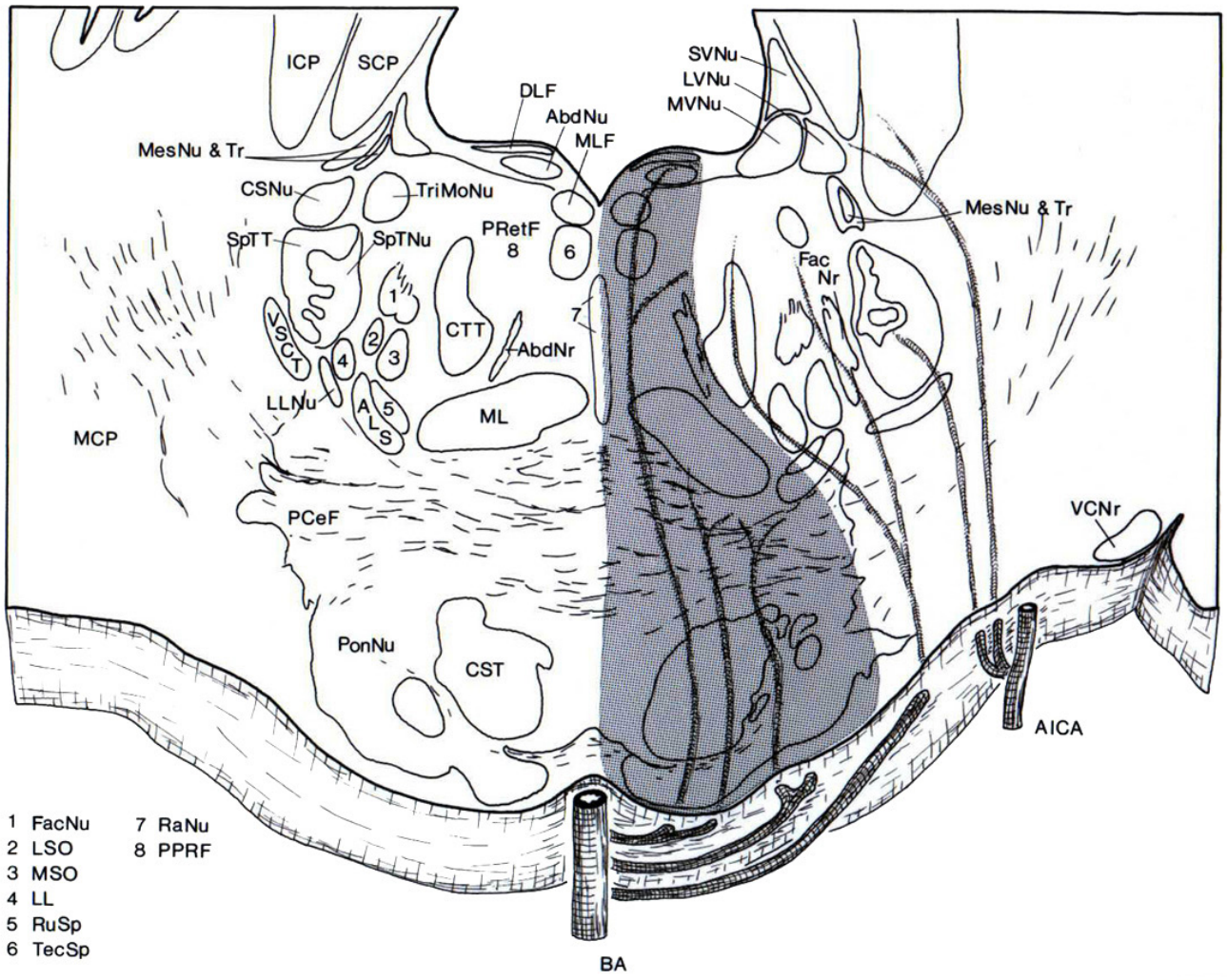

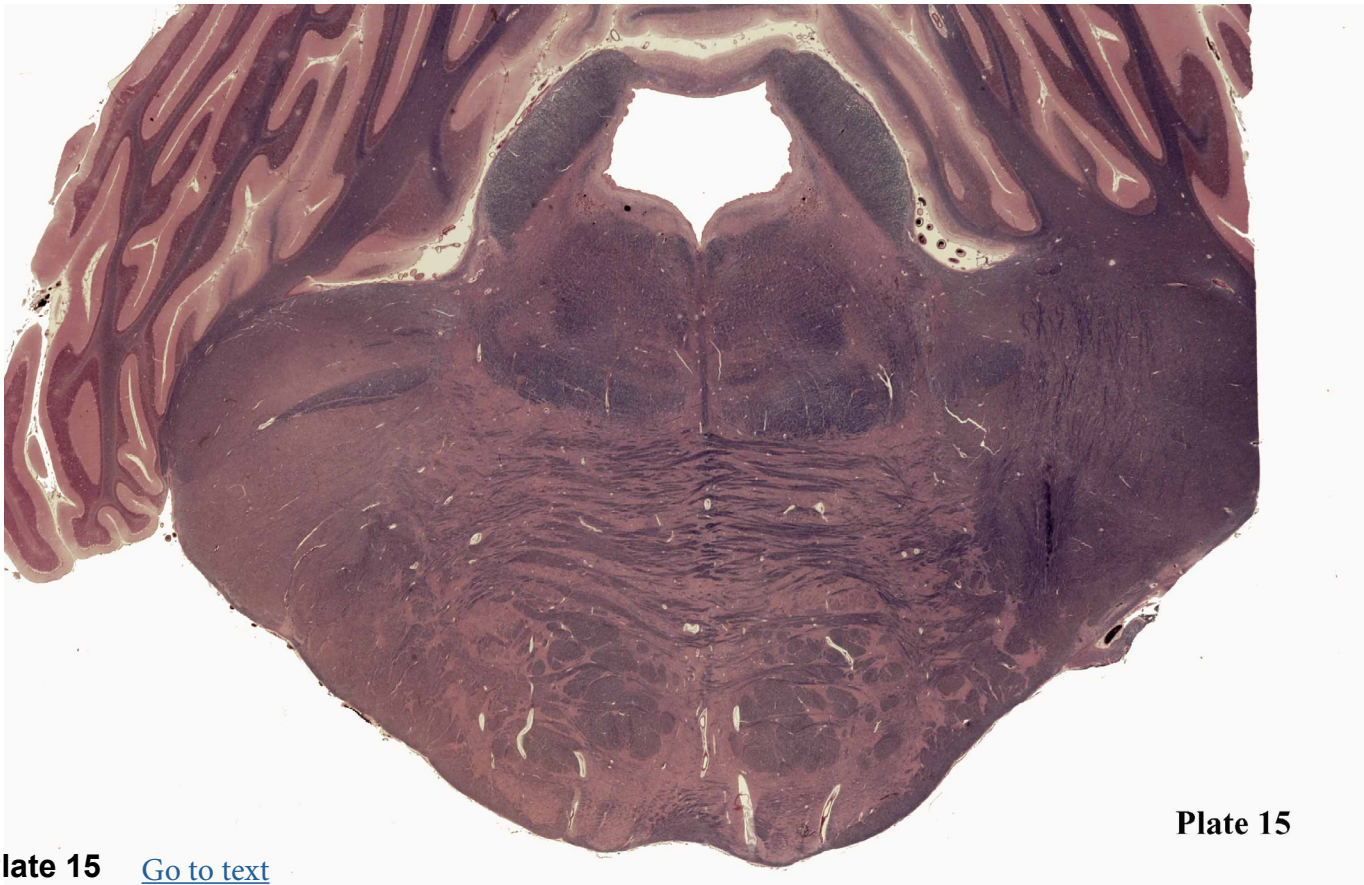

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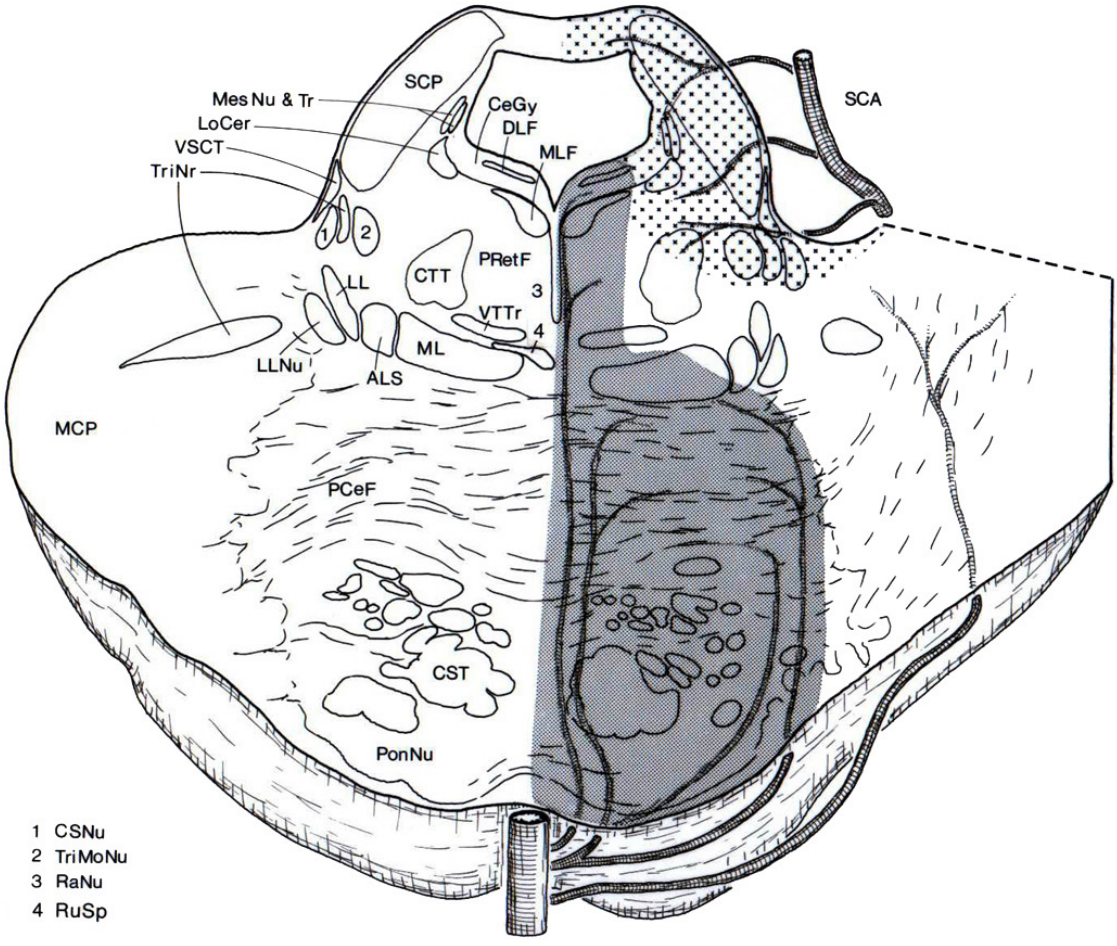

Plate 16

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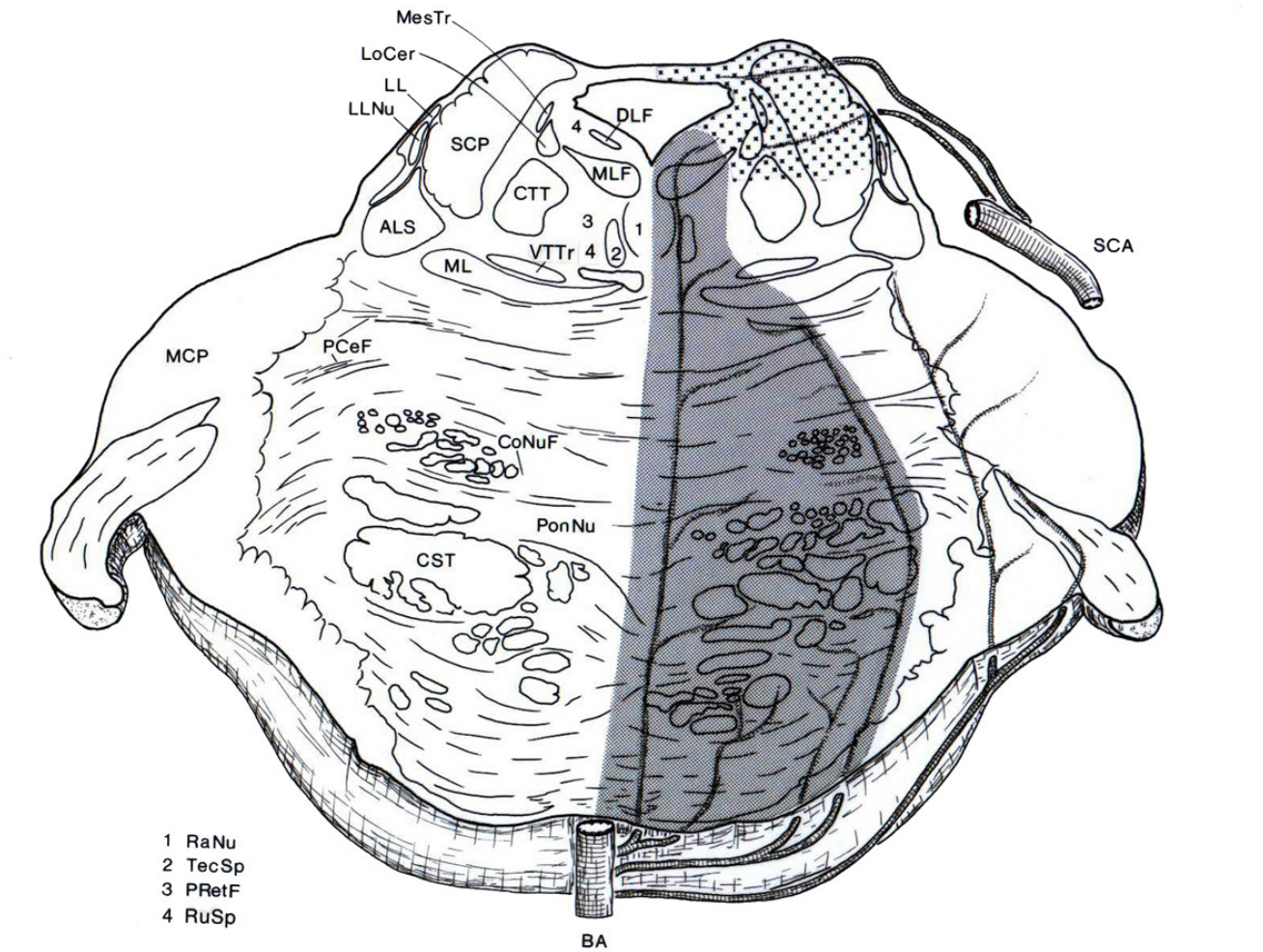

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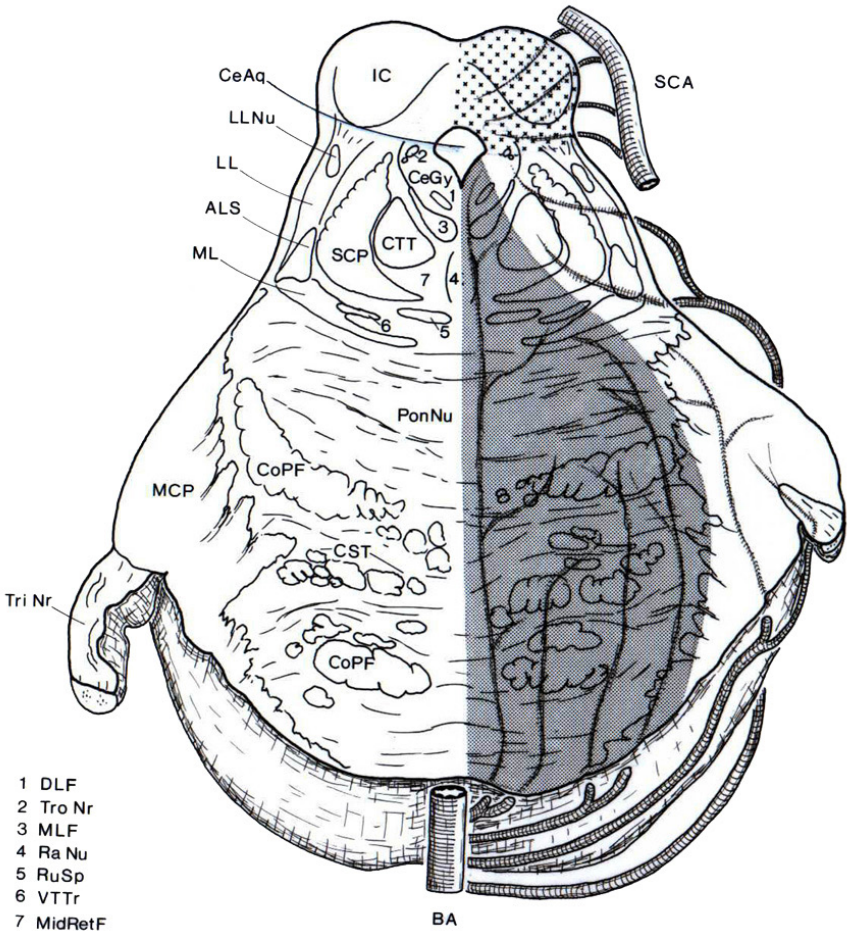

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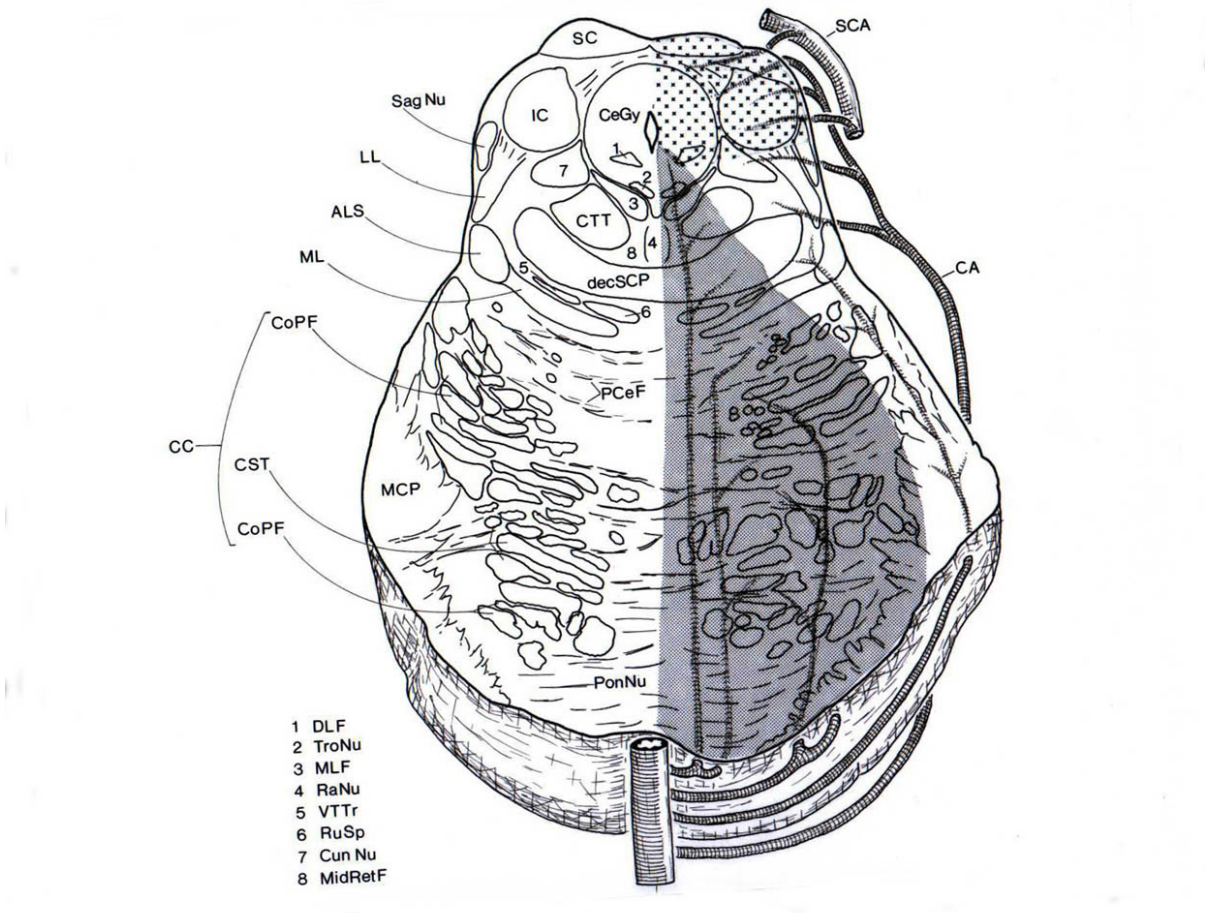

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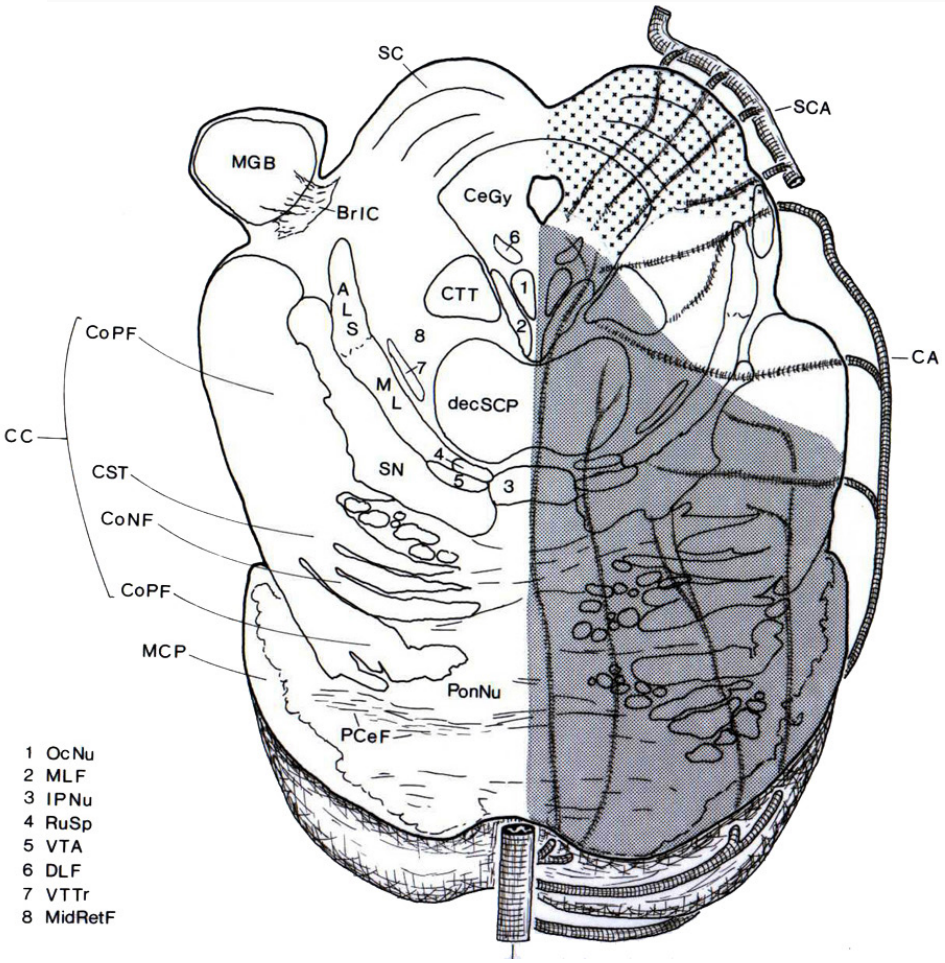

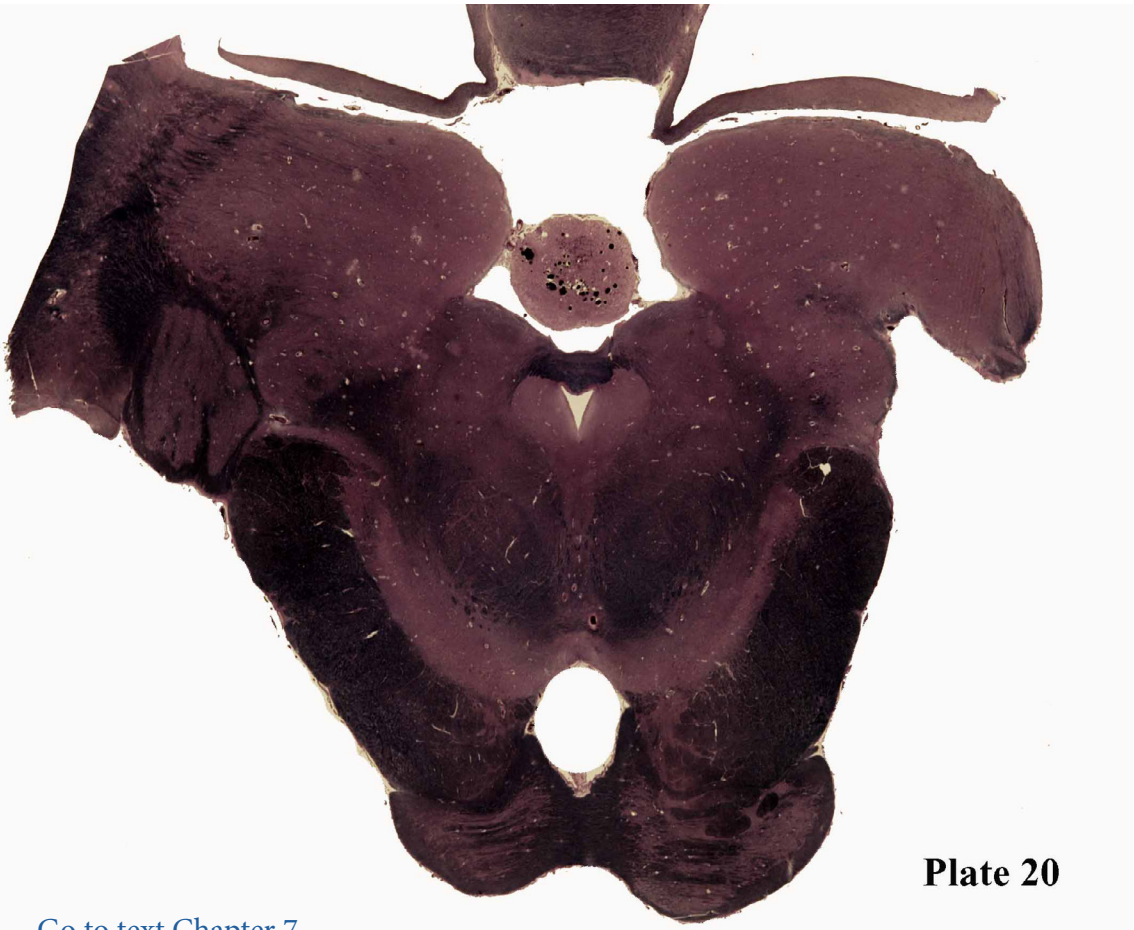

Plate 20

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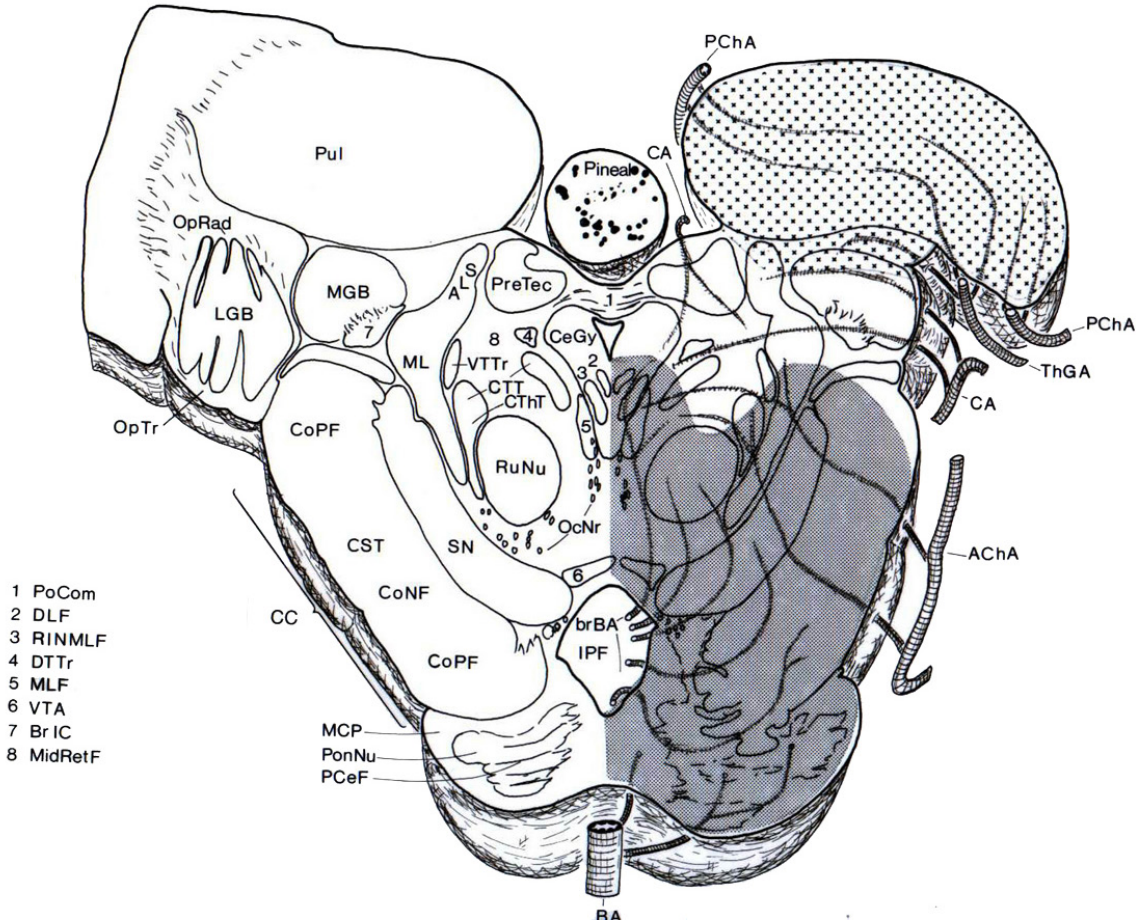

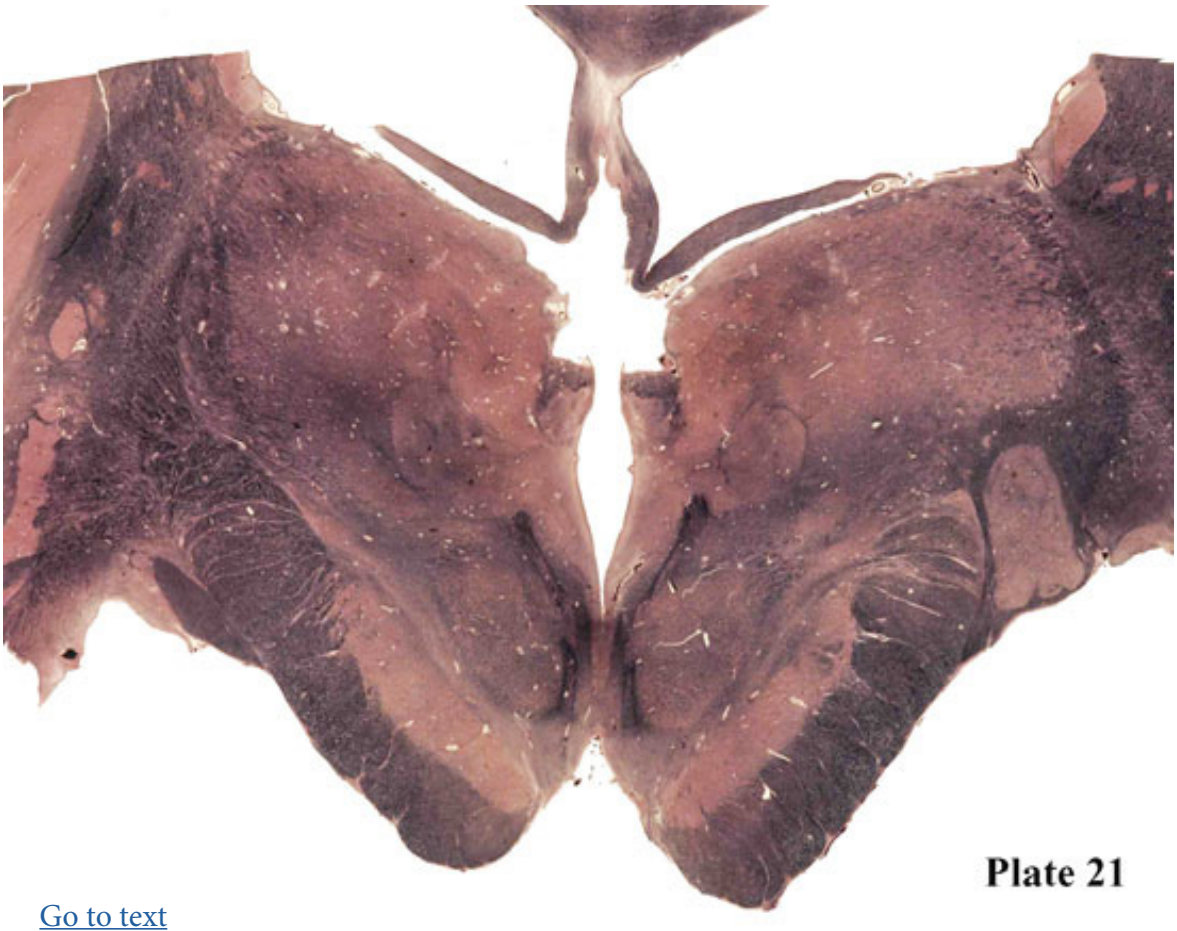

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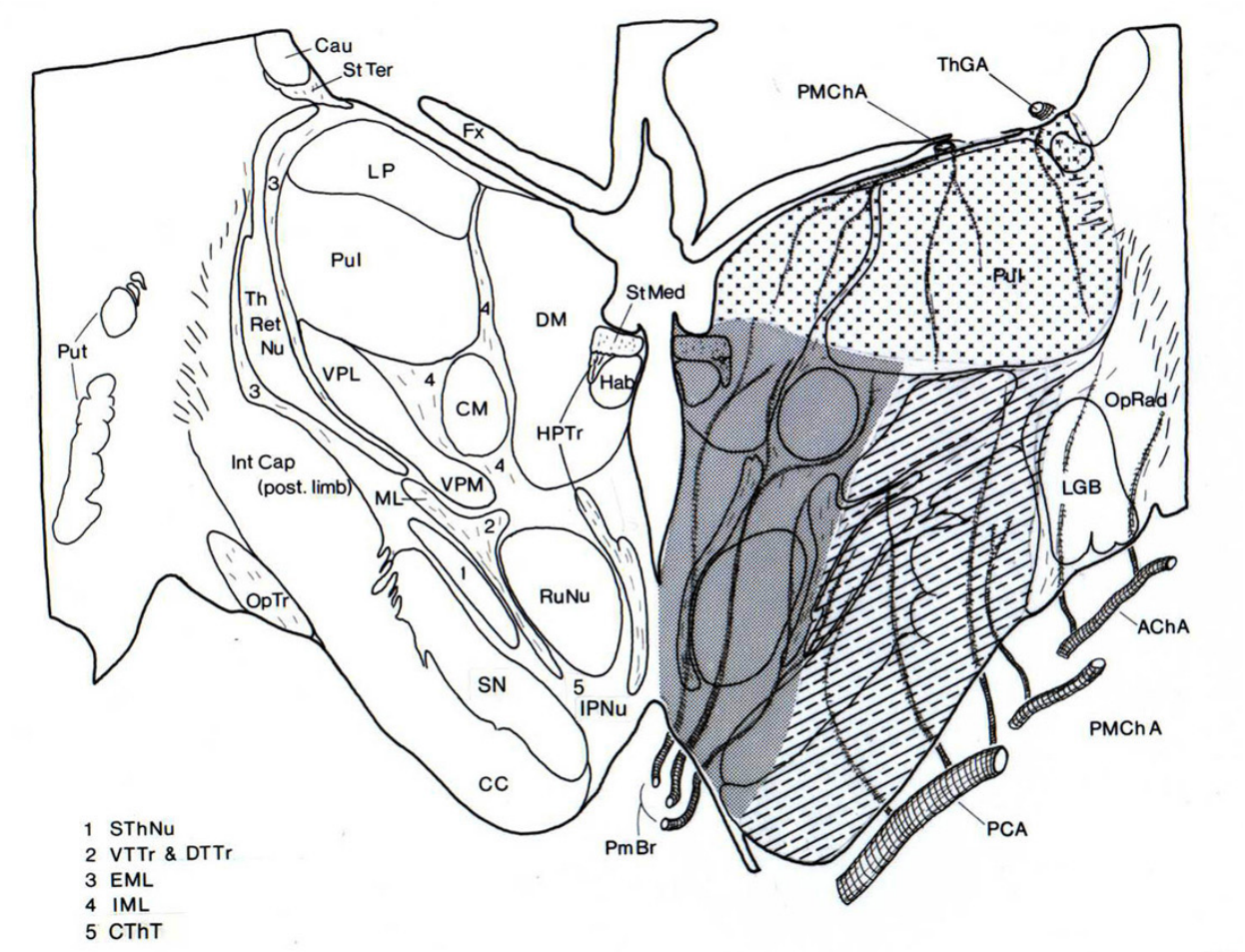


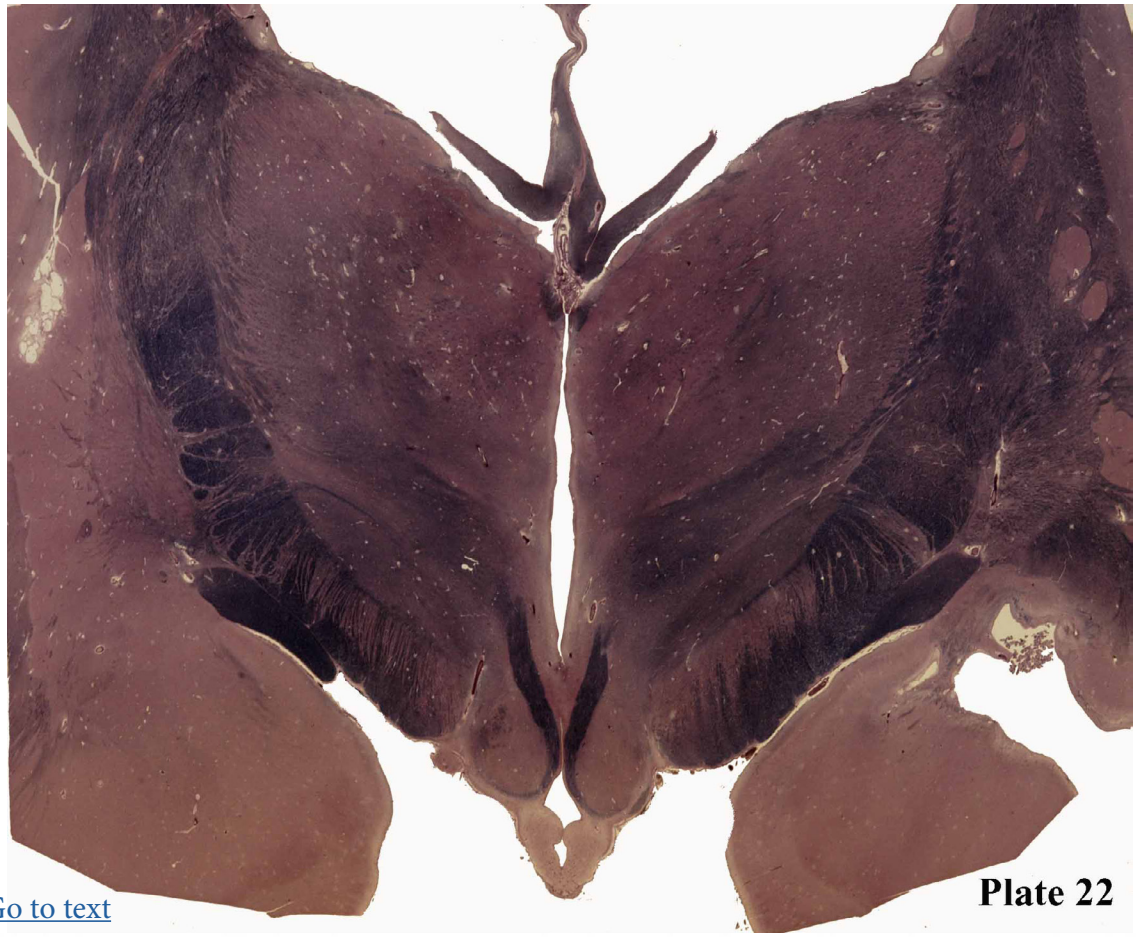
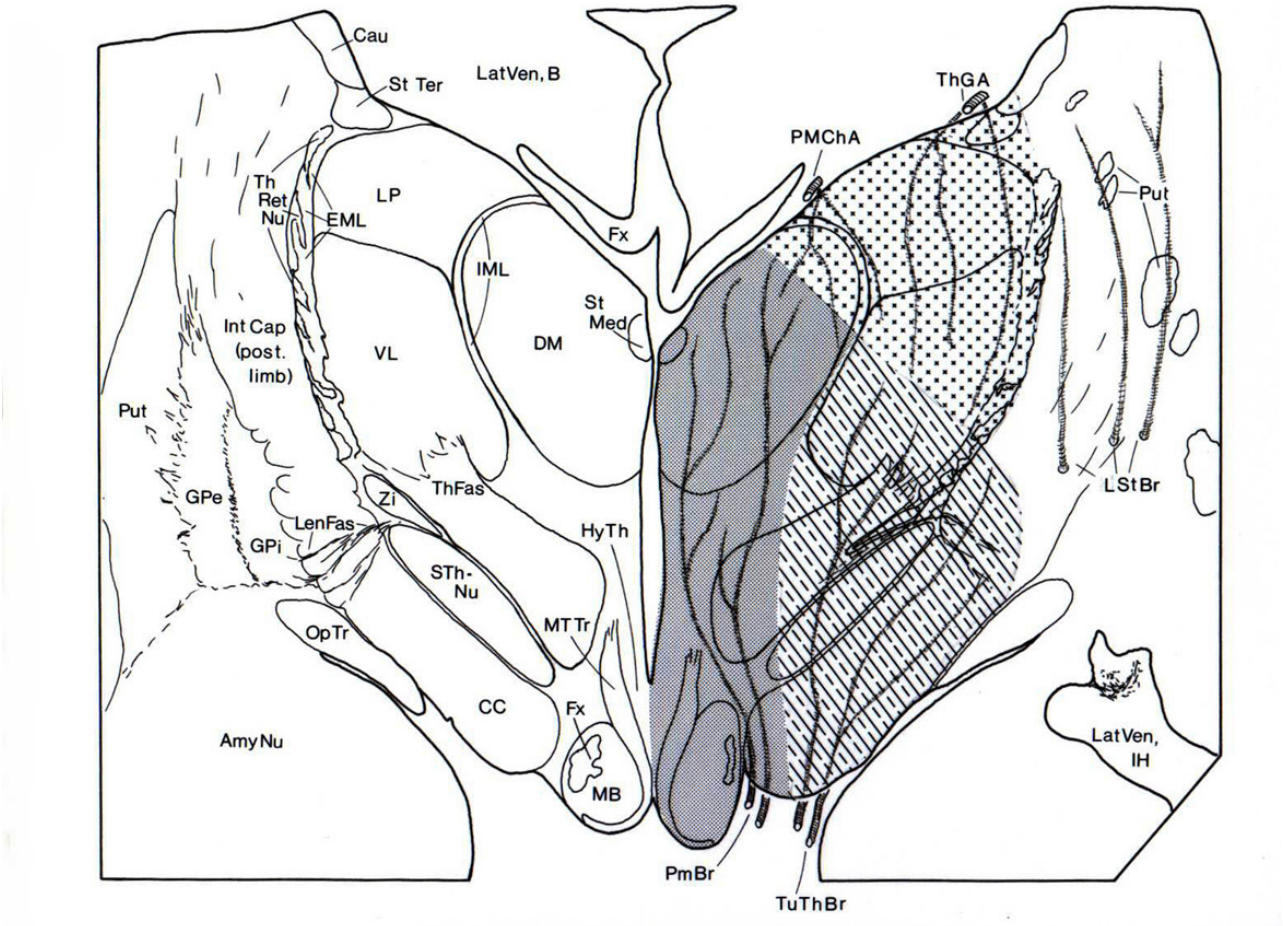


Plate 22 Go to text



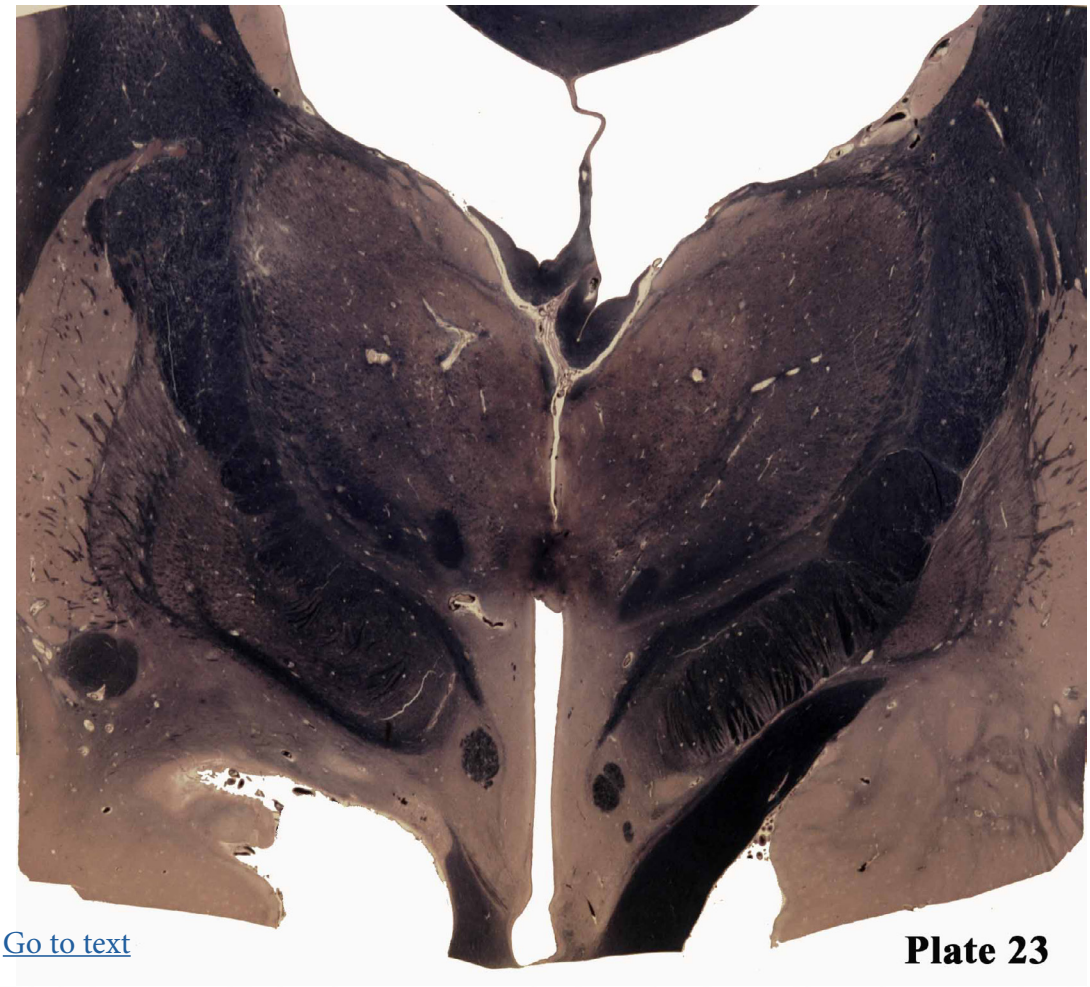
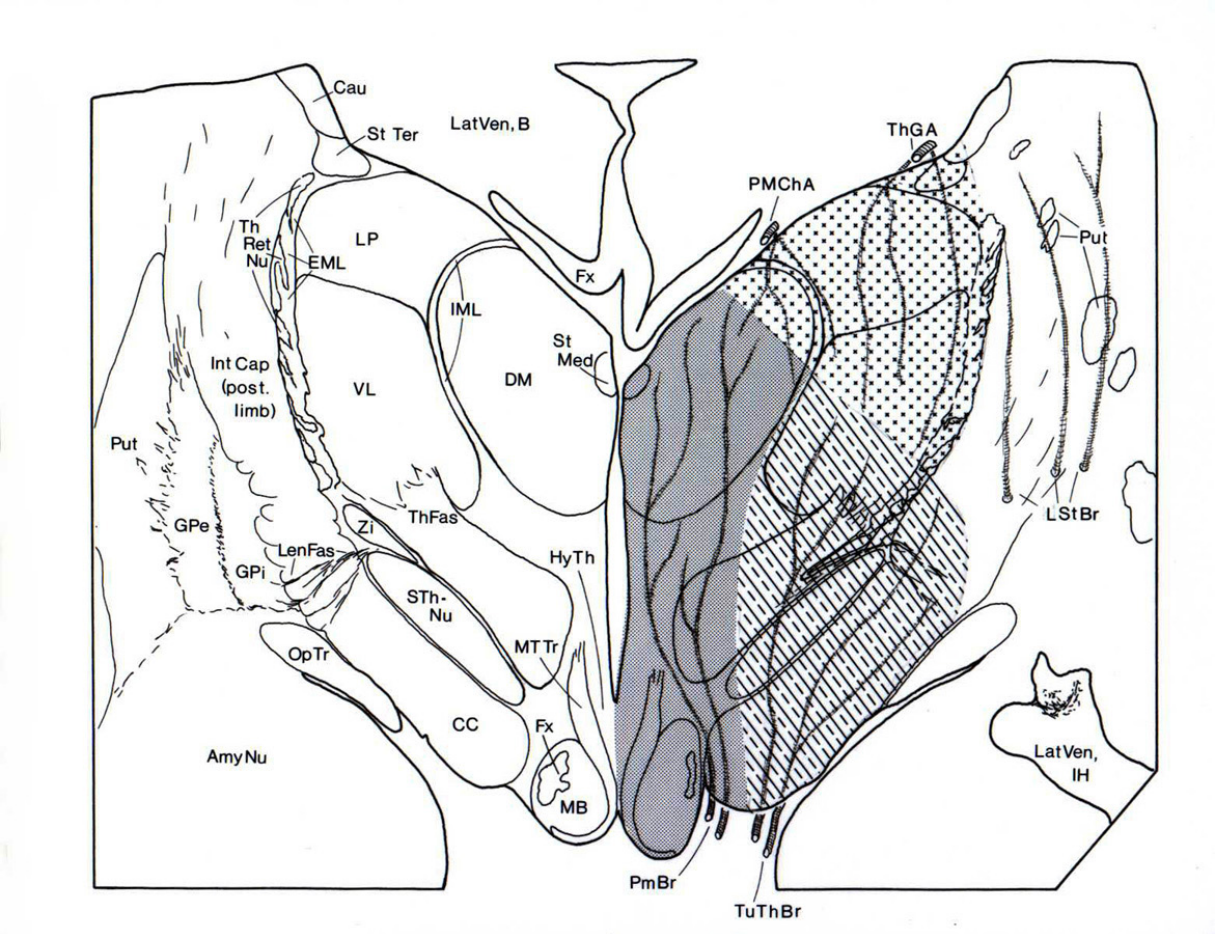


Plate 23 Go to text



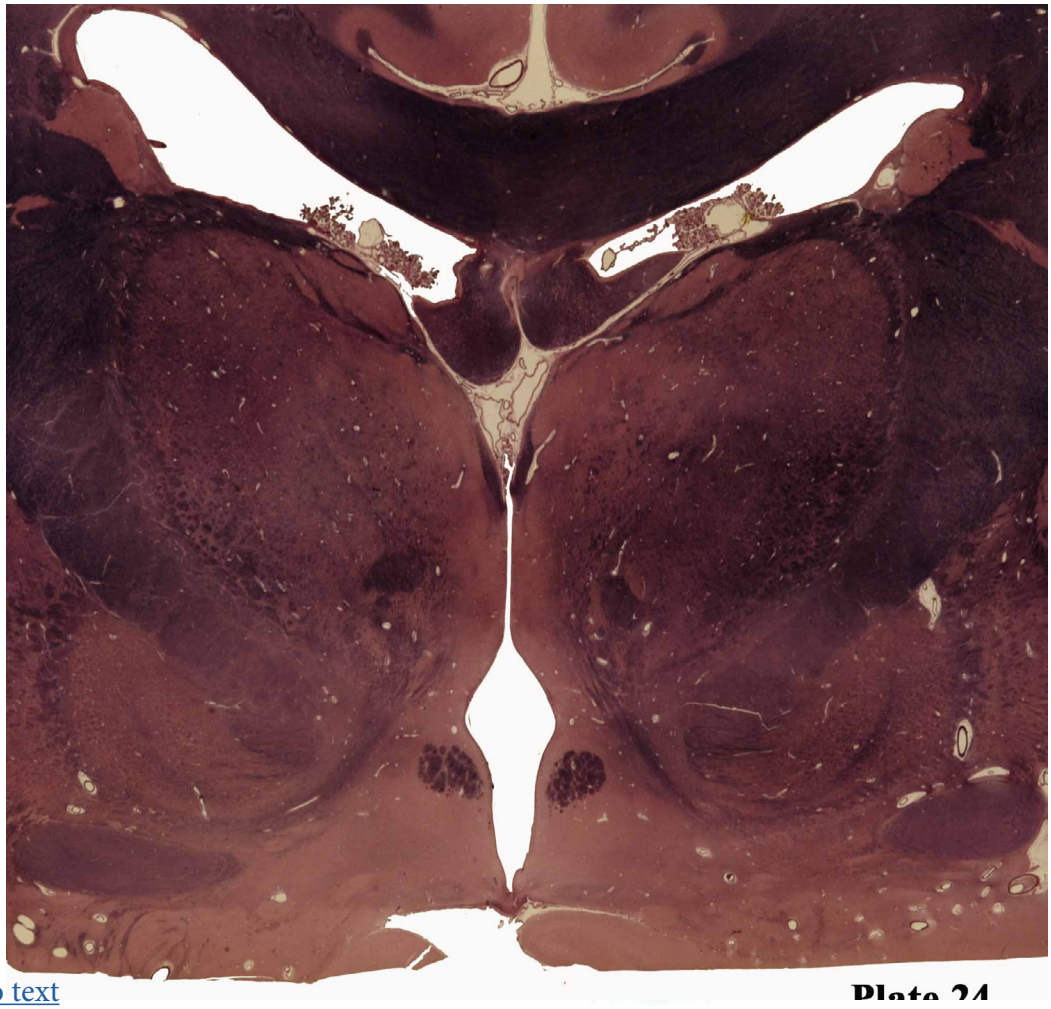
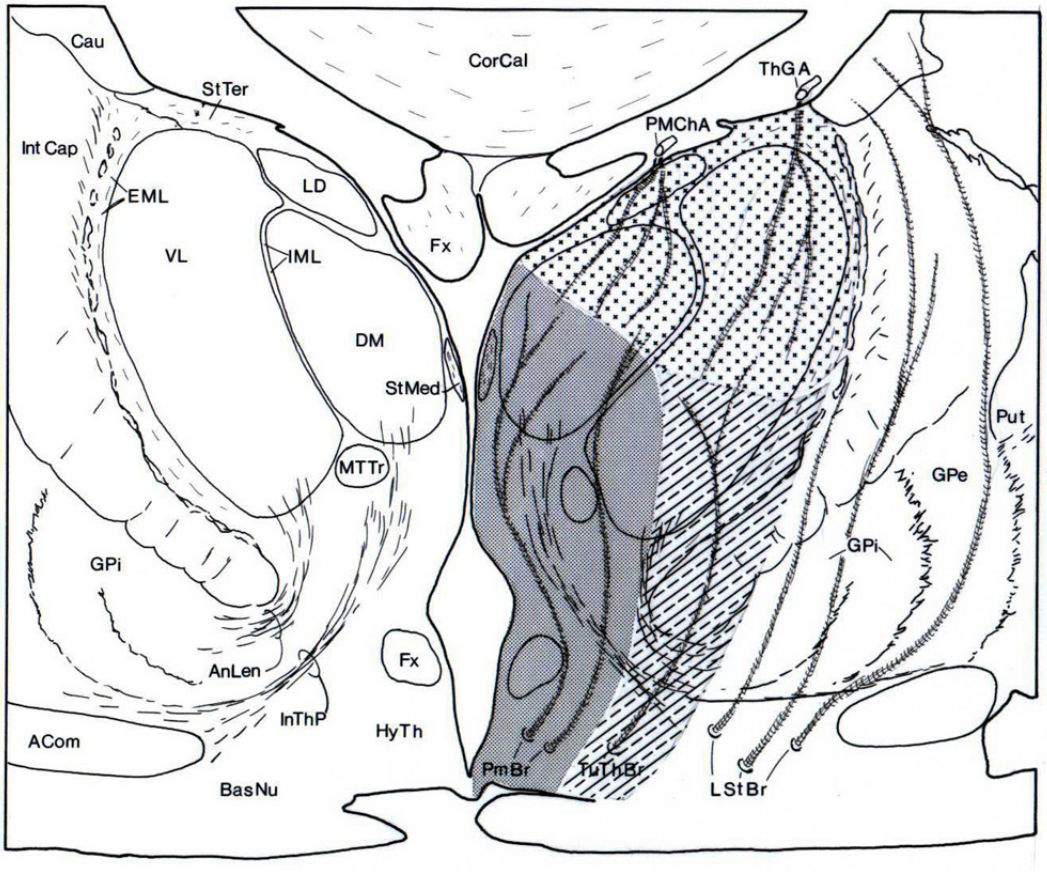


Plate 24 Go to text



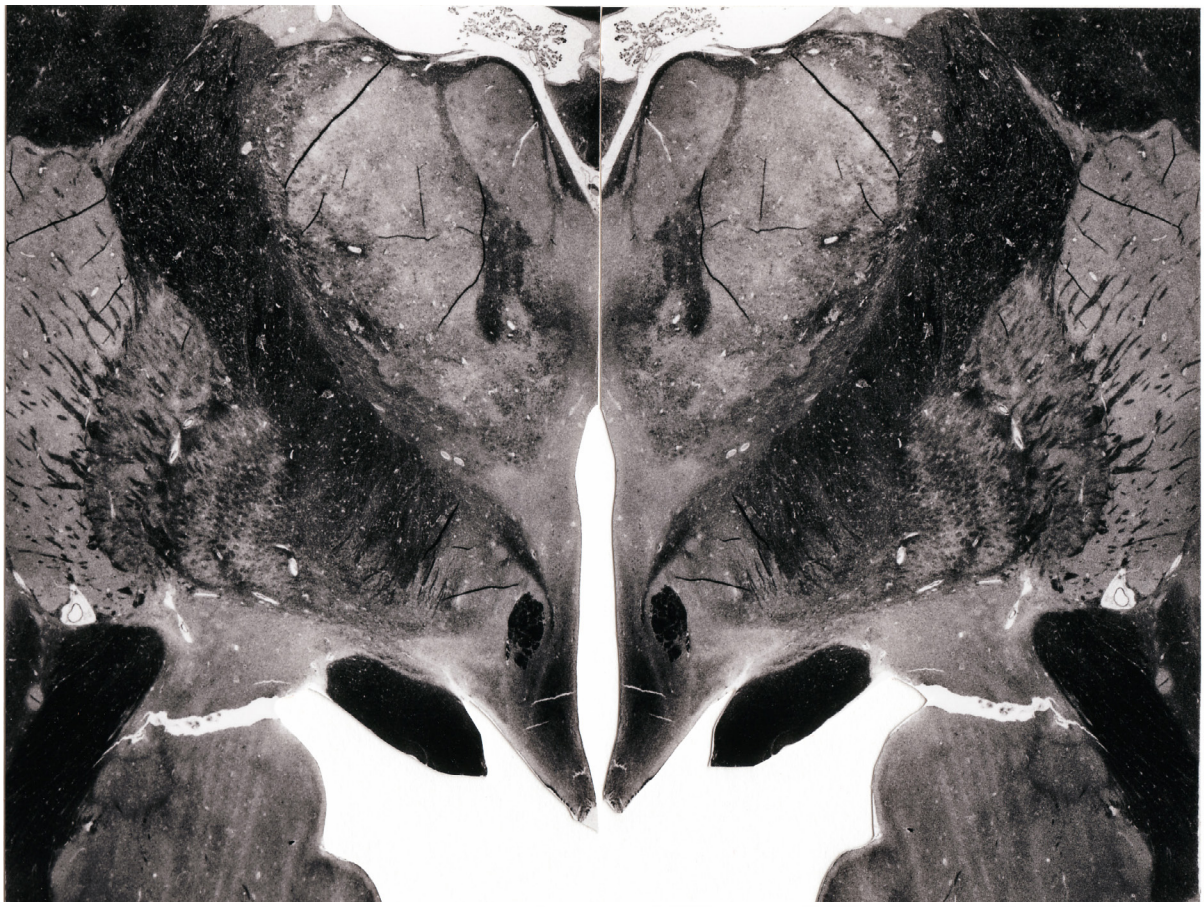


Plate 25 Go to text