THE SPINAL CORD, BRAINSTEM, AND CEREBELLUM

CHAPTER PREVIEW

It is now time to embark on a journey through macroscopic structures. We will begin this leg of the journey at the bottom, with the spinal cord, and make our way up to the brainstem, cranial nerves, and cerebellum.

IN THIS CHAPTER

In this chapter, we will . . .

• Survey the form and function of the spinal cord as well as spinal cord injury
• Explore the structure and function of the brainstem
• Review select disorders of the brainstem
• Study the cranial nerves and their relationship to speech, voice, swallowing, and hearing
• Survey the form and function of the cerebellum

LEARNING OBJECTIVES

1. The learner will label a diagram of a cross-section of the spinal cord.
2. The learner will label a diagram of the brainstem.
3. The learner will be able to list all the cranial nerves (Roman numeral and name).
4. The learner will list important cranial nerves for articulation, voice, swallowing, and hearing.
5. The learner will describe the form and function of the cerebellum.
Introduction

The spinal cord is the second major piece of the CNS, the other piece being the brain. It serves as a sort of communications superhighway for motor (efferent) communication from the brain to the body and sensory (afferent) communication from the body to the brain. The spinal cord extends from the bottom of the vertebral column up to the brainstem's medulla. This chapter will survey spinal cord form and function as well as spinal cord injury. We will begin the journey through the brain by also studying the brainstem, cranial nerves, and cerebellum.

The Spinal Cord

Ranging from 17 to 18 inches in length and ¼ to ½ inch in diameter, the spinal cord is a vital organ for interacting with our environment. Contained within it are both motor and sensory fibers that transmit information regarding our movement and sense experiences as well as our reflexes.

Spinal nerves emerge from the spinal cord and innervate the body below the neck. They are organized by neuroanatomists using the same divisions used to organize the spinal cord. The spinal nerves carry sensory (afferent) and/or motor (efferent) information. There are two types of nerve fibers in spinal nerves, general somatic and general visceral. General somatic efferent fibers (GSE) carry motor information to skeletal muscles and general visceral efferent fibers (GVE) carry motor information to smooth muscle, the heart, and glands. General somatic afferent fibers (GSA) carry sensory information from the skin and general visceral afferent fibers (GVA) carry sensory information from the lungs and digestive tract.

Beginning laterally, each spinal nerve has a dorsal ramus (branch) and a ventral ramus. The dorsal ramus carries motor and sensory information (GSE and GSA) to and from the dorsal or posterior part of the body; the ventral ramus carries the same type of information to and from the ventral or anterior part. Moving medially, these two branches meet outside the vertebral column to form the spinal nerve. Still outside the vertebral column, another branch joins the spinal nerve. This branch is called the ramus communicans, and it contains motor and sensory visceral nerve fibers (GVE and GVA). Moving inside the vertebral column, the spinal nerve splits into a dorsal and ventral root. The dorsal root is sensory, containing GVA and GSA fibers; the ventral root is motor (GVE and GSE). Bulging from the dorsal root is the dorsal root ganglion, which contains the cell bodies of unipolar neurons.

Internal Organization

A cross-section of the spinal cord is presented in Figure 5-2. It appears to show a gray butterfly in the midst of a white circle. The gray part is made up of neuron cell bodies, and the white consists of myelinated neuronal axons. The white matter is divided in half by the median fissure and the dorsal, lateral, and ventral white-matter regions or columns duplicate on each side of the spinal cord. Major ascending sensory and descending motor tracts course through these regions. These are pictured in Figure 5-3 with the green sections highlighting sensory tracts and blue sections denoting motor systems. The major motor tracts in the spinal cord's white matter are as follows:

- **Lateral corticospinal tract**: This nerve tract originates in the motor cortex of the frontal lobe, decussates (i.e., changes sides) at the lower medulla–spinal cord junction, and then inputs along the spinal cord at the ventral horns. Functionally, it is responsible for contralateral movement of the body.

- **Anterior corticospinal tract**: This originates in the motor and premotor areas of the frontal lobe and then courses ipsilateral down the spinal cord, inputting at the ventral horn. It controls the trunk muscles.

- **Rubrospinal tract**: The rubrospinal tract begins in the midbrain, where it decussates and courses down the brainstem and spinal cord until inputting in the ventral horn of the spinal cord. In terms of function, it modulates flexor tone in the upper extremities.

- **Lateral vestibulospinal tract**: This originates in the medulla and courses down the spinal cord ipsilateral until inputting into the ventral horn. Functionally, this tract controls extensor tone.

![Figure 5-1 The vertebral column and spinal cord.](image-url)
The major sensory tracts are as follows:

- **Dorsal columns**: As their name implies, the dorsal columns reside in the dorsal area of the spinal cord, but have their origin at the dorsal root ganglion. They then course to the sensory cortex via the thalamus. These columns consist of two bundles, the fasciculus gracilis (the slender bundle) and the fasciculus cuneatus (the wedge-shaped bundle). The dorsal columns relay fine and discriminative touch, pressure, and proprioceptive sensory information to the brainstem, then the thalamus, and finally the sensory cortex for final processing. **Proprioception** can be thought of as the body's eyes for itself. In other words, through various receptors throughout the body, the brain has a sense of where its various parts are in space at any given time.

- **Spinothalamic tract**: This tract lies in the lateral ventral portion of the spinal cord. It originates in the dorsal horns and then ascends through the spinal cord and brainstem to the thalamus. The thalamus then relays this tract to the sensory cortex. Functionally, this tract sends the following sensory information: pain, temperature, and crude touch.

- **Spinocerebellar tracts**: There are two spinocerebellar tracts, the ventral tract and the dorsal tract. Both lie on the lateral edge of the spinal cord, but as the names imply, one is dorsal in location and the other is more ventral. They have their origin in the dorsal root ganglions and ascend to input in the cerebellum. The spinocerebellar tracts convey proprioceptive information about the body to the cerebellum.

The gray matter consists of the dorsal horn at the top of the butterfly's upper wing and the ventral horn at the bottom. It is at these horns that the spinal nerve roots connect. Each spinal nerve passes through a notch between the vertebral, the major motor and sensory tracts and their functions have already been outlined. There is one last important topic to cover—reflexes. Reflexes are lightning-quick responses to stimuli controlled at the level of the spinal cord and spinal nerves. Instead of sending a signal all the way to the cerebral cortex and back down the spinal cord, the signal is sent to the spinal cord, which in turn responds and sends a signal back to the muscle. This is called the reflex arc, but how does it work? Muscles contain spindles, structures that detect the amount of stretch in a muscle. When a muscle is stretched (e.g., the physician's reflex hammer hitting the

**Figure 5-2 Cross-section of the spinal cord showing spinal nerve connections.**

**Figure 5-3 Cross-section of the spinal cord showing motor and sensory tracts.**

**Figure 5-4 The Spinal Cord**
patellar tendon), information is sent via sensory neurons to the dorsal roots of the spinal gray matter. This information is then sent to motor neurons via an intercalated neuron, a neuron that makes connections between two neurons. A motor message is then sent through the ventral root for the muscle to contract (or, in essence, oppose the stretching, which is called the stretch reflex). This process is illustrated in FIGURE 5-5. Reflex messages do eventually make it to the cerebral cortex for processing (e.g., pain). Damage along this pathway can cause reflexes to be diminished or absent.

**Select Disorders of the Spinal Cord**

**Spinal Cord Injury**

Spinal cord injury (SCI) involves traumatic damage to the spinal cord. There are about 12,000 new cases of SCI each year, and approximately 270,000 persons currently living with SCI in the United States. Vehicular accidents account for approximately 40% of SCIs, followed by falls (28%) and violence (14.6%). Males account for over 80% of SCIs. Damage from this type of injury can result in paresis (incomplete) or paraplegia (complete) depending on what level of the spinal cord is damaged (BOX 5-1). The term complete refers to complete loss of sensation or movement, and incomplete denotes partial loss of movement or sensation. Approximately 57% of cases are either complete or incomplete quadriplegia; the remaining 43% are complete or incomplete paraplegia (National Spinal Cord Injury Statistical Center [NSCISC], 2012).

Diagnosis of SCI is made through a neurological exam along with neuroimaging. Treatment can include surgery, steroid treatment, and rehabilitation. Treatment revolves around steroids to reduce swelling in and around the spinal cord, surgery to remove any bone fragments and to stabilize the spine, and rehabilitation. The prognosis varies from patient to patient, but the majority of cases involve some lasting impairment in movement and/or sensation.

**Spina Bifida**

Spina bifida (SB) is a neural tube defect that occurs early in development and can result in damage to the lower portion

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**FIGURE 5-4** Dermatomes of the human body.

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**BOX 5-1**

**Christopher Reeve and Spinal Cord Injury**

Christopher Reeve was an American actor best known for playing Superman in the movies. On May 27, 1995, he was thrown from a horse and became a quadriplegic. He required a wheelchair and a portable ventilator to help him breathe. After his injury, Reeve became an activist for people with spinal cord injury. He also advocated for stem cell research, believing that a cure for spinal cord injury could result from this research. He died on October 10, 2004, due to an adverse reaction to an antibiotic he was taking to treat a pressure ulcer. Reeve died of cardiac arrest at the age of 52.
of the spinal cord. Children born with the more severe form of SB can suffer from lower limb paresis as well as bowel and bladder issues.

**Myelitis**

Myelitis is a general term for inflammation of the spinal cord. If the inflammation is to only the gray matter of the spinal cord, the condition is called poliomyelitis. If it is confined to the white matter, it is called leukomyelitis. If the inflammation involves both the white and gray matter, then it is called transverse myelitis. If the inflammation extends to the meninges, it is called meningomyelitis. Poliomyelitis or polio is probably the most well-known form of myelitis because of the great epidemics of the 20th century that left many people paralyzed below the waist, including one of our presidents, Franklin D. Roosevelt (BOX 5-2).

Myelitis can be caused by a variety of factors, including viruses, bacteria, fungi, parasites, and toxic agents (e.g., lead). The primary sign of the disease is rapid loss of motor and/or sensory abilities in the legs and possibly the loss of reflexes. If it is the poliomyelitis form, motor abilities will be affected, but not sensory. In the leukomyelitis variety, motor abilities are preserved but sensory abilities are lost. In the transverse form, both motor and sensory abilities are impaired.

Myelitis is usually diagnosed through a combination of blood tests and spinal tap to discern the cause of the inflammation. If the cause is bacterial or parasitic, antibiotics will be employed. Fungal infections will be treated with antifungal medications. Viruses are difficult to treat after infection, but vaccines can prevent myelitis. Polio has all but been eradicated in the United States due to a vaccine developed in the 1950s, but it does still unfortunately occur in other places around the world (Victor & Ropper, 2001).

**Peripheral Neuropathy**

Peripheral neuropathy is an inflammation of the peripheral nervous system (PNS) that results in degeneration of the
spinal nerves. This can have a variety of causes, including toxic poisoning (e.g., alcohol abuse), infections, metabolic disorders (e.g., diabetes), and nutritional issues, like the lack of vitamin B1 in beriberi. A good causal example is diabetes, a condition that causes excessive sugars in the blood. This excess sugar degenerates small capillaries in the extremities, causing nerve fibers to die. As nerve fibers die, people lose sensation in their fingers and hands, and with this loss of sensation are susceptible to wounds that will not heal because of the diabetes. Sensory loss is the main symptom of peripheral neuropathy, but people can lose motor function as well.

Peripheral neuropathy is diagnosed through clinical presentation and laboratory tests. For example, in diabetes, a blood test will determine the presence or absence of the disease and sensory testing of the feet will tell the extent of the neuropathy if diabetes is indeed present. Treatment can consist of treating the underlying disease process. In the case of diabetes, the use of oral medications or insulin can control the disease and prevent the neuropathy from worsening. In some cases, neuropathies can be reversed if the disease is treated early enough (BOX 5-3).

**Brainstem**

At the superior end of the spinal cord is the brainstem (FIGURE 5-6). It contains both ascending (sensory) and descending (motor) tracts as well as nuclei that make up major centers for sensory and motor function. Life functions, such as breathing, heart rate, blood pressure, and digestion, are found in it, as are centers for wakefulness and alertness. It also has nuclei for most of the cranial nerves.

**External Organization of the Brainstem**

**The Medulla**

The lowest part of the brainstem is a 1-inch-long structure called the medulla (FIGURES 5-7 and 5-8). The medulla’s lower boundary is where the cranial nerve XII nuclei are located, and its upper boundary is a small triangular depression called the foramen cecum that separates the medulla from the pons. About 80% of motor fibers cross or decussate at the level of the medulla. Various life function centers are located in the medulla, including cardiac, vasoconstrictor, respiratory, and swallowing centers. In addition, several reflexes are mediated at this level, including coughing and vomiting.

**The Pons**

The pons (“bridge”) lies superior to the medulla, anterior to the cerebellum, and inferior to the midbrain (Figure 5-7). It is about an inch in length and is bulbous in shape. The cerebellum is connected to the pons by the cerebellar peduncles (“stems” or “stalks”) (FIGURE 5-9). Overall, the pons acts as a bridge, relaying neural fibers between the cerebrum, cerebellum, and lower structures like the medulla and spinal cord. It contains nuclei that help regulate respiration, swallowing, hearing, eye movements, and facial expression and sensation. There are also a number of cranial nerve nuclei in the pons (Saladin, 2007; Zemlin, 1998).

**The Midbrain**

The midbrain lies inferior to the diencephalon and superior to the pons (Figure 5-7). Its anterior portion consists of two cerebral peduncles; the posterior consists of

My Experience with Peripheral Neuropathy
When I was in my early 30s, I read a *Time* magazine article about diabetes. The article contained a list of diabetic symptoms, and as I scanned the list I realized that I had almost all the symptoms (e.g., dry mouth, frequent bathroom trips, etc.). My wife told me about a nurse at her work who had diabetes and got her blood checked. I did and got a 600 reading on my blood sugar test (normal is around 100). I saw my doctor shortly after and was put on medication. One of the symptoms I had been experiencing was strange sensation in my feet. There were times when my feet hurt or burned. Sometimes I could not wear socks or have the blankets on my feet. My doctor told me this was the beginning of peripheral neuropathy. Apparently, the extra sugar in my blood was breaking down small capillaries in my feet, which was affecting sensory nerves in my feet. He was unsure whether it would get better or not because it depended on how long I had had diabetes and the damage that had been done. Fortunately, most of the neuropathy has disappeared because my diabetes is now under control.
FIGURE 5-7  A. Anterior view of the brainstem. B. Lateral view of the brainstem. C. Posterior view of the brainstem.
tectum ("roof like"). Each peduncle has a posterior part called the tegmentum and an anterior piece called the crus cerebri. Between these is a layer of dark gray matter called the substantia nigra ("black substance") where dopamine is produced (FIGURE 5-10). Dopamine plays an important role in addiction and movement. Destruction of dopamine-producing cells can cause progressive neurological movement disorders, like Parkinson's disease. The tectum contains the paired superior and inferior colliculi ("little hills"). The inferior colliculi are the auditory center of the midbrain and are important in moving the eyes and/or head toward the source of a sound and our startle response to a loud noise. This area may play a role in disorders like posttraumatic stress disorder (PTSD) (Davis, Falls, & Gewirtz, 2000).

**Cranial Nerves**

There are 12 pairs of cranial nerves that control sensory, special sensory, motor, and parasympathetic functions of the head and neck. Most, except CN I and CN II, originate from the brainstem (FIGURE 5-11). Not all the cranial nerves play a role in speech and hearing, so critical attention should be directed toward cranial nerves II, V, VII, VIII, IX, and X. All
the cranial nerves are presented in TABLE 5-1 along with a mnemonic that has helped many students remember them.

**Cranial Nerves for Articulation** Cranial nerves involved in speaking include V, VII, IX, X, XI, and XII. These will be discussed in this section.

The trigeminal nerve (V) originates from the lateral surface of the pons. It splits into three branches: the ophthalmic, maxillary, and mandibular (FIGURE 5-12). The trigeminal is both a motor and sensory nerve. In terms of motor function, the mandibular branch innervates muscles that lower the mandible (mylohyoid and anterior belly of the digastric), raise the mandible (temporalis, masseter, and medial pterygoid), and protrude the mandible (lateral pterygoid muscle). The opening and closing movements of the mandible are important in sound production. As far as sensory function, the ophthalmic branch relays sensation from the upper face back to the brainstem and cerebral cortex. The maxillary branch carries sensory information from the nose, mouth, lower face, auditory meatus, and meninges. Finally, the sensory portion of the mandibular branch relays sensation from the lateral side of the head and scalp, lower jaw, anterior two-thirds of the tongue, and mucous membranes of the mouth. This branch also carries proprioceptive information from the muscles of chewing to the brainstem. This sensory feedback information is important for jaw opening and closing during speech.

The facial nerve (VII) has motor, sensory, special sensory, and parasympathetic functions, but only the motor aspect has relevance for speech production. The facial nerves originate from the cerebellopontine angle and have two branches, the intracranial and extracranial (FIGURE 5-13). The intracranial is involved in sensory, special sensory, and parasympathetic functions. The extracranial branch innervates all the facial muscles that are crucial in speech production. These muscles include the following:

- Orbicularis oris (constricts oral opening)
- Risorius (retracts lip corners)
- Buccinator (moves food onto molars for grinding)
- Levator labii superioris (elevates upper lip)
- Zygomatic minor (elevates upper lip)
The vagus nerve (X) has motor, sensory, special sensory, and parasympathetic functions. Only its motor and sensory functions are notable for speech (FIGURE 5-14). It innervates the stylopharyngeus muscle, a muscle that helps to elevate the pharynx and larynx. Elevation of the larynx is an important function in swallowing and may play a role in phonation. In terms of sensory function, the glossopharyngeal nerve relays sensory information from the Eustachian tube, pharynx, and tongue back to the brainstem and the sensory areas of the cerebral cortex. This provides important feedback information for the motor function of these structures. This nerve mediates the gag reflex that involves a reflex contraction of the pharyngeal constrictor that helps to evacuate foreign materials in the throat as well as assists in vomiting.

The vagus nerve (X) has motor, sensory, special sensory, and parasympathetic functions. Relevant for speech are its motor and sensory functions. The vagus nerve originates from the medulla and has three main branches: pharyngeal, superior laryngeal, and recurrent laryngeal (FIGURE 5-15).

The pharyngeal branch enters the pharynx where it connects with branches from the glossopharyngeal and superior laryngeal nerves. From there, it distributes fibers to the pharyngeal muscles, palatal muscles with the exception of the stylopharyngeus (innervated by IX) and the tensor veli palatini (innervated by V), and the palatoglossus muscle of the tongue. These connections mean that the pharyngeal branch controls pharyngeal constriction as well as palatal elevation. Palatal elevation is a key feature in speech and swallowing. For speech, the palate elevates, allowing for the production of non-nasal sounds.

The accessory nerve (XI), which begins at the medulla, is sometimes referred to as the spinal accessory nerve. It has two portions, the cranial and the spinal (FIGURE 5-16). The cranial portion joins the vagus nerve and becomes indistinguishable from it, thus playing a role in pharyngeal and laryngeal function. The spinal portion innervates the sternocleidomastoid and trapezius muscles of the neck.

Lastly, cranial nerve XII, the hypoglossal nerve (FIGURE 5-17), originates at the bottom of the medulla and controls the muscles of the tongue. The tongue is crucial for chewing, swallowing, and speech. It is the prime organ of articulation and consists of both intrinsic and extrinsic muscles. Intrinsic tongue muscles enable precise tongue...
FIGURE 5-11 The cranial nerves.
<table>
<thead>
<tr>
<th>Mnemonic</th>
<th>Number</th>
<th>Name</th>
<th>Origination</th>
<th>Function</th>
<th>Dysfunction</th>
<th>Speech/Hearing Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>On</td>
<td>I</td>
<td>Olfactory</td>
<td>Olfactory bulb</td>
<td>Special sensory: smell</td>
<td>Anosmia</td>
<td>None</td>
</tr>
<tr>
<td>Old</td>
<td>II</td>
<td>Optic</td>
<td>Thalamus</td>
<td>Special sensory: vision</td>
<td>Visual disturbances; visual loss</td>
<td>Reading/writing</td>
</tr>
<tr>
<td>Olympus</td>
<td>III</td>
<td>Oculomotor</td>
<td>Midbrain</td>
<td>Motor: eyeball movement; controls eyelid</td>
<td>Loss of pupillary light reflex; papilledema; ptosis</td>
<td>None</td>
</tr>
<tr>
<td>Towering</td>
<td>IV</td>
<td>Trochlear</td>
<td>Midbrain</td>
<td>Motor: eyeball movement</td>
<td>Diplopia; nystagmus</td>
<td>None</td>
</tr>
<tr>
<td>Tops</td>
<td>V</td>
<td>Trigeminal</td>
<td>Pons</td>
<td>Motor: chewing muscles Sensory: touch, pain, temperature, vibration for face, mouth, anterior two-thirds of tongue</td>
<td>Loss of sensations (see Function column); difficulty chewing, abnormal jaw-jerk reflex</td>
<td>Speech/chewing</td>
</tr>
<tr>
<td>A</td>
<td>VI</td>
<td>Abducens</td>
<td>Pons</td>
<td>Motor: eyeball movement</td>
<td>Strabismus; nystagmus</td>
<td>None</td>
</tr>
<tr>
<td>Fin</td>
<td>VII</td>
<td>Facial</td>
<td>Pons</td>
<td>Motor: face muscles Sensory: sense near ears Special sensory: taste in anterior two-thirds of tongue Parasympathetic: salivary glands</td>
<td>Facial paresis or plegia; loss of taste</td>
<td>Speech</td>
</tr>
<tr>
<td>And</td>
<td>VIII</td>
<td>Auditory</td>
<td>Pons/medulla</td>
<td>Special sensory: hearing and balance</td>
<td>Hearing loss; balance issues</td>
<td>Hearing</td>
</tr>
<tr>
<td>German</td>
<td>IX</td>
<td>Glossopharyngeal</td>
<td>Pons/medulla</td>
<td>Motor: pharyngeal movement Sensory: middle ear; pharynx, posterior one-third of tongue Special sensory: taste on posterior one-third of tongue Parasympathetic: parotid gland</td>
<td>Absent gag; impaired or absent swallow; loss of taste; loss of pharyngeal movement</td>
<td>Speech</td>
</tr>
</tbody>
</table>
movements, like the ones needed for articulation. These include the following:

- Superior longitudinal (elevates, retracts, and deviates tongue tip)
- Inferior longitudinal (depresses tongue tip; retracts and deviates tongue)
- Transverse (narrows the tongue)
- Vertical (pulls tongue down to mouth floor)

The extrinsic tongue muscles work to move the tongue as a whole unit. This group of muscles includes the following:

- Genioglossus (retracts, protrudes, and depresses tongue)
- Hyoglossus (pulls tongue sides down)
**FIGURE 5-14** The glossopharyngeal nerve (IX).

**FIGURE 5-15** The vagus nerve (X).

**FIGURE 5-16** The accessory nerve (XI).
Cranial Nerves for Voice  

- Styloglossus (draws tongue up and back)
- Chondroglossus (depresses tongue)

The palatoglossus is also an extrinsic tongue muscle but is controlled by cranial nerves X and XI.

**Cranial Nerves for Swallowing**  
As reviewed earlier, cranial nerves V, VII, X, XI, and XII control the muscles of articulation. These same muscles are also used for the oral preparatory and oral phases of the normal swallow. The pharyngeal phase of the swallow depends on another set of muscles to move food and liquid through the pharynx. These muscles are controlled by cranial nerves IX, X, and XI. Cranial nerve IX controls the upper pharyngeal constrictors leading to pharyngeal constriction, which is experienced as a squeezing sensation in the throat during swallowing. The muscles controlled by X and XI include the following:  
- Superior pharyngeal constrictor (narrows pharyngeal diameter)
- Middle pharyngeal constrictor (narrows pharyngeal diameter)
- Inferior pharyngeal constrictor (narrows pharyngeal diameter)
- Salpingopharyngeus (elevates lateral pharyngeal wall)

In addition, cranial nerve IX innervates the stylopharyngeus, a muscle that elevates and opens the pharynx.

**Cranial Nerves for Hearing**  
Cranial nerves V, VII, and VIII are involved in hearing. The trigeminal nerve (V) controls the tensor tympani, a muscle of the middle ear that connects the wall of the middle ear to the malleus. When this muscle contracts, it stiffens the ossicular chain of the middle ear. This protective reflex guards against intense low-frequency sounds, particularly the sound of one's own voice and
The main cranial nerve of hearing is VIII, the auditory nerve. It is also known as the vestibulocochlear nerve, a name that describes its branches, one for hearing and one for balance. The acoustic or cochlear branch transmits auditory information from the cochlea in the inner ear to the pons/medulla. The vestibular branch transmits information about the body’s position in space via the semi-circular canals to the pons/medulla juncture.

Internal Organization of the Brainstem

Tegmental Regions

The tegmentum is the core of the brainstem, which is continuous throughout the medulla, pons, and midbrain. The nontegmental areas are not continuous and lie near the surface of the brainstem. The tegmental areas include the reticular formation, inferior olivary complex, and red nucleus.

Reticular Formation

Nuclei are groups of specialized cells. The nuclei of the reticular formation are scattered throughout the tegmentum (Figure 5-9B). These nuclei receive axon collaterals from special sensory systems (e.g., hearing, vision) and project axons throughout the brain, including the brainstem, cerebellum, diencephalon, and cerebral hemispheres. The reticular formation regulates many aspects of human experience, including consciousness, the sleep–wake cycle, cardiovascular functions, and respiration.

Inferior Olivary Nucleus

The inferior olivary nucleus (not to be confused with the superior olivary nuclei related to hearing) is a bulge on the medulla (Figure 5-8). It receives axons from the cerebral cortex and after processing the information sends it to the cerebellum. Its connection to the cerebellum suggests it plays a role in the control and coordination of motor movements.

Red Nucleus

The red nucleus is a paired structure located in the tegmentum of the midbrain next to the substantia nigra (Figure 5-10). Its name comes from the fact that it is pink due to the presence of iron. It receives connections from the cerebral cortex, and its axons give rise to the rubrospinal tract that descends the brainstem and inputs into the spinal cord’s ventral horn cells. This tract modulates flexor tone in the upper extremities and probably participates in activities such as babies’ ability to crawl and arm swinging in walking.

Nontegmental Regions

As mentioned earlier, nontegmental areas of the brainstem are found at or near the brainstem’s surface rather than deep in the tegmentum. Three nontegmental areas will be briefly discussed: the tectum, cerebral peduncles, and ventral pons.

Tectum

The tectum is the roof of the midbrain. Dorsally, it has two hills: the superior colliculi and the inferior colliculi. The superior colliculi are connected to vision and the inferior colliculi to hearing. The inferior colliculi’s axons carry auditory information to the thalamus’s auditory center, the medial geniculate body, which then is projected to the cerebral cortex’s auditory areas.

Cerebral Peduncles

The cerebral peduncles or crus cerebri are bulges on the ventral side of the midbrain. The lateral corticospinal and corticobulbar tracts run through these bulges, the lateral corticobulbar tract being important for speech production. Between the peduncles and the tegmentum is the substantia nigra, which produces dopamine. The substantia nigra has a close connection to the basal ganglia, an important structure in speech production.

Ventral Pons

The corticopontine fibers originate from the motor cortex, pass through the cerebral peduncles, and input into ventral pons nuclei. Projections from the ventral pons then course to the cerebellum. Because of the pontine nuclei’s close connection to the cerebellum, it is thought this connection plays a role in motor movement error correction. Error correction is an important aspect of learning new motor skills (think of learning tennis). This would be an important skill for learning to speak both a first and a second language.

Select Disorders of the Brainstem

The Medulla

One disorder that can result from medullar damage is Wallenberg syndrome (also called lateral medullary syndrome). It is typically caused by a stroke involving one of the arteries that supplies blood to the medulla. Patients with this condition experience contralateral loss of pain and temperature in the body, ipsilateral loss of pain and temperature in the face, vertigo, ataxia, paralysis of the ipsilateral palate and vocal cord, and dysphagia. One additional symptom is frequent and violent hiccups that can last for weeks and make speaking, eating, and sleeping difficult. Treatment for Wallenberg syndrome is generally centered on relieving symptoms, rehabilitation, and counseling patients in adjusting to life with the syndrome. The prognosis varies from patient to patient, with some making a complete recovery, whereas others may have ongoing disability and/or handicap.

The Pons

Damage to the ventral pons can result in coma and/or locked-in syndrome (LIS). LIS is characterized by quadriplegia and cranial nerve paralysis except for eye movements. Basically, the person is locked inside his or her body, unable to move, but is cognitively intact. The person cannot speak or swallow, and somatosensory abilities may or may not remain intact. Treatment involves support and rehabilitation, especially establishing a system for communication. The prognosis is poor for patients with LIS; 90% of those with the condition die within 4 months of onset.

The memoir The Diving Bell and the Butterfly by Jean-Dominique Bauby (1998), as well as the film of the same title, familiarized the general public with this condition.
Bauby did not recover from LIS and died about a year and a half after his stroke. Though extremely rare, there have been documented cases of people with LIS having spontaneous, full recoveries. A British woman named Kate Allatt suffered a brainstem stroke around the age of 40 and was diagnosed with LIS, but made a complete recovery (British Broadcasting Corporation [BBC], 2012). Another British woman, Kerry Pink, also reportedly recovered from the syndrome (BBC, 2010).

The Midbrain

Midbrain damage can result in Weber’s or Benedikt’s syndrome. Weber’s syndrome is characterized by contralateral hemiplegia and ipsilateral oculomotor paralysis with ptosis. The hemiparesis affects the lower face muscles and tongue. Benedikt’s syndrome is similar to Weber’s but results in contralateral hemiparesis and ataxic tremor.

The Cerebellum

Anatomy of the Cerebellum

The cerebellum (Latin for “little brain”) lies inferior to the cerebral hemispheres and posterior to the pons (FIGURE 5-18). It looks like a piece of cauliflower in that it has numerous wrinkles, called folia, that give the cerebellum enormous surface area like the cerebral cortex. The cerebellum also has lobes similar to the cerebral cortex. The cerebellum’s lobes include the anterior, posterior, and flocculonodular (Latin for “small mass”) lobes (FIGURE 5-19). It also has two hemispheres like the cerebral cortex, a right hemisphere and a left hemisphere.

The two hemispheres are separated by a mound of tissue called the vermis. Each hemisphere is made up of a central core of white matter and a surface of gray matter. There are three large bundles of fibers called peduncles connect the cerebellum with the spinal cord, brainstem, and cerebral hemispheres. There are three of these bundles, the inferior, middle, and superior cerebellar peduncles. The inferior and middle cerebellar peduncles carry mainly afferent information, whereas the superior peduncle carries primarily motor information.

Cerebellar Function

Functionally, the cerebellum is like a second brain, monitoring sensory input from a wide array of sensory sources and integrating this feedback into motor movement. It monitors head and body position at rest as well as muscle tension and spinal cord activity. The cerebellum participates in the planning, monitoring, and correction of motor movement using all the sensory input it collects. This structure is also involved in our learning of motor skills. Cerebellar control is ipsilateral as compared to the cerebral cortex, where the majority of control is contralateral in nature.

The function of the cerebellum can be tested through a variety of methods. The finger–nose–finger method involves a person touching the examiner’s finger, then his or her own nose, and then the examiner’s finger again. The observer is looking for accuracy and smoothness of movement. Another test is diadochokinesia ability. This is a person’s ability to make rapid, alternating movements with either the fingers or the mouth. For the mouth, the examiner will ask the patient to say “pa-ta-ka” as fast as possible. Uncoordinated, sloppy movement may indicate cerebellar damage.

Cerebellar Disorders

All cerebellar disorders are motor in nature. The symptoms of these disorders are shown in TABLE 5-2. Three specific syndromes are discussed in the following sections.
### TABLE 5-2

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Ataxia</td>
<td>Discoordinated, clumsy movements</td>
</tr>
<tr>
<td>Dysmetria</td>
<td>Over- or undershooting, touching a mark</td>
</tr>
<tr>
<td>Dysdiadochokinesia</td>
<td>Inability to perform rapid, alternating movements of hand or mouth</td>
</tr>
<tr>
<td>Nystagmus</td>
<td>Fast, involuntary eye movements either side-to-side or up and down</td>
</tr>
<tr>
<td>Ataxic dysarthria</td>
<td>Slurred or scanning (broken into syllables) speech</td>
</tr>
<tr>
<td>Hypotonia</td>
<td>Reduced muscle tone and reflexes; muscles tire</td>
</tr>
</tbody>
</table>

**Cerebellar Hemispheral Syndrome**

Cerebellar hemispheral syndrome can be caused by stroke, tumor, and multiple sclerosis. The syndrome primarily affects the ipsilateral limbs causing tremor, dysmetria, and dysdiadochokinesia. Patients also experience the Holmes rebound phenomenon, which can be elicited by the patient holding out one of his or her arms while the examiner tries to push down on it. The rebound phenomenon occurs when the examiner lets go of the patient’s arm, which then bounces up significantly.

**Vermal Syndrome**

Vermal syndrome is due to damage to the vermis. Common causes include stroke, tumor, multiple sclerosis, and other degenerative disorders. The condition primarily affects the trunk muscles, causing unsteadiness, tremor, postural issues, and gait ataxia. Gait ataxia involves the patient walking with a wide base (i.e., the feet wide apart), which gives the sense of extra stability.

**Friedreich’s Ataxia**

Friedreich’s ataxia is an inherited, progressive neurological disorder that follows an autosomal recessive inheritance pattern. Symptoms begin between the ages of 8 and 14 years and can include progressive muscle weakness in the limbs, loss of coordination, dysmetria, dysarthria, curvature of the spine, and vision and hearing issues. Most patients have cardiac issues and, due to this, the median age of death is 35 years.

**Cerebellar Agenesis**

Can a person live without a cerebellum? The answer is yes and the condition is known as primary cerebellar agenesis. Yu et al. (2014) present a case of a 24-year-old woman who was admitted to the hospital with a 1-month history of dizziness and nausea. Her mother reported that she began to walk at age 7 and speak at age 6. Doctors at the hospital performed a CT scan and discovered that she did not have a cerebellum. Cerebral spinal fluid filled the space where the cerebellum should have been. The woman was remarkably functional despite this significant loss of 10% of the brain’s volume and 50% of the brain’s neurons, demonstrating how the brain rewires itself and compensates for losses. Though primary cerebellar agenesis is rare, other cases have been reported in the literature (Boyd, 2010; Glickstein, 1994).

### Conclusion

What has happened in this chapter is akin to tracing a tree up its trunk and up through its branches. The spinal cord is the trunk that transitions into the brainstem and cerebellum. From the brainstem, branches called cranial nerves extend away from the brainstem and connect to head and neck structures. These nerves play a role in linking the cerebrum to the body by relaying either motor, sensory, special sensory, or parasympathetic information or some combination of the four. Many of these nerves are of concern to the speech-language pathologist and audiologist because they relay information related to articulation, voice, hearing, and swallowing.
The following were the main learning objectives of this chapter. The information that should have been learned is below each learning objective.

1. The learner will label a diagram of a cross-section of the spinal cord.

2. The learner will label a diagram of the brainstem.

3. The learner will be able to list all the cranial nerves (Roman numeral and name).

<table>
<thead>
<tr>
<th>On</th>
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<th>Olympus</th>
<th>Towering</th>
<th>Tops</th>
<th>A</th>
<th>Fin</th>
<th>And</th>
<th>German</th>
<th>Viewed</th>
<th>Some</th>
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<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Olfactory</td>
<td>I</td>
<td>Optic</td>
<td>III</td>
<td>Oculomotor</td>
<td>IV</td>
<td>Trochlear</td>
<td>V</td>
<td>Trigeminal</td>
<td>VI</td>
<td>Abducens</td>
<td>VII</td>
<td>Facial</td>
<td>VIII</td>
<td>Auditory</td>
<td>IX</td>
<td>Glossopharyngeal</td>
<td>X</td>
<td>Vagus</td>
<td>XI</td>
<td>Spinal accessory</td>
<td>XII</td>
<td>Hypoglossal</td>
</tr>
</tbody>
</table>

4. The learner will list important cranial nerves for articulation, voice, swallowing, and hearing.
   - **Articulation**: Cranial nerves involved in speaking include V, VII, X, XI, and XII.
   - **Voice**: Cranial nerves for voice include V, VII, X, and XII.
   - **Swallowing**: Cranial nerves V, VII, X, XI, and XII are used for the oral preparatory and oral phases of the normal swallow. The pharyngeal phase of the swallow depends on another set of muscles to move food and liquid through the pharynx. These muscles are controlled by cranial nerves IX, X, and XI.
   - **Hearing**: Cranial nerves V, VII, and VIII are involved in hearing.
5. The learner will describe the form and function of the cerebellum.
   - The cerebellum is located inferior to the cerebral hemispheres and posterior to the pons.
   - It has lobes similar to the cerebral cortex. The cerebellum's lobes are the anterior, posterior, and flocculonodular (Latin for “small mass”) lobes.
   - It also has two hemispheres like the cerebral cortex, a right hemisphere and a left hemisphere.
   - It monitors head and body position at rest as well as muscle tension and spinal cord activity.
   - It participates in the planning, monitoring, and correction of motor movement using all the sensory input it collects.
   - It is involved in our learning of motor skills.

Key Terms

Anterior corticospinal tract
Benedikt's syndrome
Cerebellar peduncles
Cerebral peduncles
Crus cerebri
Dermatome
Dorsal columns
Foramen cecum
Friedreich's ataxia
General somatic afferent (GSA) fibers
General somatic efferent (GSE) fibers
General visceral afferent (GVA) fibers
General visceral efferent (GVE) fibers
Interior colliculi
Lateral corticospinal tract
Locked-in syndrome (LIS)
Medulla
Midbrain
Myelitis
Peripheral neuropathy
Pons
Primary cerebellar agenesis
Proprioception
Red nucleus
Reflex arc
Rubrospinal tract
Spinal cord injury (SCI)
Spinocerebellar tracts
Spinthalamic tract
Substantia nigra
Tectum
Tegmentum
Vermis syndrome
Wallenberg syndrome
Weber's syndrome

Draw It to Know It

1. Sketch a cross-section of the spinal cord along with its spinal nerve (see Figure 5-2). Label all the important structures.
2. Sketch a cross-section of the spinal cord and label all the motor and sensory tracts (see Figure 5-3).
3. Sketch the brainstem and label the midbrain, pons, and medulla.

Questions for Deeper Reflection

1. Describe the functions of the brainstem.
2. List and describe disorders that can occur in brainstem injury.
3. List the cranial nerves involved in each of the following: speech, voice, swallowing, hearing.
Suggested Projects

1. Take one of the disorders in this chapter and write two to three pages about it including the following sections: cause, signs and symptoms, diagnosis, treatment, and speech/swallowing/hearing issues.

2. Create a digital movie using your smartphone, teaching the class about reflexes and the reflex arc. Include reflexes important in communication disorders.

References

