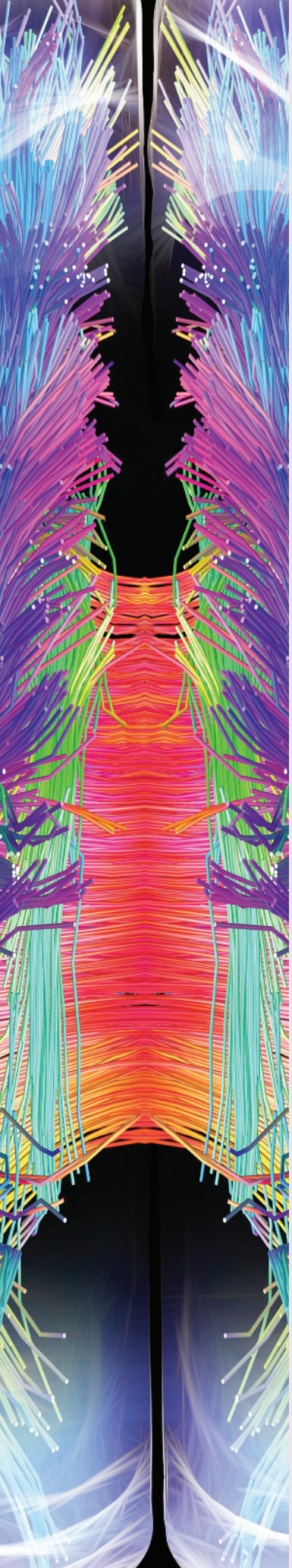


CHAPTER 1

Overview of the nervous system

Learning objectives

1. Describe the basic subdivisions of the human nervous system.
2. Understand basic neuroanatomical terminology.
3. Identify the major structures on the external surface of the gross brain.
4. Identify the major structures on the midsagittal surface of the brain.
5. Identify the cranial nerves.

Divisions of the nervous system 5

Anatomic

1. Central nervous system (CNS)
   a) Brain and spinal cord
   b) Collection of nerve cell bodies = nucleus
2. Peripheral nervous system (PNS)
   a) Peripheral nerves
   b) Collection of nerve cell bodies = ganglia

Functional

1. Sensory (afferent)
   a) General – touch
   b) Special senses – sight, sound, taste, smell, balance
2. Motor (efferent)
   a) Voluntary (somatic) – skeletal muscle
   b) Involuntary (autonomic) – smooth and cardiac muscle
      i. Parasympathetic – craniosacral (III, VII, IX, X, S2–S4)
      ii. Sympathetic – thoracolumbar (T1–L2)
3. Integrative – interneurons within the CNS

Components of the nervous system 8

Neurons

1. Highly specialized, excitable cells
2. Morphologic diversity

Glia – supporting cells

1. Schwann cells (neurolemmocytes) – myelin producing
2. Oligodendrocytes – myelin producing

Essential Clinical Neuroanatomy, First Edition. Thomas H. Champney.

Companion website: www.wileyessential.com/neuroanatomy

3. Astrocytes – nutritional support
4. Microglia – macrophages (immune support)

Neurons 8

Cellular structure

1. Dendrites
2. Axon
   a) Axon hillock
   b) Terminal arborization/terminal boutons
   c) Synapse/synaptic vesicles
   d) Anterograde/retrograde flow
3. Soma (perikaryon, cell body)
   a) Nucleus/nucleolus
   b) Nissl bodies (rough endoplasmic reticulum and polyribosomes)
   c) Lipofuscin
4. Cell membrane (plasmalemma, neurolemma)
5. Types: unipolar, bipolar, multipolar, pseudounipolar

Glia – central nervous system 9

Oligodendrocytes – myelin production; one oligodendrocyte for many axons

Astrocytes – support cells, glial fibrillary acid protein (GFAP), end feet

1. Fibrous astrocytes – white matter
2. Protoplasmic astrocytes – gray matter

Microglia – macrophage-like, scavenging cells

Ependymal cells – columnar, ciliated cells lining the ventricles

Central nervous system 9

Gray matter

1. Nerve cell bodies (nuclei)
2. Dendrites and axons
3. Glia

White matter

1. Nerve fibers (axons) – myelinated
2. Glia

Brain neuroanatomy 11

Orientation of the brain – 90 degree rotation at midbrain flexure

1. Superior – inferior
2. Anterior – posterior
3. Dorsal – ventral
4. Rostral – caudal

Planes of the brain

1. Sagittal plane
   a) Midsagittal
   b) Parasagittal
2. Horizontal plane (transverse, axial)
3. Frontal plane (coronal)

Views of the brain

1. Superior
   a) Interhemispheric fissure (sagittal)
   b) Precentral gyrus (primary motor)
   c) Central sulcus
   d) Postcentral gyrus (primary somatosensory)
2. Inferior
   a) Interhemispheric fissure (sagittal)
   b) Lateral fissure (Sylvian)
   c) Midbrain – cerebral peduncles
   d) Pons
   e) Medulla oblongata – pyramids, inferior olives
   f) Cerebellum
   g) Olfactory bulb and tract
   h) Optic chiasm and tract
   i) Infundibulum (pituitary stalk)
   j) Mammillary bodies
   k) Cranial nerves (12)
      i. Olfactory nerve (I)
      ii. Optic nerve (II)
      iii. Occulomotor nerve (III)
      iv. Trochlear nerve (IV)
      v. Trigeminal nerve (V)
      vi. Abducens nerve (VI)
      vii. Facial nerve (VII)
      viii. Vestibulocochlear nerve (VIII)
      ix. Glossopharyngeal nerve (IX)
      x. Vagus nerve (X)
      xi. Spinal accessory nerve (XI)
      xii. Hypoglossal nerve (XII)
3. Lateral
   a) Lateral fissure (Sylvian)
   b) Brain stem (midbrain, pons, and medulla)
   c) Cerebellum
   d) Central sulcus
   e) Precentral gyrus (primary motor)
   f) Postcentral gyrus (primary sensory)
   g) Lobes of the brain
      i. Frontal lobe
      ii. Parietal lobe
      iii. Occipital lobe (vision)
      iv. Temporal lobe (auditory)
   h) Insular cortex
   i) Superior temporal gyrus (auditory)
4. Midsagittal
   a) Frontal cortex
   b) Parietal cortex

Introduction

The nervous system is a remarkable communication system that can send a message from one part of the body to the brain, react to that message, and produce a response within seconds. The goal of this chapter is to introduce the components and organization of the nervous system. This may be a review for some, but it will set a foundation on which the remainder of the text can be built.

Nervous system organization

The nervous system can be described in two ways: anatomically or functionally. Anatomically, the nervous system is divided into a central component (**brain** and **spinal cord**) and a peripheral component (**cranial nerves** and **peripheral nerves**). The central component, called the **central nervous system (CNS)**, is made of groups of neuronal cell bodies (called **nuclei**), their dendritic and axonal processes, as well as many

supporting cells (**glia**). The peripheral component, called the **peripheral nervous system (PNS)**, is composed primarily of axonal neural processes, but there are also small collections of neuronal cell bodies (called **ganglia**) and only one type of supporting cell (**Schwann cells** or neurolemmacytes) (Figure 1.1). It should be borne in mind that a collection of neural cell bodies has a different name depending on its anatomical location: ganglia in the PNS and nuclei in the CNS. These nuclei are collections of cell bodies and should not be confused with cellular nuclei that contain chromosomes. Also, to complicate matters, there are some nuclei in the central nervous system that are referred to as the basal ganglia. This is not the best nomenclature and can be confusing.

Functionally, the nervous system is divided into three components: a **sensory** (**afferent**, input) component; an **integrative**, decision-making component; and a **motor** (**efferent**, output) component (Figure 1.1). The sensory portion contains peripheral receptors that respond to numerous factors (e.g. touch, vibration, pain, chemical compounds (taste, smell), light (vision), sound (hearing), and position sense (balance)). These receptors interact with peripheral axons that propagate the signal towards the central nervous system. The majority of these neurons have their cell bodies in the periphery (in ganglia) and send a process into the central nervous system carrying the signal. Within the central nervous system, these processes can take a number of paths. They can ascend to inform the brain (cortex and cerebellum) of the information and they can also synapse in the spinal cord to produce reflexes. This information can be relayed by other neurons to numerous portions of the central nervous system, where the information can be **integrated** with other inputs and a **motor output** can be executed. As a simple example, you could place your hand on a hot stove and feel the heat and pain associated with the stove. You would then rapidly remove your hand by a reflex arc with the muscles in the hand, forearm, and arm. This will actually occur within the spinal cord and before you have any conscious awareness of the pain. If you want to continue to "cook" your hand, you can voluntarily override the reflex arc and force

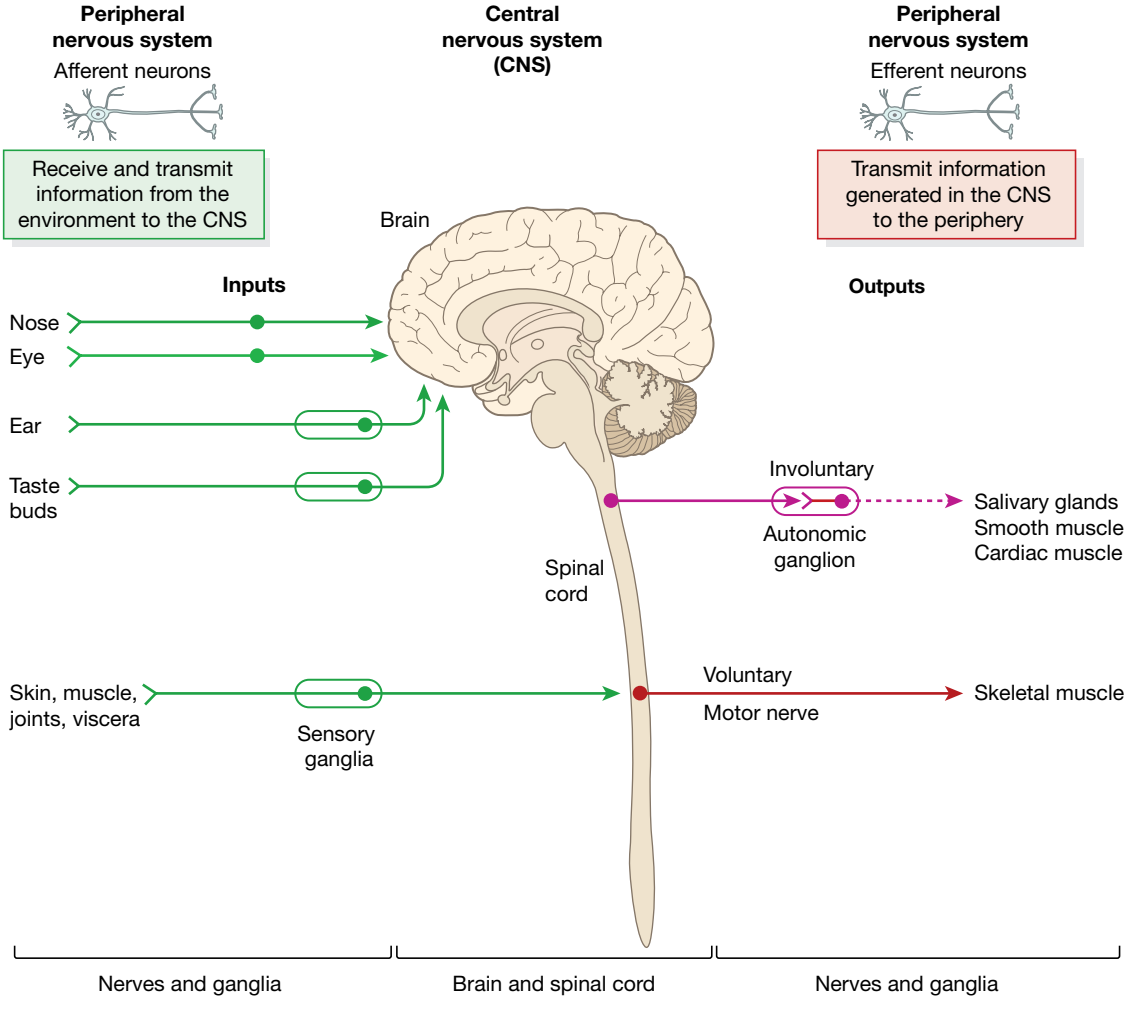


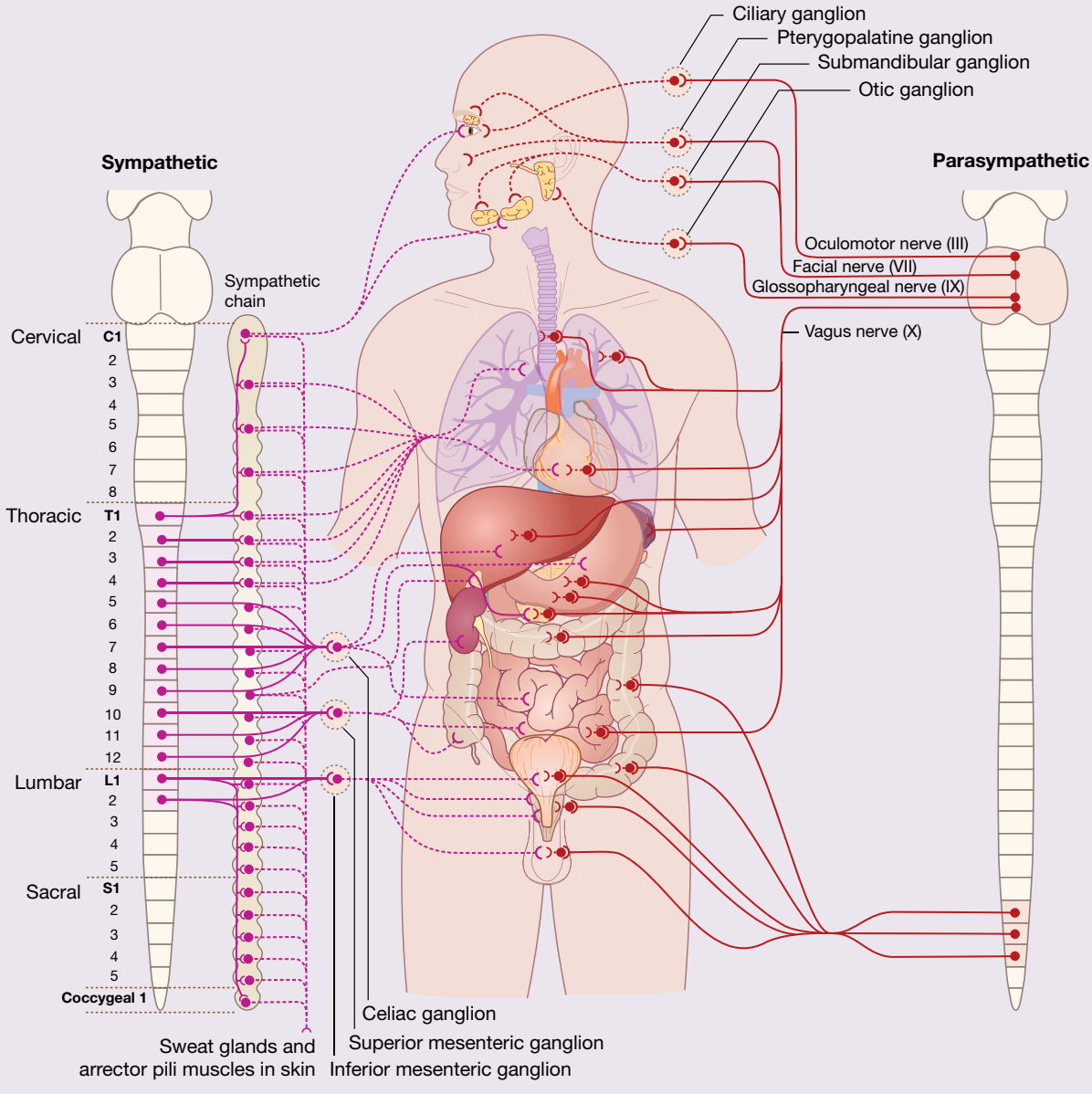
Figure 1.1 A diagrammatic representation of the central and peripheral nervous system with a collection of central cell bodies referred to as a nucleus (plural: nuclei), while a collection of peripheral cell bodies is referred to as a ganglion (plural: ganglia).

Clinical box 1.1

The autonomic nervous system is particularly important in clinical medicine since dysfunction of the heart, lungs, and digestive systems can be linked to autonomic nerves. Physicians modify a patient's autonomic nerve function by prescribing drugs that stimulate or inhibit the firing of these nerves or their receptors. For example, individuals with heart problems can be prescribed "beta blockers" which are drugs that interact at the beta adrenergic receptors in the heart modifying the autonomic tone to the heart. It is, therefore, quite important to know the organization and distribution of the autonomic nervous system.

Both of the subdivisions of the autonomic nervous system (the parasympathetic and sympathetic systems) are a two neuron chain in which acetylcholine is released at the preganglionic synapse. In the parasympathetic nervous system, acetylcholine is also released at the postganglionic synapse with the target organ, while in the sympathetic system, norepinephrine is released at the postganglionic synapse (except for sweat glands which also use acetylcholine). Therefore, cholinergic compounds can interact at both systems, while noradrenergic compounds only affect sympathetic function.

For further details on this system, consult a basic anatomy textbook (Moore, *et al*., 2014), as well as a neuropharmacology textbook (Stahl, 2013).



your hand to stay on the stove. This is using the integrative function of the brain to direct a willful activity.

With the previous discussion, the output used skeletal muscles to move an extremity. This is called a **voluntary** (**somatic**) motor response. There is also an **involuntary** (**autonomic** or visceral) motor response that drives smooth muscle and cardiac muscle. For example, you can see a portion of your favorite food, hot and ready for you to eat, and you will begin to salivate and your stomach may make sounds. These are involuntary smooth muscle actions as you prepare to eat. The **autonomic motor system** is further subdivided into two components: a **parasympathetic** and a **sympathetic** portion. The parasympathetic portion has its central neuronal cell bodies located in the brain stem or in a small portion of the sacral spinal cord (the second through fourth sacral nerves). The sympathetic system has its central neuronal cell bodies located in the spinal cord in the thoracic region and upper two lumbar segments. These two systems generally produce opposite effects, with the parasympathetic system stimulating the digestive system and decreasing heart rate and respiration (rest and digest), while the sympathetic system activates numerous systems (increases heart rate, respiration, and blood flow to skeletal muscle: flight or fright).

Components of the nervous system

The cells in the nervous system can be subdivided into the **neurons** that react to stimuli, interact with each other and produce outputs, and the supporting cells that make sure the neurons can do their job. Neurons are excitable cells with a high degree of specialization and a large morphological diversity. The majority of neurons are unable to divide and cannot replenish themselves if damaged. The supporting cells (**glia**) are smaller than most neurons, can divide to replenish their numbers, and have numerous roles in neuronal support.

A typical neuron contains a large cell body (**soma**) and numerous processes. One of the processes (the **axon**) is usually quite long and is the main conduit for information from the cell body to other cells. The remaining processes (**dendrites**) are usually much shorter and typically they bring information from other cells to the cell body, where it is summated for determination if the axon should fire. The cell body of a neuron has distinguishing characteristics including: 1) a large **euchromatic nucleus** (meaning it is highly active) sometimes referred to as a "bird's eye" nucleus; 2) a large quantity of rough endoplasmic reticulum and polyribsomes (called **Nissl bodies** or **Nissl substance** which stain a dark blue with typical histologic stains); and 3) accumulated cellular waste in the form of **lipofuscin**. The axon exits the cell body from a clear staining region (the **axon hillock**) and ends at synapses with other cells (Figure 1.2). A single axon may branch at its end to supply a number of adjacent cells (a terminal arborization) and within these terminals small **vesicles** can be observed. Because of the extreme length of some axons (from the spinal cord to the foot – over a meter in length), there are mechanisms which allow for transport of materials to and from one end of the axon to the other. Flow from the cell body to the terminals is termed **anterograde axoplasmic transport**, while flow from the terminal to the cell body is termed **retrograde axoplasmic transport**. As mentioned previously, the neuron is an excitable cell and this excitation is maintained and modified by the specific characteristics of the neuronal cell membrane (the plasmalemma or neurolemma). The membrane has numerous ion channels and ion pumps that can maintain an ionic gradient across the membrane, producing the excitability.

A typical neuron is described as a large cell body and nucleus with numerous small dendrites and one very long axon. This is a **multipolar neuron**, which is found in many parts of the nervous system (Figure 1.2). There are, however, a number of other morphologically distinct neurons. For example, in the retina, there are both unipolar and bipolar neurons. The **unipolar neurons** are photoreceptors that do not have any dendrites and only a small axon. The **bipolar neurons** have a single dendrite and a single axon. The chapter on the visual system will describe these cells in greater detail. Another unique neuron is the **pseudounipolar cell** that acts as the main cell for sensory input from the periphery into the central nervous system. This neuron has its cell body "parked" off to the side of the single axon, which

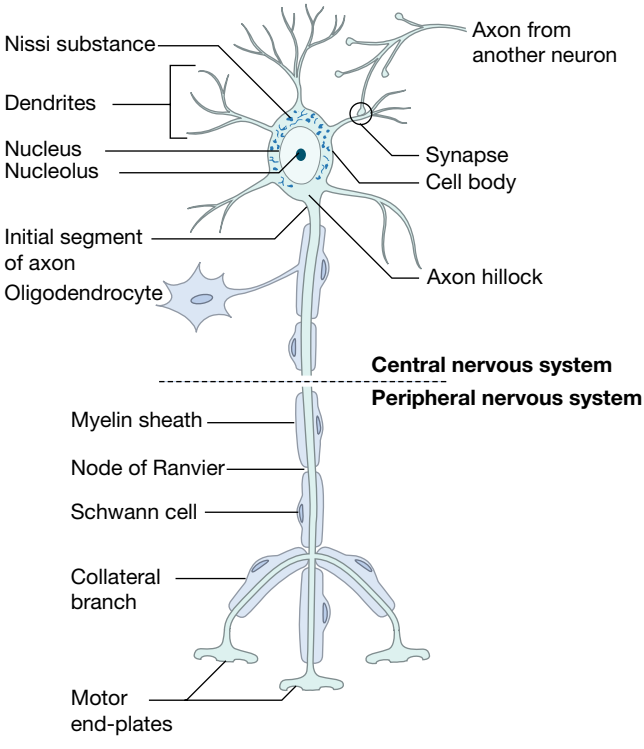


Figure 1.2 A representation of a typical large motor, multipolar neuron with a large euchromatic nucleus and prominent nucleolus, dark staining Nissl substance in the cytoplasm, numerous dendrites, and a long axon extending into the periphery.

has a peripheral projection and a central projection. This allows for rapid input of sensory information from the periphery to the central nervous system without the need to summate or interpret the information at the cell body.

The glial supporting cells are found in both the peripheral and central nervous systems. In the peripheral nervous system, the **Schwann cell** (neurolemmacyte) protects the axons as they are distributed throughout the body. In some cases the Schwann cells simply enclose the axons in their cell membrane, providing nutritional and mechanical support. These are termed **unmyelinated axons** and there may be many of this type of axon supported by one Schwann cell. In other cases, a single Schwann cell will support only one portion of an axon and it will wrap its cell membrane around the axon numerous times, insulating the axon. This is termed a **myelinated axon**. Since one Schwann cell only myelinates a small portion of an axon, other Schwann cells are required to myelinate the remaining length of the axon. Where the myelin layers of the adjacent Schwann cells meet, there is a small gap between the cells, a **node of Ranvier**. While this myelin sheath insulates and protects the axon, it also modifies the ionic flow across the axon cell membrane, producing a stronger, faster, and more reliable axonal signal (saltatory conduction). Therefore, myelinated nerves are faster than their unmyelinated counterparts.

In the central nervous system, there are other glial cells that provide support. The myelin producing cells in the central nervous system are the **oligodendrocytes**. They produce myelin sheaths for a number of axons in the area. The ability to myelinate neurons has important clinical aspects, since there are diseases, such as multiple sclerosis, that can affect myelination and neural function. Another glial cell within the central nervous system is the **astrocyte**. The astrocyte is a supporting cell that provides nutrition for neurons, modifies neurotransmitter uptake, and, importantly, has foot processes that surround the blood vessels in the brain, producing a special immunologically privileged area: the **blood-brain barrier**. There are two types of astrocytes; the fibrous astrocyte associated with white matter and the protoplasmic astrocyte associated with gray matter. Astrocytes can be immunohistochemically identified by the presence of a particular intermediate filament: **glial fibrillary acidic protein (GFAP)**. This protein can also be used in clinical diagnosis of central nervous system tumors. If GFAP is present in a tumor, it means that the tumor was originally derived from astrocytes. Another glial cell within the central nervous system is the **microglia**. These are small macrophage-like cells that act as a local immune response agent, phagocytosing foreign materials. The microglia can be identified using similar immunologic techniques that would identify macrophages in the periphery. An additional supporting cell within the central nervous system is the **ependymal cell**. This is an epithelial, simple columnar, ciliated cell that lines the ventricular system. Modified versions of these cells are responsible for the production of cerebrospinal fluid.

Clinical box 1.2

There are numerous diseases associated with improper glial cell function. **Multiple sclerosis** is an autoimmune disease in which a patient develops antibodies to their own myelin sheaths. The antibodies damage the myelin sheath covering the axon and disrupt the neuronal firing. There are different types of multiple sclerosis, depending on the severity and progression of the disease. There is also an interesting global distribution of the disease, with more cases found in countries further away from the equator and more cases in industrialized nations. The reason for this distribution is not known.

Central nervous system structure

When examining the central nervous system, it is apparent that there are two distinct regions. Historically, these regions were named by their color. One region looked white and was called the **white matter**. This is due to the highly myelinated nerve fibers present in this region. Myelin is made of numerous wrappings of cell membrane and therefore contains large quantities of cholesterol, phospholipids, and other lipid-based compounds. This produces the white appearance of the white matter. The other region of the central nervous system contains both myelinated fibers and neuronal cell bodies. This area is, therefore, less white and is referred to as **gray matter**. Therefore, the gray matter contains neuronal cell bodies, axons, and glia, while the white matter contains only axons and their supporting glial cells (Figure 1.3).

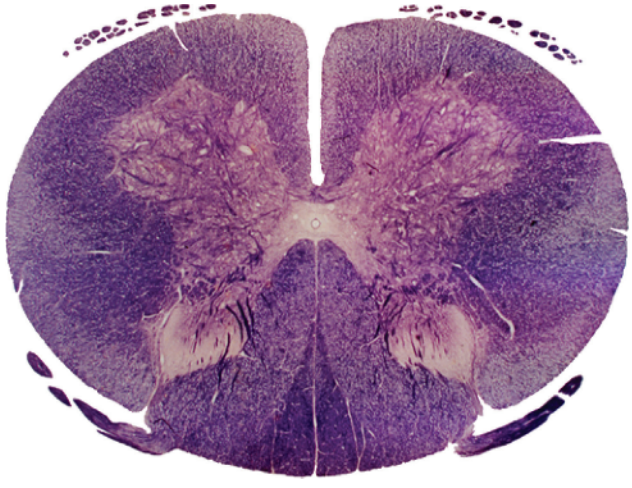
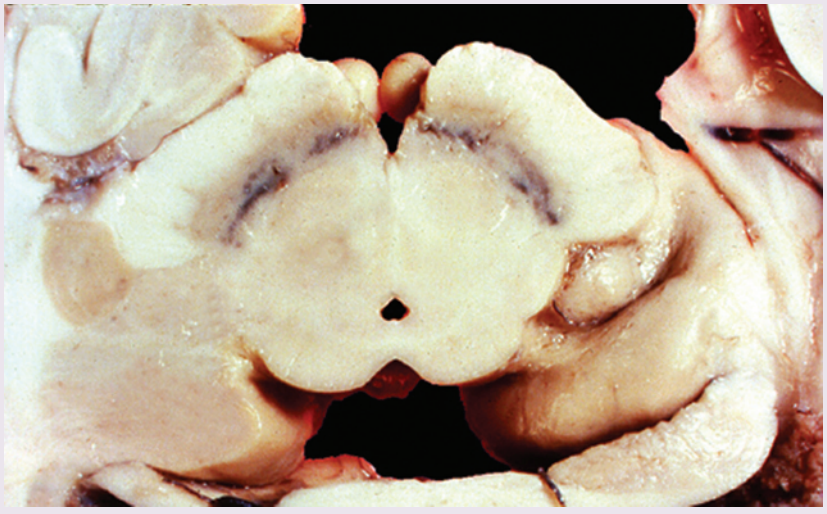


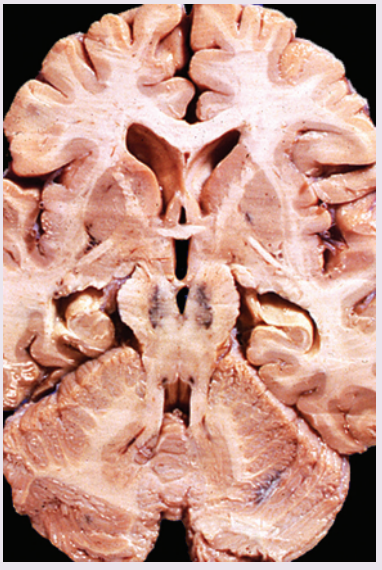
Figure 1.3 A typical cross section of the spinal cord, stained to indicate the presence of myelin, with the outer white matter (containing axons and glia) more densely stained and the inner gray matter (containing neuronal cell bodies, axons, and glia) less densely stained. Note the clinical orientation, with the posterior aspect of the spinal cord at the bottom of the image.

Clinical box 1.3

There are numerous methods utilized to view the components of the central nervous system. Clinically, the use of plain films, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound are used routinely to visualize a patient's brain or spinal cord. Chapter 18 on Imaging Essentials provides details on these and other techniques that are used clinically. However, the resolution of these techniques is presently not detailed enough to provide good differentiation of the nuclei and tracts within the central nervous system, so neuroanatomists still rely on specific histologic methods to visualize the components of the nervous system.

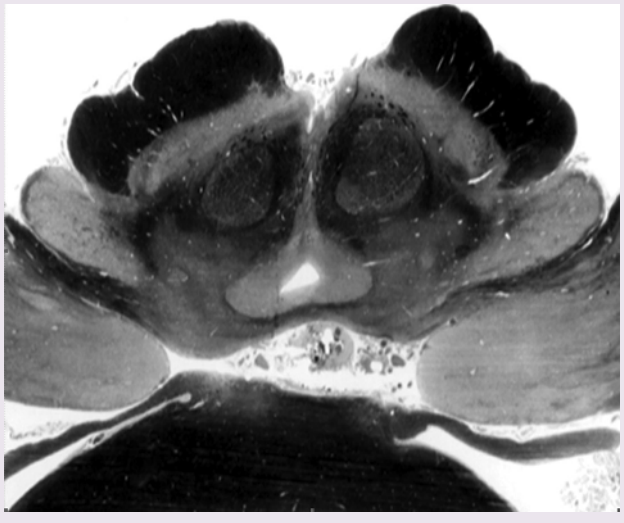
The simplest visualization of the nervous system is with the naked eye. Fresh tissue sections of the brain and spinal cord can be viewed with white matter and gray matter easily distinguishable. Structures such as the substantia nigra in the midbrain are easily observed in fresh tissue.

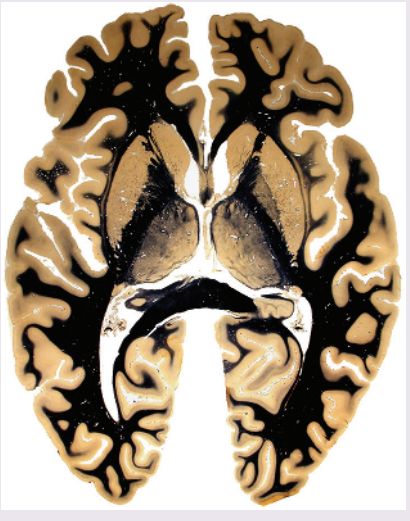




These are fresh tissue sections of the midbrain and surrounding cortical tissues without any staining or treatment. Note the two dark regions in the upper middle portion of the field (the substantia nigra). These areas are normally dark due to the presence of neuromelanin in the cells. The white matter and gray matter can also be observed, although the gray matter actually has a brown coloration in fresh tissue.

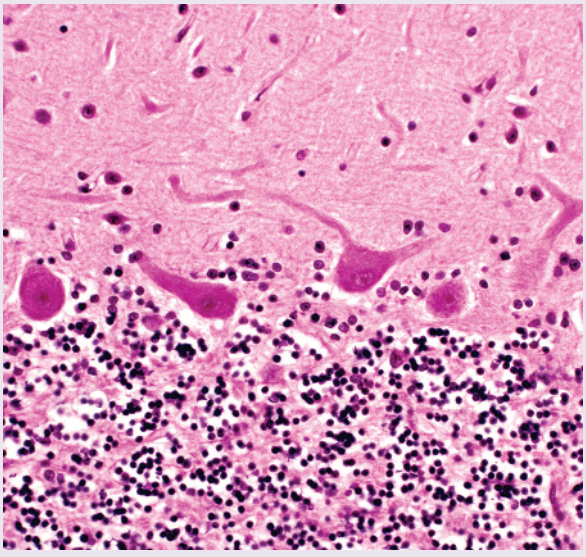
Similar sections of midbrain and cortex can be histologically processed to indicate the presence of myelin (a myelin stain). This is a typical presentation that highlights the tracts and nuclei of the central nervous system.

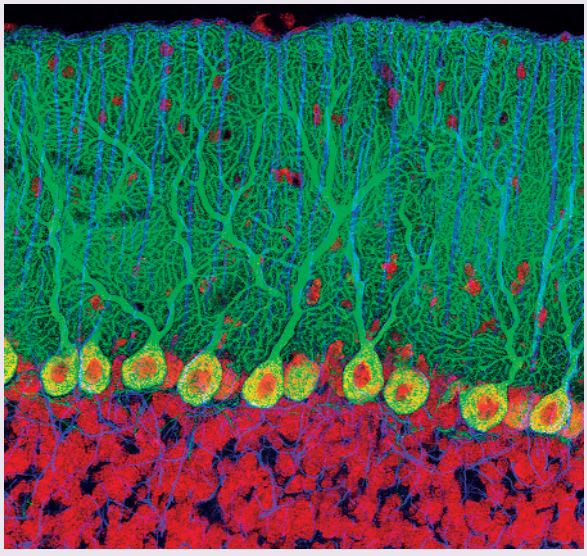




These are myelin stained sections of the midbrain and cortex. Note that the dark staining regions are the tracts of myelinated axons (white matter), while the light staining regions are the nuclei (gray matter). The lighter staining gray matter is variable in density, depending on the quantity of cell bodies present and whether myelinated axons pass by or through the area. In this presentation, the substantia nigra is light staining due to the presence of many cell bodies, with the neuromelanin not visualized.

There are also special histologic stains and techniques that can be used to further identify specific types of neurons. For example, a typical hematoxylin and eosin stain can be used to identify the nucleus in a neuronal cell body, while immunocytochemistry and fluorescence microscopy can be used to identify individual types of cells.





Source: Science Photo Library/Dr Gladden Willis; Science Photo Library/Thomas Deerinck.

These are histologic slides of the cerebellum with a standard hematoxylin and eosin presentation on the left and a histofluorescence presentation on the right. Note the ability to distinguish individual cells with both techniques.

When examining figures, it is important to determine the type of presentation used, since it can be confusing when comparing a fresh tissue section with a myelin stained section (compare the first four figures in this box). As clinical imaging develops in the future, it may be possible to use these non-invasive techniques to visualize all of the neuroanatomical tracts and nuclei without the need to use other histologic methods.

Within the spinal cord, the white matter is found on the periphery of the spinal cord and the gray matter is found centrally. The gray matter forms a central "butterfly" shaped appearance, while the white matter fills in these spaces around the butterfly (Figure 1.3). In the brain, however, the white matter is found centrally and the gray matter is found peripherally. Notice that this is opposite of the arrangement in the spinal cord and the mechanism of this transition will be described at a later point.

Central nervous system orientation

When examining the central nervous system, remember that the nervous system developed as a long tube with a central canal (see Chapter 3 for further details). The end of the neural tube closest to the nose is the **rostral** end, while the end of the neural tube closest to the legs is the **caudal** end. The region of the tube nearest the back is the **posterior** portion (**dorsal**), while the area nearest the abdomen is the **anterior** portion (**ventral**).

During embryologic development, this tube becomes more complex at the rostral (nasal) end, due to the extensive development of the cerebrum, cerebellum, and the brain stem. With this complex development, the brain rotates **90 degrees anteriorly**. This also positions the eyes, nose, and mouth on the anterior (ventral) portion of the body as opposed to the rostral end. This means that there is a change in orientation at the midbrain, causing an anterior rotation termed the **midbrain flexure**. Therefore, what was anterior (ventral) now becomes inferior and what was posterior (dorsal) now becomes superior (Figure 1.4). This rotation can be confusing and needs to be kept in mind when discussing the orientation of cerebral structures.

When viewing the brain, it is important to keep in mind the various planes that can be viewed, especially with the advent of computed tomography (CT) and magnetic

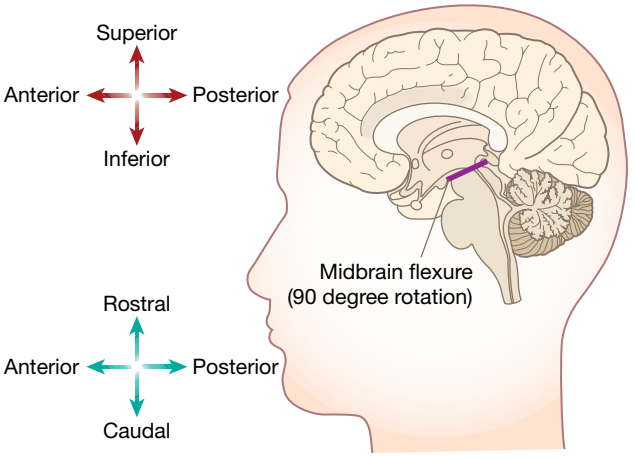


Figure 1.4 A drawing of the midbrain flexure indicating the brain rotation of 90 degrees anteriorly during development. This produces a shift in describing positions in the brain compared to the spinal cord.

resonance imaging (MRI). If a cross section of the body occurs, this would section the spinal cord, the brain stem, and various levels of the cerebrum in a **horizontal (transverse) plane**. If a sagittal section of the body is continued into the brain, this produces two hemispheres of the brain with a section through the interhemispheric fissure **(sagittal plane)**. Parallel cuts in this orientation are **parasagittal** sections. The third dimension for viewing sections of the brain is a **frontal (coronal) plane**. This plane is perpendicular to a sagittal plane and can be thought of as the patient walking into a door (Figure 1.5).

When viewing cross sections of the brain or spinal cord, the orientation of the cross section must be determined. This is especially important in the spinal cord, due to a difference between the **clinical view** and the **anatomic view**. Historically, anatomists oriented a cross section of the spinal cord with the posterior (dorsal) surface of the spinal cord at the top of the field and the anterior (ventral) surface at the bottom. Neuroanatomists have used this orientation for decades. With the development of cross-sectional radiology, radiologists set the standard orientation with the patient lying on his back being viewed from his

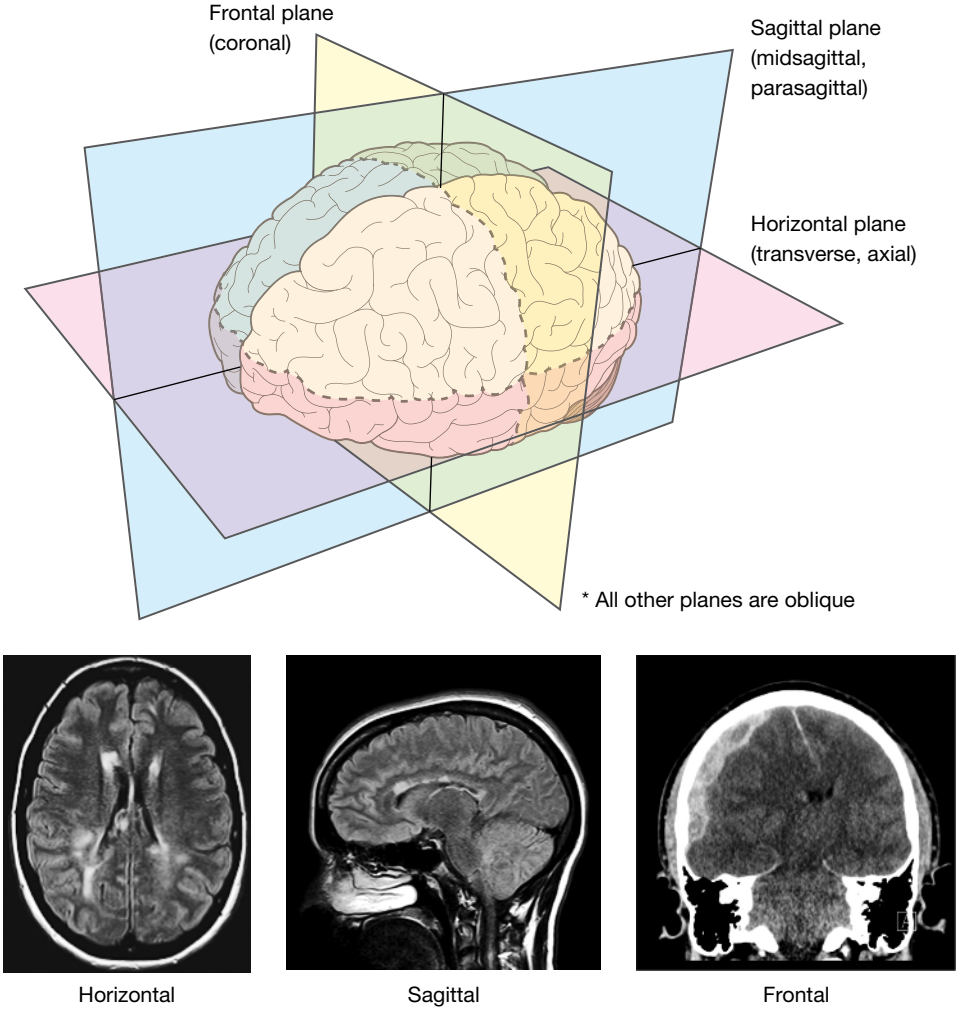


Figure 1.5 Anatomic planes of the nervous system that can be viewed by modern radiographic techniques.

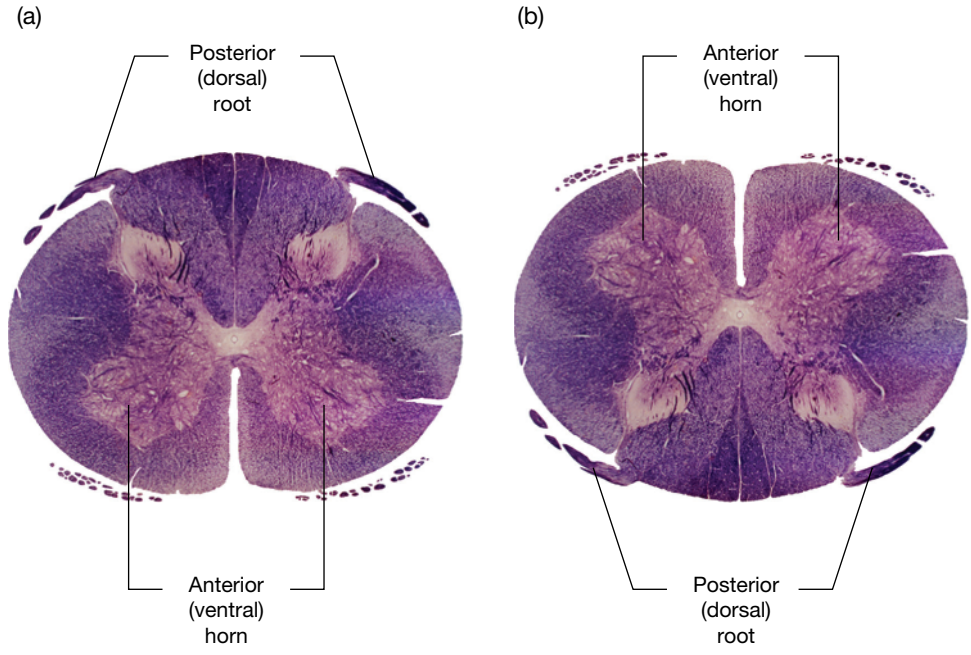


Figure 1.6 Anatomical (a) versus clinical (b) view of the spinal cord. The clinical view is the view that is used with CT, MRI, and other imaging systems and is described as the patient lying on their back (supine) in bed with the clinician viewing them from the foot of the bed (inferiorly). This view (b) will be consistently used throughout this text, since it is the clinically relevant, standard view. The anatomical view may still be used in older textbooks and atlases.

feet. In this orientation, the posterior (dorsal) surface of the spinal cord would be at the bottom of the field, while the anterior (ventral) surface of the spinal cord would be at the top of the field (opposite from the anatomic view). This has caused confusion in the past when examining cross sections of the spinal cord. In this text, the clinical view (CT view) will be used in order to maintain consistency and clinical relevance. However, other neuroanatomy texts may use the anatomic view and this requires the appropriate adjustment (Figure 1.6).

Views of the brain

When viewing the whole brain anatomically, it can be seen from three distinct views – **superior** (dorsal), **inferior** (ventral), and **lateral**. An additional view, a **sagittal midline view**, can be described that involves cutting the brain in half through the interhemispheric fissure in the sagittal plane.

In the superior view of the brain, the lobes of the cortex can be identified, along with the **interhemispheric fissure**. Midway along the superior surface of the brain, a primary sulcus can be found, the **central sulcus**. On either side of the central sulcus reside two primary gyri: the **precentral gyrus**, which is the primary motor gyrus, and the **postcentral gyrus**, which is the primary somatosensory gyrus.

On the lateral surface of the brain, the most prominent feature is the **lateral (Sylvian) fissure**. Above the fissure are the frontal and parietal lobes of the cortex, while below the fissure the temporal lobe of the cortex is found. Posterior to the fissure, the occipital cortex can be seen. It is also possible to identify the **central sulcus** and the **precentral** and **postcentral gyri**. If the lateral fissure is spread open, a portion of cerebral cortex (the **insular cortex**) is observed within the fissure (Figure 1.7).

In the inferior view of the brain, the lobes of the cortex can also be identified, along with portions of the interhemispheric fissure and the **lateral (Sylvian) fissure**. In addition, the midbrain with the cerebral peduncles, the pons with the middle cerebellar peduncles, and the medulla oblongata with the pyramids, can be observed. The base of the brain and the brain stem also contain the roots of the twelve cranial nerves, including the **olfactory bulbs** and the **optic nerves and chiasm**. Caudal to the optic chiasm is the **infundibulum** (pituitary stalk) and the **mammillary bodies**. In this area the primary blood supply to the brain is also found – the **cerebral arterial circle** (of Willis). It is important to be able to identify all of these components on the inferior surface of the brain (Figure 1.8).

On a midsagittal view of the brain, portions of the lobes of the cerebral cortex can also be identified. A large white arc of myelinated nerve fibers can be observed and is known as the **corpus callosum**. Superior to the corpus callosum is the **cingulate gyrus**. Inferior to the corpus callosum is the **septum pellucidum** separating the two **lateral ventricles**. Inferior to the septum pellucidum is the **diencephalon** with the **thalamus**, **hypothalamus**, and **pineal gland** easily identifiable. In addition, the midbrain, pons, medulla, and cerebellum can be observed in sagittal section (Figure 1.9).

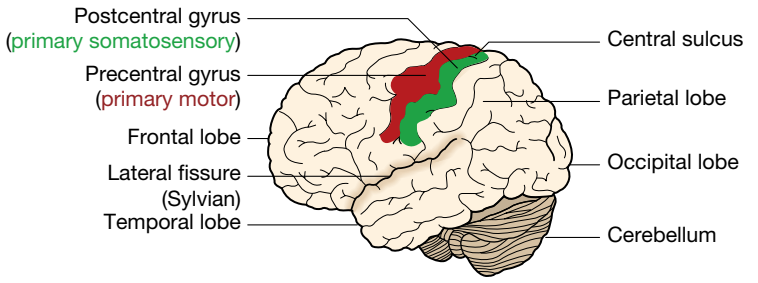


Figure 1.7 A lateral view of the brain highlighting the major sulci and gyri, including the lateral fissure (Sylvian), the central sulcus, and the precentral and postcentral gyri. The lobes of the brain can also be observed: the frontal lobe, parietal lobe, temporal lobe, and occipital lobe.

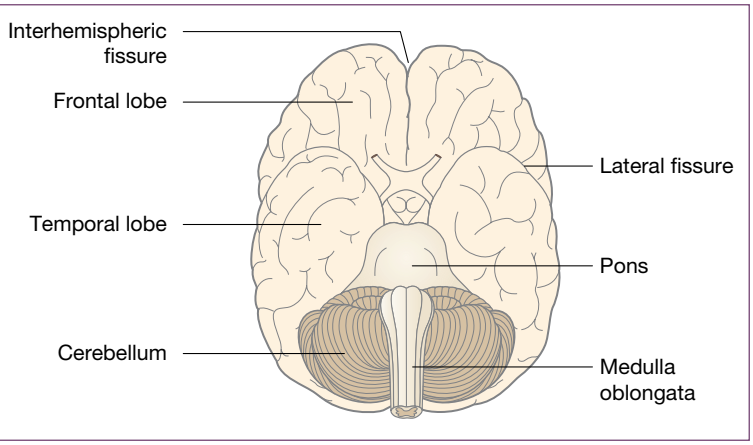


Figure 1.8 A ventral view of the brain highlighting the interhemispheric fissure, the lateral fissure (Sylvian), the brain stem with the prominent pons, the roots of the cranial nerves, and the cerebellum. The frontal and temporal lobes of the brain can also be observed.

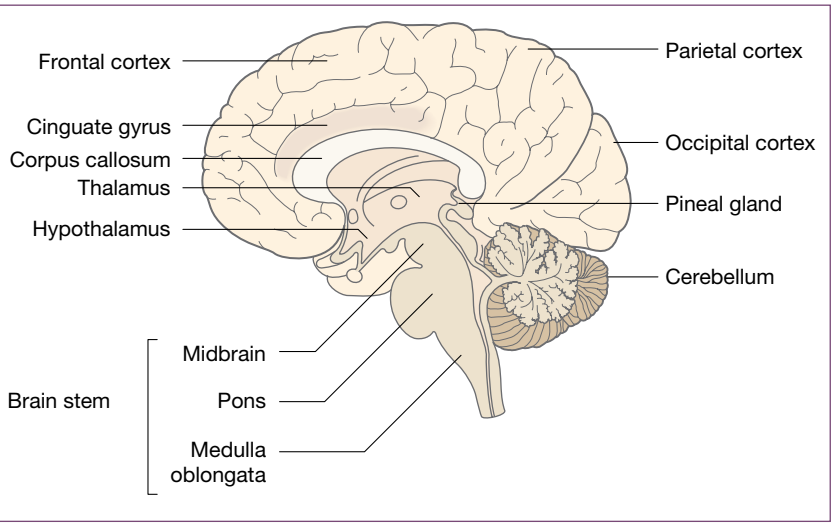


Figure 1.9 A midsagittal section of the brain highlighting the diencephalon, with the thalamus, the brain stem with the prominent pons, and the cerebellum. The frontal, parietal, and occipital lobes of the brain can also be observed.

Central nervous system subdivisions

The central nervous system can be subdivided anatomically. Beginning caudally (or inferiorly), the **spinal cord** is found inside the vertebral column and extends from the base of the cranium to the second or third lumbar vertebrae. The spinal cord continues into the cranium as the **brain stem**. The brain stem is subdivided into three specific regions based on the relationship to the **pons**. The structure caudal to the pons is the **medulla** or, more specifically, the **medulla oblongata**. The structure rostral to the pons is the **midbrain**. Extending from the midbrain is the **diencephalon**, comprised of the hypothalamus, thalamus, and epithalamus. The diencephalon extends into the remainder of the skull as the **telencephalon**, principally made up of the large cerebral cortex. A unique structure located posterior to the brain stem and at the caudal end of the cortex is the **cerebellum** (Figure 1.9).

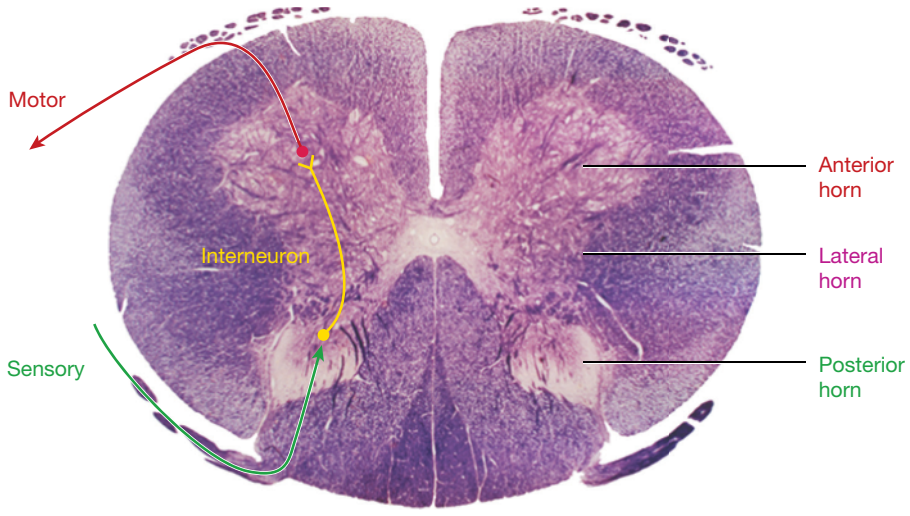


Figure 1.10 The regions of the spinal cord including the posterior (dorsal) horn, lateral horn, and anterior (ventral) horn, with their general functions indicated (posterior horn = sensory = green; lateral horn = autonomic motor function = purple; anterior horn = somatic motor function = red). These colors will be used throughout the text to indicate the functional attributes associated with the labeled structures.

Spinal cord

As an introduction to the overall structure of the central nervous system, each region will be described briefly. The **spinal cord** when viewed in cross section consists of an outer portion termed the **white matter** and an inner "butterfly-shaped" region termed the **gray matter**. These were named based on their coloration in fresh tissue; the white matter containing only nerve fibers (many that are myelinated) and the gray matter containing nerve cell bodies along with nerve fibers, as mentioned previously. The gray matter can be subdivided into a posterior (dorsal) region termed the **posterior (dorsal) horn** and an anterior (ventral) region termed the **anterior (ventral) horn**. Generally, each of these horns is responsible for a separate function; the posterior horn is responsible for incoming sensory activity and the anterior horn is responsible for outgoing motor activity. In some regions of the spinal cord, there is a small **lateral horn** which contains nerve cell bodies of the autonomic nervous system. Within the spinal cord, incoming sensory nerves can be linked to outgoing motor nerves by small **interneurons**, providing basic reflex actions (Figure 1.10).

The spinal cord is composed of 31 spinal segments, producing 31 spinal nerves and subdivided by the region of the vertebral column where each nerve exits. The first eight segments are in the neck and are termed the **cervical nerves** (C1–C8). The second region of the spinal cord is the thoracic section, containing 12 segments (**thoracic nerves**) (T1–T12). The third region of the spinal cord is the lumbar section, containing five segments (**lumbar nerves**) (L1–L5). The fourth region of the spinal cord is the sacral section, containing five segments (**sacral nerves**) (S1–S5). The fifth and final region of the spinal cord is the coccygeal section, containing just one segment (Cy1) (see chapter 4 for more details).

Brain stem

The upper cervical level of the spinal cord enters the cranium through the foramen magnum and expands to form the brain stem. The sensory fibers ascending in the spinal cord continue into the brain stem by passing through the **medulla oblongata**, then into the **pons**, and further into the **midbrain** (the three subdivisions of the brain stem), before reaching the **diencephalon**. Likewise, fibers descend from the diencephalon through the midbrain, pons, and medulla before reaching the spinal cord. The pathways taken by these fibers and the nuclei present in these regions can be quite complex and will be discussed in greater detail in subsequent chapters.

Diencephalon

The diencephalon contains a major relay region of the central nervous system, the **thalamus**. Virtually all information that is sent to the cerebral cortex passes through the thalamus. The diencephalon also contains regions that maintain an individual's homeostasis, the metabolic and hormonal balance throughout the body. These regions include the **hypothalamus** (that communicates with the pituitary gland) and the **epithalamus** (with its associated **pineal gland**) (Figure 1.9).

Telencephalon

The telencephalon is a large region that makes up the majority of the neural structures within the skull. The telencephalon includes the **cerebral cortex** with its subdivided lobes: the **frontal lobe**, the **parietal lobe**, the **occipital lobe**, the **temporal lobe**, and the **insular cortex**. Generally, these lobes have specific functions associated with them, although each lobe has integrative aspects. For example, the temporal lobe is associated with hearing, while the occipital lobe is associated with vision. The parietal lobe has a major role in receiving primary sensory input, as well as directing primary motor output. The frontal lobe is associated with personality and decision-making capacity (Figures 1.7, 1.8, 1.9).

The cerebral cortex, when examined microscopically, displays six cellular layers. Each of these layers contain variable quantities of neurons and can be morphologically distinct. The telencephalon also includes centrally located structures such as the **basal ganglia** and the components of the **limbic system**. All of these structures will be discussed in more detail in subsequent chapters.

Cerebellum

The cerebellum is a small "brain" of its own that receives input from virtually all sources of the nervous system, but most notably the vestibular system. It processes these inputs and provides balance, localization, and motor control information to the central nervous system. The cerebellum has a simpler cortical structure than the cerebral cortex, with only three layers: the molecular layer, Purkinje cell layer, and the granule cell layer (see chapter 10 for more details).

Cranial nerves

Just as there are spinal nerves which exit from specific spinal segments, there are twelve nerves which enter or exit the skull. These nerves are termed **cranial nerves** and are denoted by a Roman numeral (I–XII). A brief description of each cranial nerve follows, with greater detail in subsequent chapters. These cranial nerves can be observed leaving the inferior surface of the brain and are considered part of the peripheral nervous system at this point. The cranial nerve cell bodies (nuclei) and the portion of their axons within the brain or brain stem are considered part of the central nervous system.

Cranial nerve one is the **olfactory nerve (I)** and it relays the sense of smell to the central nervous system. The second cranial nerve is the **optic nerve (II)** and it relays vision to the central nervous system. The third cranial nerve is the **oculomotor nerve (III)** and it supplies five small optic muscles within the orbit which move the eye and raise the eyelid. The oculomotor nerve also contains parasympathetic neurons which innervate muscles that constrict the pupil and modify the shape of the lens. The fourth cranial nerve is the **trochlear nerve (IV)** and it supplies one optic muscle, the superior oblique muscle. The fifth cranial nerve is the **trigeminal nerve (V)**, with three major branches (ophthalmic, maxillary, and mandibular). The trigeminal nerve (V) relays general sensation from the face to the central nervous system as well as supplying motor activity to the muscles of mastication and four other small muscles. The sixth cranial nerve is the **abducens nerve (VI)** and it controls one optic muscle, the lateral rectus muscle.

The seventh cranial nerve is the **facial nerve (VII)** and it supplies the muscles of facial expression, as well as supplying parasympathetic innervation to the lacrimal gland, the nasal cavity, the submandibular gland, and the sublingual gland. The facial nerve (VII) also relays the sense of taste from the anterior tongue to the central nervous system. The eighth cranial nerve is the **vestibulocochlear nerve (VIII)** and it relays the sense of hearing and balance to the central nervous system. The ninth cranial nerve is the **glossopharyngeal nerve (IX)** and it relays general sensation from the pharynx and the posterior tongue to the central nervous system. The glossopharyngeal nerve (IX) also supplies one pharyngeal muscle. The tenth cranial nerve is the **vagus nerve (X)** and it has a multitude of functions. The vagus nerve (X) relays general sensation from the larynx as well as visceral sensation from the heart, lungs, and gastrointestinal system to the central nervous system. This nerve also provides the skeletal muscles of the larynx and pharynx as well as parasympathetic innervation to the heart, lungs, and gastrointestinal system. The eleventh cranial nerve is the **spinal accessory nerve (XI)** and it does not arise from the brain stem. It arises from the upper five cervical segments, ascends through the foramen magnum and exits the skull through the jugular foramen to supply the sternocleidomastoid and trapezius muscles. The twelfth cranial nerve is the **hypoglossal nerve (XII)** and it supplies the majority of muscles in the tongue.

Caveats

It is important to highlight a few nomenclature issues that arise when studying neuroanatomy. One such issue is the use of the terms dorsal and ventral instead of posterior and anterior. Posterior and anterior are the more appropriate anatomical terms. Historically neuroanatomists have, however, used the terms dorsal and ventral in place of posterior and anterior. Some more recent texts have switched to the proper anatomical terminology and have replaced the term dorsal with posterior and the term ventral with anterior.

Another important nomenclature issue is the use of the terms **ipsilateral** and **contralateral**. These terms are used to describe the location of symptoms in a patient compared to the location of the nervous system lesion that produces the symptoms. For example, if a lesion were to occur on the left side of the nervous system and the symptoms were displayed on the left side, then this would be an **ipsilateral** effect. On the other hand, if a lesion were to occur on the left side of the nervous system and the symptoms were displayed on the right side of the body, then this would be a **contralateral** effect. This allows clinicians to refer to the location of a lesion in relation to the side of the symptoms without resorting to a right or left determination.

The final caveat to be described was mentioned previously, but is important to reiterate. This is the difference between an **anatomical** cross-sectional view (with the posterior (dorsal) surface at the top of the field) compared with a **clinical** cross-sectional view (with the posterior (dorsal) surface at the bottom of the field). In order to maintain consistency and to present relevant clinical information, the **clinical view** will be utilized throughout the text.

Clinical considerations

One take home message from this chapter is that specific areas of the brain are responsible for specific functions. Therefore, a patient's symptoms can be critical in determining the location and extent of a neural lesion. Throughout this text, numerous cases will be presented in which specific neural lesions have occurred. While real estate agents may use the slogan "location, location, location", neuroanatomists use a variation on that slogan – "**lesion, lesion, lesion**". These lesions could be due to vascular damage (ischemia or stroke) or they can be due to traumatic injury. In either case, it is especially important to understand the neuroanatomical location of specific structures

and their functional attributes. With this knowledge, a clinician can pinpoint a lesion based on the presentation of symptoms in the patient. In addition, it is important to understand which neural structures are located in close proximity to other structures, since a lesion may impact multiple structures in a small area. This is referred to as the "**neighborhood effect**", since structures in the neighborhood can be damaged by a small localized lesion.

Case 1

Mrs Daniela Jones is a 46-year-old mother of three, with a catering business. While preparing meals, she notices a tingling in her hands and chalks it up to overuse. A few weeks later, she becomes quite fatigued and has muscle weakness in both her lower limbs. Again, she believes this is due to the stress of her job and her hectic schedule. After a few days' bed rest, the symptoms go away and she returns to her job. One month later, she has a spell of dizziness and vertigo, as well as a loss of sensation from her right arm. This concerns her and she schedules an appointment with her physician, Dr Jill Jameson. When she sees her physician, two weeks later, all of the symptoms have been resolved.

Dr Jameson, after taking a detailed history, and hearing Daniela describe the neural signs and frequency of problems, decides to schedule Daniela for further tests. First, she is scheduled for a magnetic resonance image (MRI) (see Chapter 18) and the results of the MRI suggest that small plaques are found in various white matter regions of the brain (Figure 1.11). With this information, Daniela is then scheduled for a lumbar puncture (see Chapter 2) to gather a small amount of cerebrospinal fluid. The fluid is tested for the presence of oligoclonal bands of IgG – an inflammation marker. When this test is positive, Dr Jameson meets with Daniela and suggests that she may have **multiple sclerosis**, an inflammatory, autoimmune disease that targets the neuronal myelin sheaths in the central nervous system. Recall that myelin is produced in the central nervous system by oligodendrocytes and in the peripheral nervous system by Schwann cells. With a reduction in myelination of random nerves, a variety of neural symptoms can occur.

While there is no cure for multiple sclerosis, Daniela is given guidance on managing the disease. This includes avoiding stress (which can reduce the ability to fight inflammation), as well as avoiding inflammation provoking events. She is given oral corticosteroids to use during an event (which may help lower the severity of the attack) and is told of other pharmacologic treatments that may be available if the number and severity of events increases. She is asked to monitor her experiences, so that a time course for the progression of the disease can be determined. If she is lucky, she can live a reasonably full life without serious complications from her multiple sclerosis.

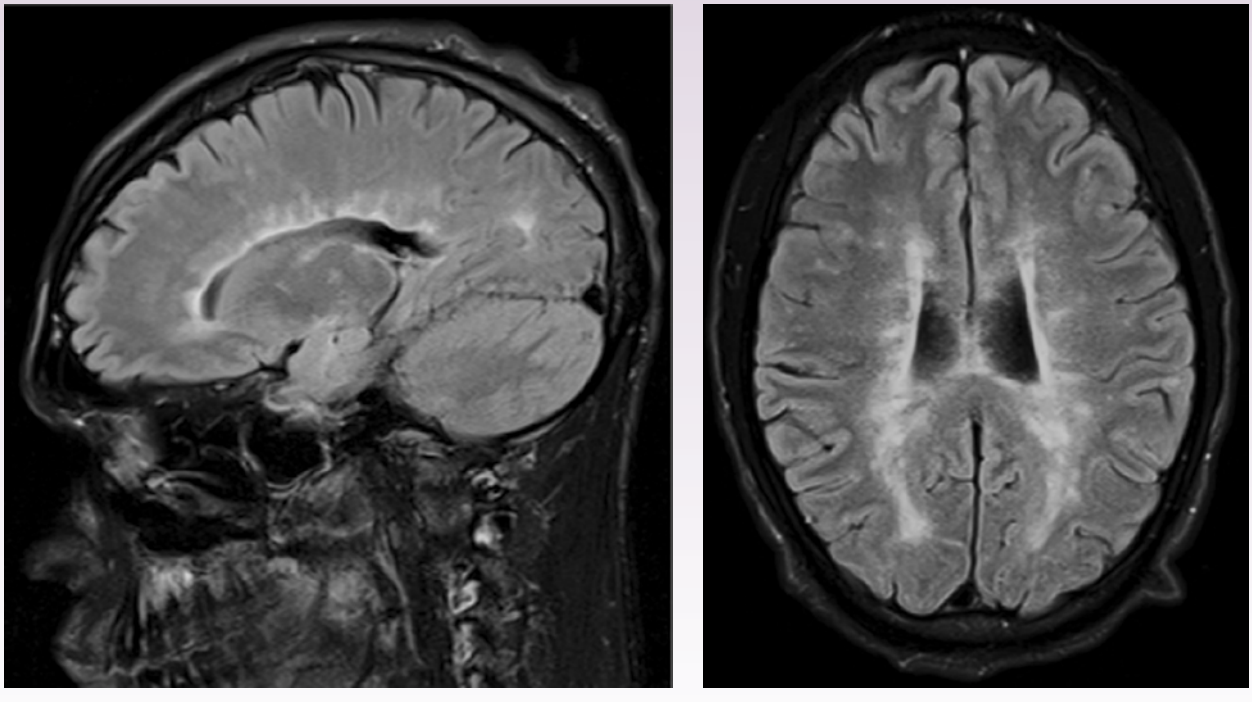


Figure 1.11 A sagittal and axial (horizontal) magnetic resonance image (MRI) of a patient with multiple sclerosis. Note the hyperintensity near the ventricles and the small plaques located in white matter regions.

Case 2

Mr Timothy Woods is a 78-year-old retired truck driver who lives with his wife in a small single family home. His wife notices that Timothy will forget where he placed small items like the car keys and that he becomes easily frustrated with simple memory tasks like remembering phone numbers or addresses. During his yearly physical examination, his physician, Dr Bill Adams, performs a simple neurological exam and notices that Timothy has some memory impairment. Upon further questioning with Timothy and his wife, Dr Adams suspects that Timothy may have symptoms of **age-related cognitive decline** (Figure 1.12).

Dr Adams attempts to determine if there is a systemic reason for Timothy's cognitive decline, including drugs that he may be taking, any vascular disorders (blood pressure or atherosclerosis), or lifestyle issues (smoking, vitamin deficiencies). While Timothy does not appear to have a systemic reason for his decline, Dr Adams encourages him to increase his exercise (by a daily brisk walk), to take a daily vitamin supplement, and to engage in daily mental activity (crossword puzzle). While there is still debate about the effectiveness of these life style changes, many individuals can experience slight improvements or a reduction in the cognitive decline (perhaps due to a placebo effect). With these modest changes, both Timothy and his wife notice that his memory, while not perfect, does improve slightly. If his memory were to continue to decline, Timothy could utilize pharmacologic treatments that can improve or prevent further memory loss.

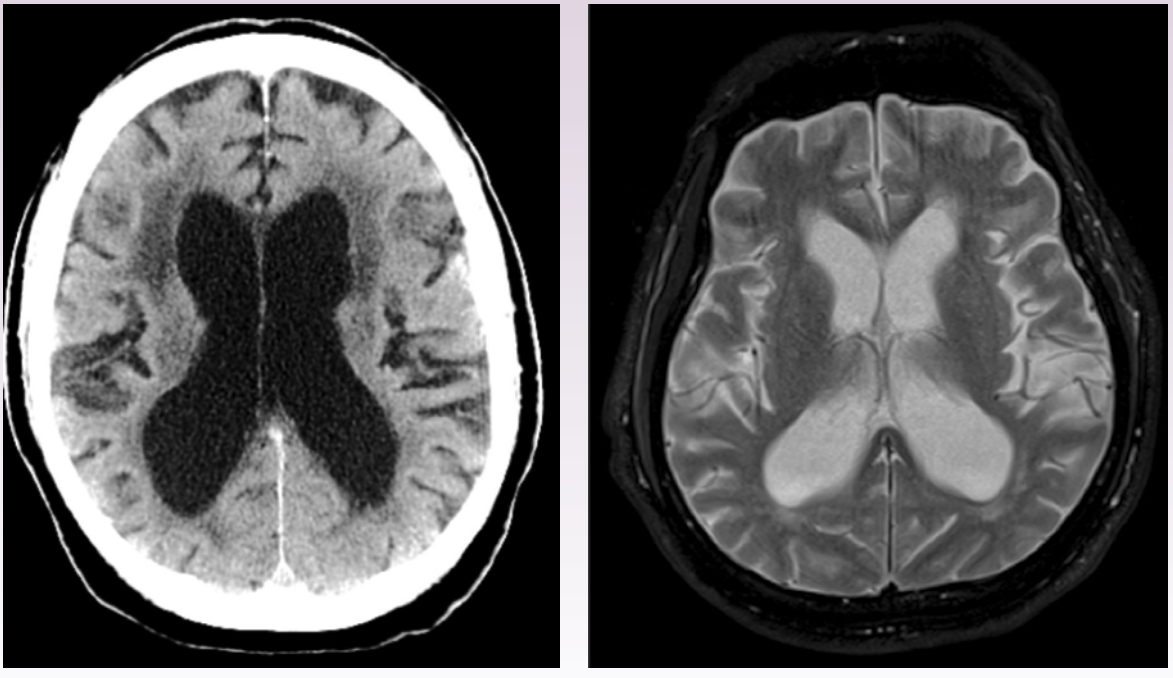


Figure 1.12 An axial (horizontal) computer tomograph (CT) and magnetic resonance image (MRI) of the same elderly patient with age-related cognitive decline. Note the enlarged ventricles and atrophy of the cortex (larger than normal sulci) in the brain.

Study questions

1. When examining a CT of a patient with a spinal cord lesion, and the symptoms occur on the same side as the lesion, the _____ surface would be at the top of the field and the lesion would produce _____ effects.

a) posterior (dorsal), ipsilateral
b) posterior (dorsal), contralateral
c) anterior (ventral), ipsilateral
d) anterior (ventral), contralateral

2. In order to determine where a patient has had a small cerebral cortical stroke, it is important to equate structure with function. If a patient presents with a primary motor deficit, then a stroke could have occurred in the:

a) precentral gyrus
b) postcentral gyrus

c) cingulate gyrus
d) superior temporal gyrus
e) calcarine gyrus

3. If a patient presents with multiple sclerosis (a central myelination disorder), which of the following cells would be primarily involved?
a) Schwann cells
b) astrocytes
c) ependymal cells
d) microglia
e) oligodendrocytes

4. The diencephalon contains the hypothalamus, the thalamus, and the:
a) cingulate gyrus
b) pineal gland
c) midbrain
d) pituitary gland
e) cerebellum

5. Create a table listing the twelve cranial nerves with their name and number, then list whether they have a sensory role, motor role, or carry both functions, describe how they leave the skull, and, if lesioned, the general symptoms that would be present.

For more self-assessment questions, visit the companion website at **www.wileyessential.com/neuroanatomy**

FURTHER READING

For additional information on the general overview of neuroanatomy, the following textbooks may be helpful:

Blumenfeld H. 2002. *Neuroanatomy Through Clinical Cases*. Sinauer Associates, Sunderland, Massachusetts.

Felten DL, Shetty A. 2009. *Netter's Atlas of Neuroscience*, 2nd edition. Saunders Elsevier, Philadelphia, Pennsylvania.

Haines DE. 2012. *Neuroanatomy: An Atlas of Structures, Sections and Systems*, 8th edition. Lippincott Williams & Wilkin, Baltimore, Maryland.

Moore KL, Dalley AF, Agur AMR. 2014. *Moore Clinically Oriented Anatomy*, 7th edition. Lippincott, Williams & Wilkins, Philadelphia, Pennsylvania.

Patestas MA, Gartner LP. 2006. *A Textbook of Neuroanatomy*. Blackwell Publishing, Malden, Massachusetts.

Stahl SM. 2013. *Stahl's Essential Psychopharmacology*, 4th edition. Cambridge University Press, Cambridge, England.