CHAPTER 5: NERVOUS SYSTEM

At the end of this chapter, student will be able to:

a) Name the divisions of the nervous system and the parts of each, and state the general functions of the nervous system.
b) Name the parts of a neuron and state the function of each.
c) Explain the importance of Schwann cells in the peripheral nervous system and neuroglia in the central nervous system.
d) Describe the electrical nerve impulse, and describe impulse transmission at synapses
e) Describe the types of neurons, nerves, and nerve tracts.
f) State the names and numbers of the spinal nerves, and their destinations.
g) Explain the importance of stretch reflexes and flexor reflexes.
h) State the functions of the parts of the brain; be able to locate each part on a diagram.
i) Name the meninges and describe their locations.

5.1 INTRODUCTION

The **nervous system** is one of the smallest and yet the most complex of the 11 body systems with a mass of only 2 kg about 3% of total body weight. The nervous system is an intricate, highly organized network of billions of neurons and even more neuroglia. The structures that make up the nervous system include **the brain, cranial nerves and their branches, the spinal cord, spinal nerves and their branches, ganglia, enteric plexuses, and sensory receptors**.

The skull encloses the **brain,** which contains about 100 billion neurons. Twelve pairs (right and left) of **cranial nerves,** numbered I through XII, emerge from the base of the brain. A **nerve** is a bundle of hundreds to thousands of axons plus associated connective tissue and blood vessels that lies outside the brain and spinal cord.

The **spinal cord** connects to the brain through the foramen magnum of the skull and is encircled by the bones of the vertebral column. It contains about 100 million neurons. **Ganglia** are small masses of nervous tissue, consisting primarily of neuron cell bodies, that are located outside the brain and spinal cord. Ganglia are closely associated with cranial and spinal nerves.

In the walls of organs of the gastrointestinal tract, extensive networks of neurons, called **enteric plexuses,** help regulate the digestive system.

The term **sensory receptor** is used to refer to the dendrites of sensory neurons, specialized cells that monitor changes in the internal or external environment, such as photoreceptors in the retina of the eye.

5.2 FUNCTIONS OF THE NERVOUS SYSTEM

The activities of nervous system can be grouped into three basic functions: **sensory, integrative, and motor.**

- **Sensory function.** Sensory receptors detect internal stimuli and external stimuli, this sensory information is then carried into the brain and spinal cord through cranial and spinal nerves.
- **Integrative function.** The nervous system integrates (processes) sensory information by analyzing and storing some of it and by making decisions for appropriate responses. An important integrative function is **perception,** the conscious awareness of sensory stimuli. Perception occurs in the brain.
- **Motor function.** Once sensory information is integrated, the nervous system may elicit an appropriate motor response by activating **effectors** (muscles and glands) through cranial and spinal nerves. Stimulation of the effectors causes muscles to contract and glands to secrete.

5.3 HISTOLOGY OF NERVOUS TISSUE.

Nervous tissue consists of two types of cells: **neurons and neuroglia**.

Neurons provide most of the unique functions of the nervous system, such as sensing, thinking, remembering, controlling muscle activity, and regulating glandular secretions.

Neuroglia support, nourish, and protect the neurons and maintain homeostasis in the interstitial fluid that bathes them.

NEURONS

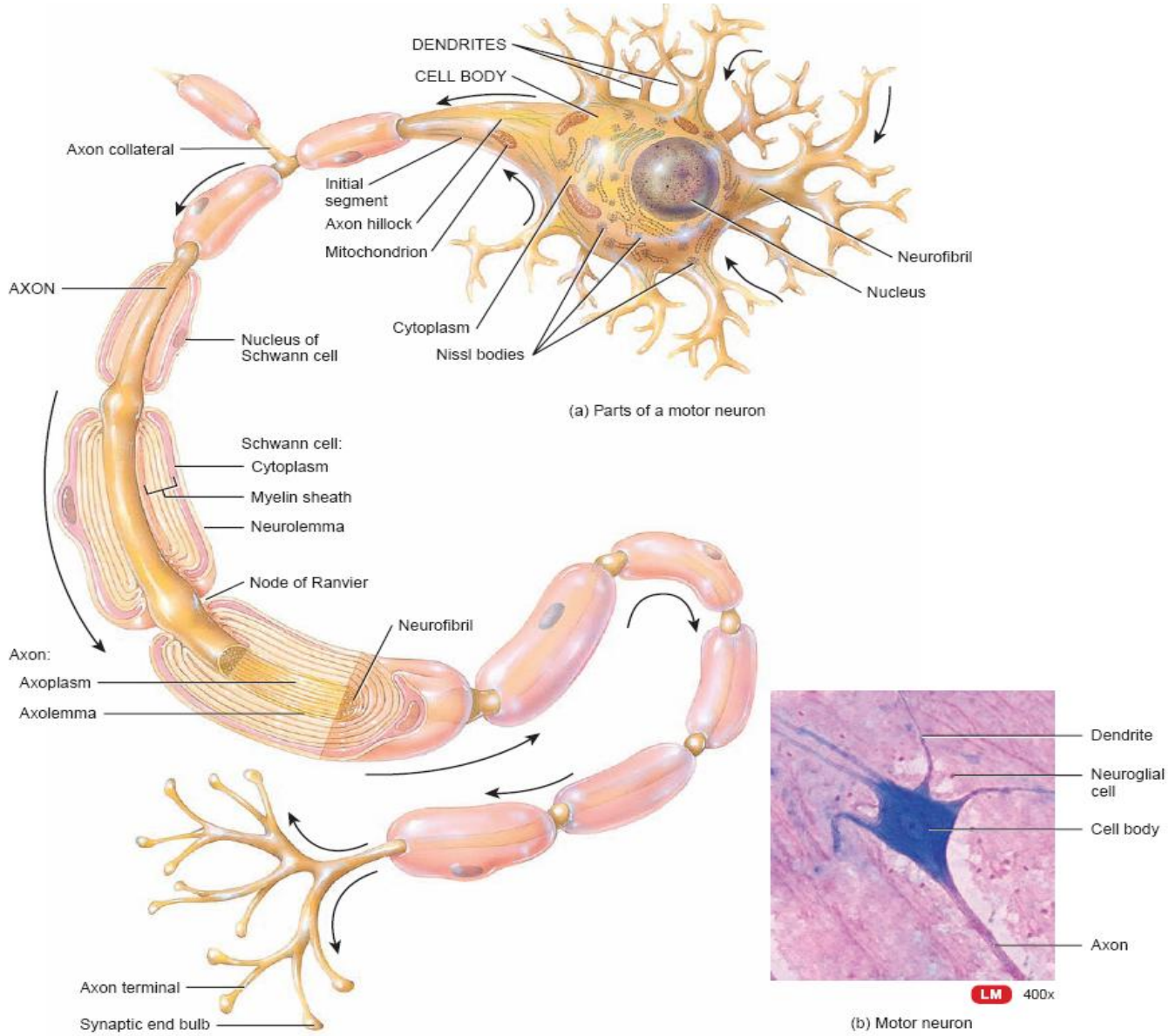
Like muscle cells, **neurons (nerve cells)** possess **electrical excitability,** the ability to respond to a stimulus and convert it into an action potential.

A **stimulus** is any change in the environment that is strong enough to initiate an action potential.

An **action potential (nerve impulse)** is an electrical signal that propagates (travels) along the surface of the membrane of a neuron. It begins and travels due to the movement of ions (such as sodium and potassium) between interstitial fluid and the inside of a neuron through specific ion channels in its plasma membrane.

Parts of a Neuron

Most neurons have three parts: (1) **a cell body**, (2) dendrites, and (3) **an axon**.



The **cell body,** also known as the **perikaryon or soma**, contains a **nucleus** surrounded by **cytoplasm** that includes typical cellular organelles such as lysosomes, mitochondria, and a Golgi complex. Neuronal cell bodies also contain free ribosomes and prominent clusters of rough endoplasmic reticulum, termed Nissl bodies. The ribosomes are the sites of protein synthesis. Newly synthesized proteins produced by Nissl bodies are used to replace cellular components as material for growth of neurons and to regenerate damaged axons in the PNS.

A **nerve fiber** is a general term for any neuronal process (extension) that emerges from the cell body of a neuron. Most neurons have two kinds of processes: **multiple dendrites and a single axon**.

Dendrites are the receiving or input portions of a neuron. Their cytoplasm contains Nissl bodies, mitochondria, and other organelles.

The single **axon** of a neuron propagates nerve impulses toward another neuron, a muscle fiber, or a gland cell.

An axon often joins the cell body at a cone-shaped elevation called the **axon hillock.**

The part of the axon closest to the axon hillock is the **initial segment.** In most neurons, nerve impulses arise at the junction of the axon hillock and the initial segment, an area called the **trigger zone,** from which they travel along the axon to their destination. An axon contains mitochondria, microtubules, and neurofibrils. The cytoplasm of an axon, called **axoplasm,** is surrounded by a plasma membrane known as the **axolemma.** Along the length of an axon, side branches called **axon collaterals** may branch off, typically at a right angle to the axon.

The axon and its collaterals end by dividing into many fine processes called **axon terminals (telodendria).**

SYNAPSES

Neurons that transmit impulses to other neurons do not actually touch one another. The small gap or space between the axon of one neuron and the dendrites or cell body of the next neuron is called the **synapse**. Within the synaptic knob (terminal end) of the presynaptic axon is a chemical **neurotransmitter** that is released into the synapse by the arrival of an electrical nerve impulse. The neurotransmitter diffuses across the synapse, combines with specific receptor sites on the cell membrane of the postsynaptic neuron, and there generates an electrical impulse that is, in turn, carried by this neuron's axon to the next synapse, and so forth.

CLASSIFICATION OF NEURONS

Both structural and functional features are used to classify the various neurons in the body.

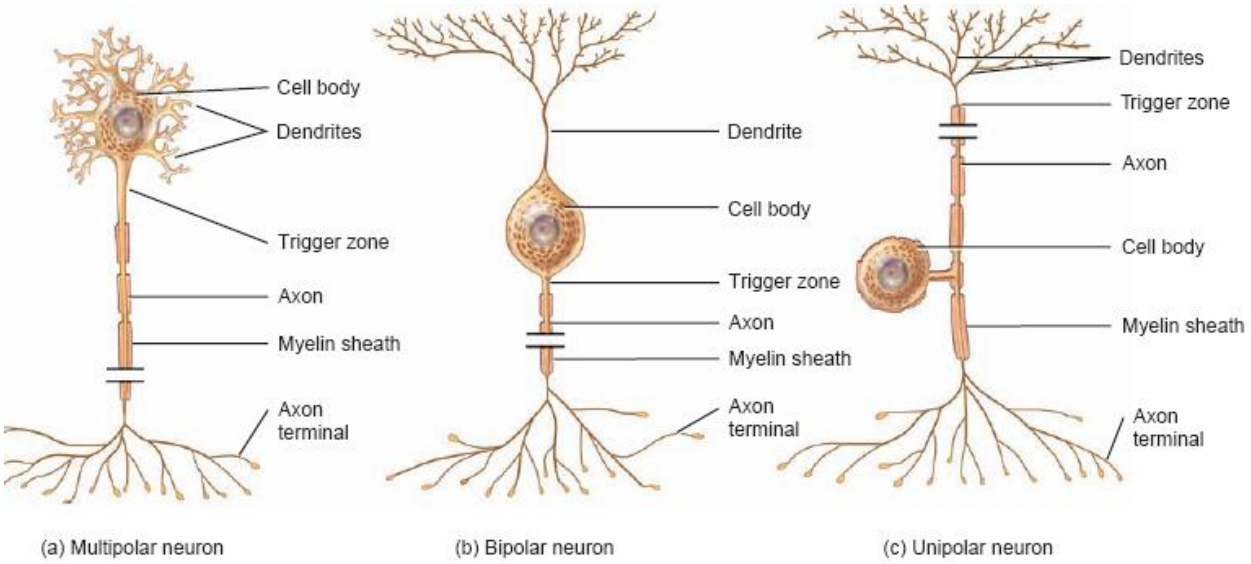
Structural classification:

Structurally, neurons are classified according to the number of processes extending from the cell body.

1. Multipolar neurons usually have several dendrites and one axon. Most neurons in the brain and spinal cord are of this type.

2. Bipolar neurons have one main dendrite and one axon. They are found in the retina of the eye, in the inner ear, and in the olfactory area of the brain.

3. Unipolar neurons have dendrites and one axon that are fused together to form a continuous process that emerges from the cell body. The dendrites of most unipolar neurons function as **sensory receptors** that detect a sensory stimulus such as touch, pressure, pain, or thermal stimuli. The trigger zone for nerve impulses in a unipolar neuron is at the junction of the dendrites and axon. The impulses then propagate toward the synaptic end bulbs. The cell bodies of most unipolar neurons are located in the ganglia of spinal and cranial nerves.



(a) Multipolar neuron (b) Bipolar neuron (c) Unipolar neuron

Functional classification:

Functionally, neurons are classified according to the direction in which the nerve impulse (action potential) is conveyed with respect to the CNS.

1. Sensory or **afferent neurons:** either contain sensory receptors at their distal ends (dendrites) or are located just after sensory receptors that are separate cells. Once an appropriate stimulus activates a sensory receptor, the sensory neuron forms an action

potential in its axon and the action potential is conveyed **into** the CNS through cranial or spinal nerves. Most sensory neurons are unipolar in structure.

2. Motor or **efferent neurons** convey action potentials **away** from the CNS to **effectors** (muscles and glands) in the periphery (PNS) through cranial or spinal nerves. Most motor neurons are multipolar in structure.

3. Interneurons or **association neurons** are mainly located within the CNS between sensory and motor neurons. Interneurons integrate (process) incoming sensory information from sensory neurons and then elicit a motor response by activating the appropriate motor neurons. Most interneurons are multipolar in structure.

NEUROGLIA

Neuroglia or **glia** make up about half the volume of the CNS. Generally, neuroglia are smaller than neurons, and they are 5 to 50 times more numerous. In contrast to neurons, glia do not generate or propagate action potentials, and they can multiply and divide in the mature nervous system. In cases of injury or disease, neuroglia multiply to fill in the spaces formerly occupied by neurons. Brain tumors derived from glia, called **gliomas,** tend to be highly malignant and to grow rapidly.

Of the **six types of neuroglia**, **four**: astrocytes, oligodendrocytes, microglia, and ependymal cells are found only in the CNS. The remaining **two types**: Schwann cells and satellite cells are present in the PNS.

NEUROGLIA OF THE CNS

Neuroglia of the CNS can be classified on the basis of size, cytoplasmic processes, and intracellular organization into four types: astrocytes, oligodendrocytes, microglia, and ependymal cells.

ASTROCYTES

The functions of astrocytes include the following:

(1) Astrocytes contain microfilaments that give them considerable strength, which enables them to support neurons.

(2) Processes of astrocytes wrapped around blood capillaries isolate neurons of the CNS from various potentially harmful substances in blood by secreting chemicals that maintain the unique selective permeability characteristics of the endothelial cells of the capillaries. In

effect, the endothelial cells create a *blood-brain barrier*, which restricts the movement of substances between the blood and interstitial fluid of the CNS.

(3) In the embryo, astrocytes secrete chemicals that appear to regulate the growth, migration, and interconnection among neurons in the brain.

(4) Astrocytes help to maintain the appropriate chemical environment for the generation of nerve impulses.

(5) Astrocytes may also play a role in learning and memory by influencing the formation of neural synapses.

OLIGODENDROCYTES

Oligodendrocyte processes are responsible for forming and maintaining the myelin sheath around CNS axons. The **myelin sheath** is a multilayered lipid and protein covering around some axons that insulates them and increases the speed of nerve impulse conduction. Such axons are said to be **myelinated.**

MICROGLIA

Microglia function as phagocytes. Like tissue macrophages, they remove cellular debris formed during normal development of the nervous system and phagocytize microbes and damaged nervous tissue.

EPENDYMAL CELLS

These cells line the ventricles of the brain and central canal of the spinal cord. Functionally, ependymal cells produce, possibly monitor, and assist in the circulation of cerebrospinal fluid. They also form the blood-cerebrospinal fluid barrier.

NEUROGLIA OF THE PNS

Neuroglia of the PNS completely surround axons and cell bodies. The two types of glial cells in the PNS are Schwann cells and satellite cells.

SCHWANN CELLS

These cells encircle PNS axons. Like oligodendrocytes, they form the myelin sheath around axons. Schwann cells participate in axon regeneration, which is more easily accomplished in the PNS than in the CNS.

SATELLITE CELLS

These flat cells surround the cell bodies of neurons of PNS ganglia. Besides providing structural support, **satellite cells** regulate the exchanges of materials between neuronal cell bodies and interstitial fluid.

MYELINATION

Axons surrounded by a multilayered lipid and protein covering, called the myelin sheath, are said to be myelinated. The sheath electrically insulates the axon of a neuron and increases the speed of nerve impulse conduction. Axons without such a covering are said to be **unmyelinated**.

Two types of neuroglia produce myelin sheaths: Schwann cells (in the PNS) and oligodendrocytes (in the CNS).

The inner portion, consisting of up to 100 layers of **Schwann cell membrane**, is the myelin sheath. **The outer** nucleated cytoplasmic layer of the Schwann cell, which encloses the myelin sheath, is the **neurolemma (sheath of Schwann).**

A neurolemma is found only around axons in the PNS.

When an axon is injured, the neurolemma aids regeneration by forming a regeneration tube that guides and stimulates regrowth of the axon. Gaps in the myelin sheath, called **nodes of Ranvier** appear at intervals along the axon.

In the CNS, an oligodendrocyte myelinates parts of several axons.

A neurolemma is not present, Nodes of Ranvier are present, but they are fewer in number.

Axons in the CNS display little regrowth after injury. This is thought to be due, in part, to the absence of a neurolemma, and in part to an inhibitory influence exerted by the oligodendrocytes on axon regrowth.

The amount of myelin increases from birth to maturity, and its presence greatly increases the speed of nerve impulse conduction.

An infant's responses to stimuli are neither as rapid nor as coordinated as those of an older child or an adult, in part because myelination is still in progress during infancy.

COLLECTIONS OF NERVOUS TISSUE.

The components of nervous tissue are grouped together in a variety of ways. **Neuronal cell bodies** are often grouped together in **clusters**. The **axons** of neurons are usually grouped together in **bundles**. In addition, widespread regions of nervous tissue are grouped together as either **gray matter or white matter.**

Clusters of Neuronal Cell Bodies

A **ganglion** (plural is ganglia) refers to a cluster of neuronal cell bodies located in the *PNS*. As mentioned earlier, ganglia are closely associated with cranial and spinal nerves. By contrast, a **nucleus** is a cluster of neuronal cell bodies located in the *CNS*.

Bundles of Axons

A **nerve** is a bundle of axons that is located in the *PNS*. Cranial nerves connect the brain to the periphery, whereas spinal nerves connect the spinal cord to the periphery. A **tract** is a bundle of axons that is located in the *CNS*. Tracts interconnect neurons in the spinal cord and brain.

Gray and White Matter

In a freshly dissected section of the brain or spinal cord, some regions look **white** and glistening, and others appear **gray**.

White matter is composed primarily of myelinated axons. The whitish color of myelin gives white matter its name.

The **gray matter** of the nervous system contains neuronal cell bodies, dendrites, unmyelinated axons, axon terminals, and neuroglia. It appears grayish, rather than white, because the Nissl bodies impart a gray color and there is little or no myelin in these areas. Blood vessels are present in both white and gray matter.

In the spinal cord, the white matter surrounds an inner core of gray matter and is shaped like a butterfly or the letter *H*;

In the brain, a thin shell of gray matter covers the surface of the largest portions of the brain, the cerebrum and cerebellum.

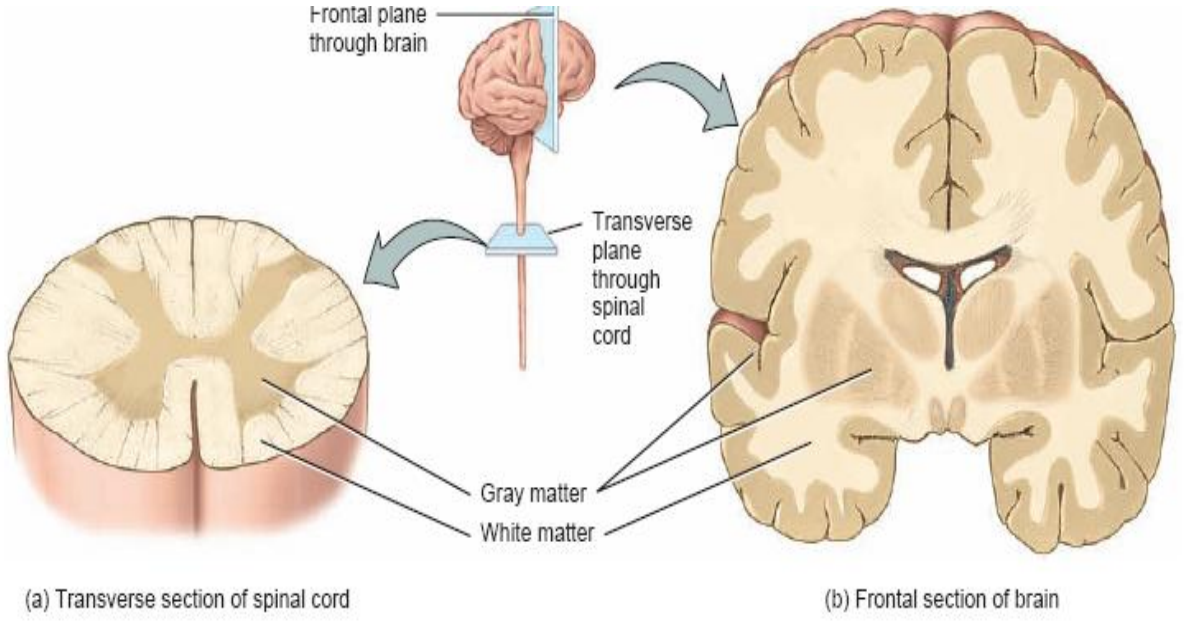


Figure: Distribution of gray matter and white matter in the spinal cord and brain.

5.4 ORGANISATION OF NERVOUS SYSTEM

The nervous system consists of two main subdivisions: **the central nervous system and the peripheral nervous system.**

5.4.1 CENTRAL NERVOUS SYSTEM

The **central nervous system (CNS)** consists of the brain and spinal cord. The CNS processes many different kinds of incoming sensory information. It is also the source of thoughts, emotions, and memories. Most nerve impulses that stimulate muscles to contract and glands to secrete originate in the CNS.

5.4.2 PERIPHERAL NERVOUS SYSTEM

The **peripheral nervous system (PNS)** includes all nervous tissue outside the CNS Components of the PNS include cranial nerves and their branches, spinal nerves and their branches, ganglia, and sensory receptors.

The PNS may be subdivided further into a **somatic nervous system (SNS)**, an **autonomic nervous system (ANS)**, and an **enteric nervous system (ENS)**.

The **SNS** consists of:

(1) **sensory neurons** that convey information from somatic receptors in the head, body wall, and limbs and from receptors for the special senses of vision, hearing, taste, and smell to the CNS and

(2) **motor neurons** that conduct impulses from the CNS to **skeletal muscles** only. Because these motor responses can be consciously controlled, the action of this part of the PNS is **voluntary**.

The **ANS** consists of:

(1) **sensory neurons** that convey information from autonomic sensory receptors, located primarily in visceral organs such as the stomach and lungs, to the CNS, and

(2) **motor neurons** that conduct nerve impulses from the CNS to smooth muscle, cardiac muscle, and glands. Because its motor responses are not normally under conscious control, the action of the ANS is **involuntary**. The motor part of the ANS consists of two branches, the **sympathetic division** and the **parasympathetic division.** With a few exceptions, effectors receive nerves from both divisions, and usually the two divisions have opposing actions. For example, sympathetic neurons increase heart rate, and parasympathetic neurons slow it down. In general, the sympathetic division helps support exercise or emergency actions, so-called "fight-or-flight" responses, and the parasympathetic division takes care of "rest-and-digest" activities.

The operation of the **ENS**, the "brain of the gut," is involuntary.

Once considered part of the ANS, the ENS consists of approximately 100 million neurons in enteric plexuses that extend most of the length of the gastrointestinal (GI) tract. Many of the neurons of the enteric plexuses function independently of the ANS and CNS to some extent, although they also communicate with the CNS via sympathetic and parasympathetic neurons **Sensory neurons** of the ENS monitor chemical changes within the GI tract as well as the stretching of its walls.

Enteric motor neurons govern contraction of GI tract smooth muscle to propel food through the GI tract, secretions of the GI tract organs such as acid from the stomach, and activity of GI tract endocrine cells, which secrete hormones.

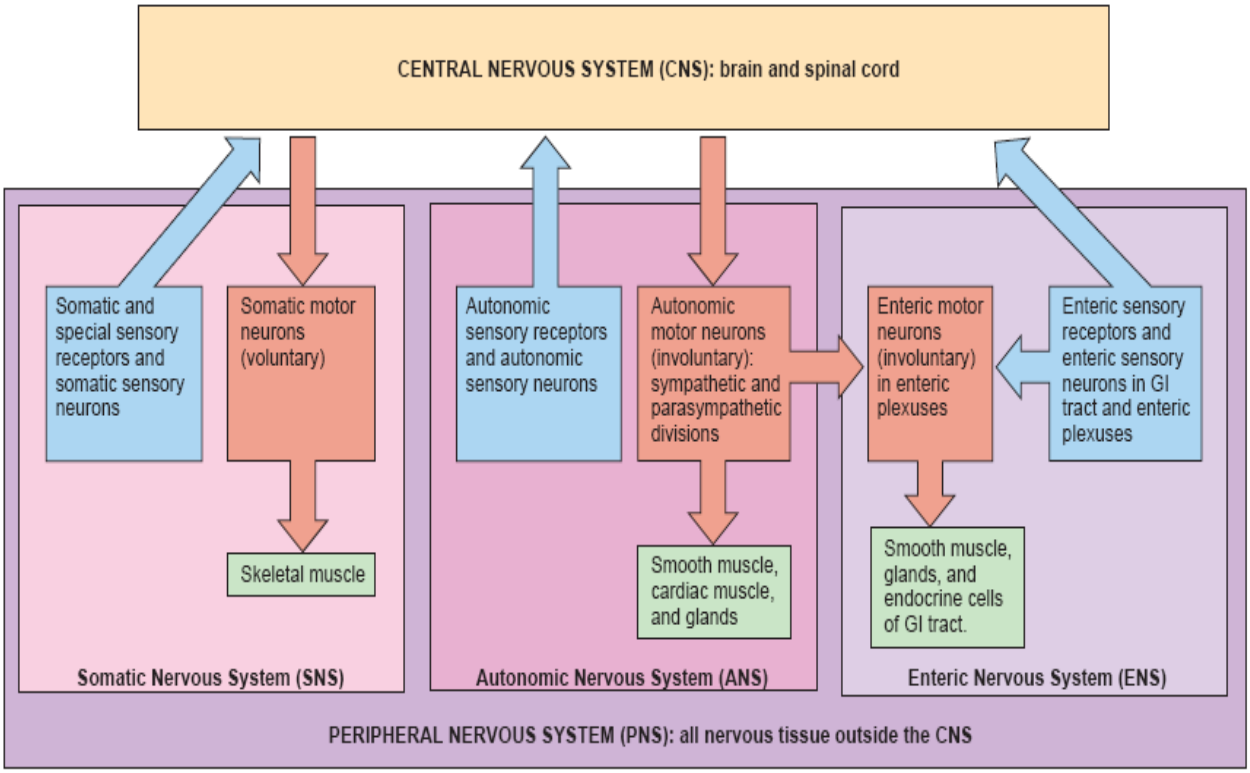


Figure: Organization of the nervous system.

SPINAL CORD ANATOMY.

Protective stractures

Two types of connective tissue coverings: **bony vertebrae** and tough, connective tissue **meninges**, plus a **cushion** of cerebrospinal fluid (produced in the brain) surround and protect the delicate nervous tissue of the spinal cord.

Vertebral Column

The spinal cord is located within the **vertebral canal** of the vertebral column. The surrounding vertebrae provide a strong protection for the enclosed spinal cord. The vertebral ligaments, meninges, and cerebrospinal fluid provide additional protection.

Meninges

The **meninges** are three connective tissue coverings that encircle the spinal cord and brain. The **spinal meninges** surround the spinal cord and are continuous with the **cranial meninges,** which encircle the brain.

The **most superficial** of the three spinal meninges is the **dura mater.** It forms a sac from the level of the foramen magnum in the occipital bone, where it is continuous with the dura mater of the brain, to the second sacral vertebra. The spinal cord is also protected by a cushion of fat and connective tissue located in the **epidural space,** a space between the dura mater and the wall of the vertebral canal.

The middle **meninx** is an avascular covering called the **arachnoid mater.** It is deep to the dura mater and is continuous with the arachnoid mater of the brain. Between the dura mater and the arachnoid mater is a thin **subdural space,** which contains interstitial fluid.

The innermost meninx is the **pia mater** a thin transparent connective tissue layer that adheres to the surface of the spinal cord and brain. **Within** the pia mater are **many blood vessels** that supply oxygen and nutrients to the spinal cord. Between the arachnoid mater and the pia mater is the **subarachnoid space,** which contains **cerebrospinal fluid** that serves as a shock absorber and suspension system for the spinal cord and brain.

External anatomy of spinal cord.

In adults, it extends from the medulla oblongata, the inferior part of the brain, to the superior border of the second lumbar vertebra. In newborn infants, it extends to the third or fourth lumbar vertebra. During early childhood, both the spinal cord and the vertebral column grow longer as part of overall body growth.

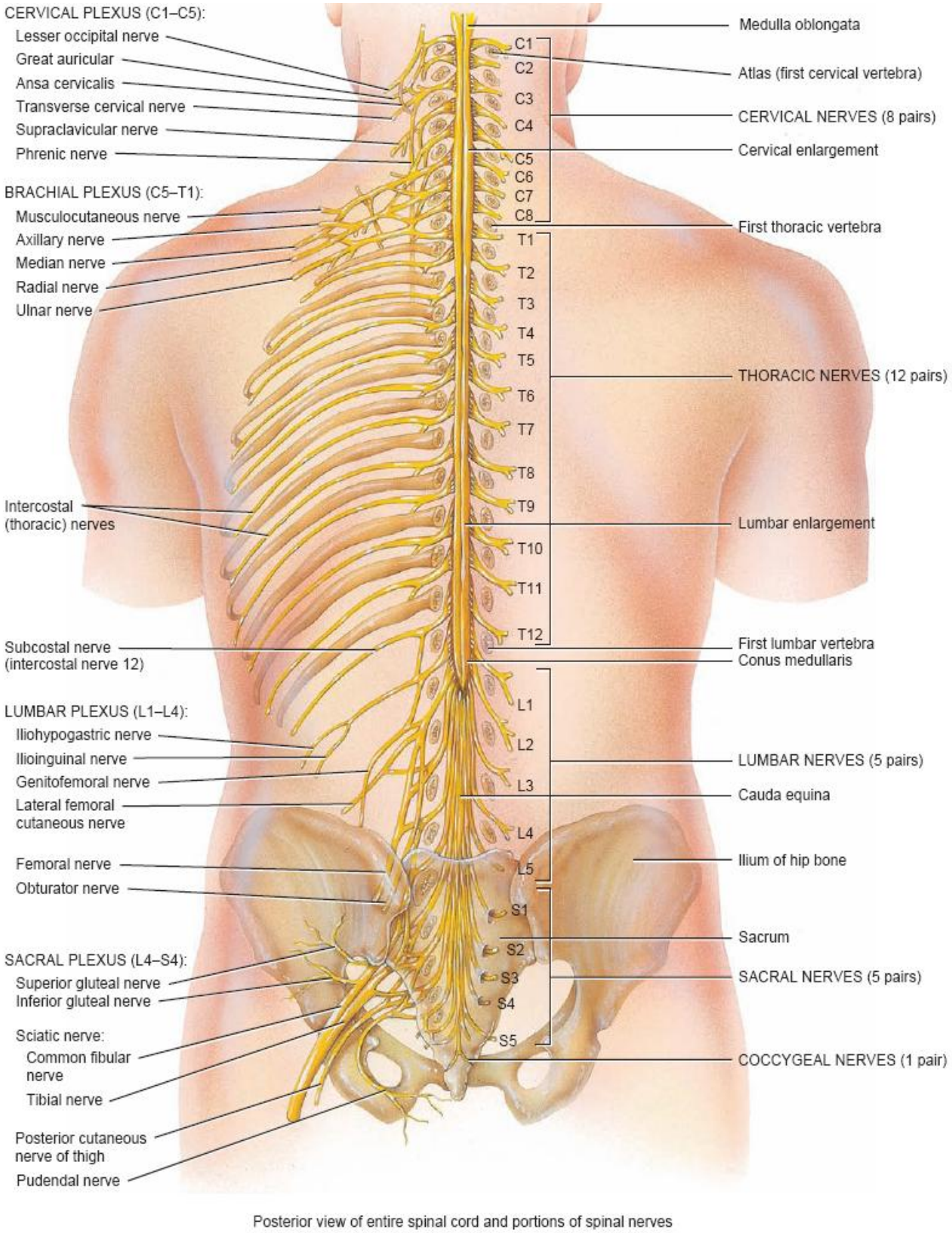
When the spinal cord is **viewed externally**, two conspicuous enlargements can be seen.
The s**uperior** enlargement, the **cervical enlargement,** extends from the fourth cervical vertebra to the first thoracic vertebra. Nerves **to and from** the upper limbs arise from the cervical enlargement.
The **inferior** enlargement, called the **lumbar enlargement,** extends from the ninth to the twelfth thoracic vertebra. Nerves to and from the lower limbs arise from the lumbar enlargement.
Inferior to the lumbar enlargement, the spinal cord terminates as a tapering, conical structure called the **conus medullaris** which ends at the level of the intervertebral disc between the first and second lumbar vertebrae in adults. Arising from the conus medullaris is the **filum**

terminale an extension of the pia mater that extends inferiorly and blends with the arachnoid mater and dura mater and anchors the spinal cord to the coccyx.

Spinal nerves are the paths of communication between the spinal cord and specific regions of the body. The spinal cord appears to be segmented because the **31 pairs** of spinal nerves emerge at regular intervals from intervertebral foramina.

Certainly, each pair of spinal nerves is said to arise from a **spinal segment**. Within the spinal cord there is no obvious segmentation but, for convenience, the naming of spinal nerves is based on the segment in which they are located. There are 8 pairs of **cervical nerves** represented C1–C8, 12 pairs of **thoracic nerves** (T1–T12), 5 pairs of **lumbar nerves** (L1–L5), 5 pairs of **sacral nerves** (S1–S5), and 1 pair of **coccygeal nerves** (Co1).

Because the spinal cord is shorter than the vertebral column, nerves that arise from the lumbar, sacral, and coccygeal regions of the spinal cord do not leave the vertebral column at the same level they exit the cord. **The roots** of these spinal nerves angle inferiorly in the vertebral canal from the end of the spinal cord like wisps of hair. Appropriately, the roots of these nerves are collectively named the **cauda equine** , meaning "horse's tail".



Posterior view of entire spinal cord and portions of spinal nerves

Figure: External anatomy of the spinal cord and the spinal nerves.

Two bundles of axons, called **roots,** connect each spinal nerve to a segment of the cord by **even** smaller bundles of axons called **rootlets**. The **posterior (dorsal) root** and rootlets

contain only sensory axons, which conduct nerve impulses from sensory receptors in the skin, muscles, and internal organs into the central nervous system. Each posterior root has a swelling, the **posterior (dorsal) root ganglion,** which contains the cell bodies of sensory neurons. The **anterior (ventral) root** and rootlets contain axons of motor neurons, which conduct nerve impulses from the CNS to effectors (muscles and glands).

Internal anatomy of the spinal cord

A freshly dissected section of the spinal cord reveals regions of **white matter** that surround an inner core of gray matter.

The white matter of the spinal cord consists primarily of bundles of myelinated axons of neurons. Two grooves penetrate the white matter of the spinal cord and divide it into right and left sides. The **anterior median fissure** is a wide groove on the anterior (ventral) side. The **posterior median sulcus** is a narrow furrow on the posterior (dorsal) side.

The gray matter of the spinal cord is shaped like the letter H or a butterfly; it consists of dendrites and cell bodies of neurons, unmyelinated axons, and neuroglia.

The **gray commissure** forms the crossbar of the H. In the center of the gray commissure is a small space called the **central canal;** it extends the entire length of the spinal cord and is filled with **cerebrospinal fluid**. At its superior end, the central canal is continuous with the fourth ventricle (a space that contains cerebrospinal fluid) in the medulla oblongata of the brain. **Anterior** to the gray commissure is the **anterior (ventral) white commissure,** which connects the white matter of the right and left sides of the spinal cord.

The gray matter on each side of the spinal cord is subdivided into regions called **horns**.

The **posterior (dorsal) gray horns** contain cell bodies and axons of interneurons as well as axons of incoming sensory neurons.

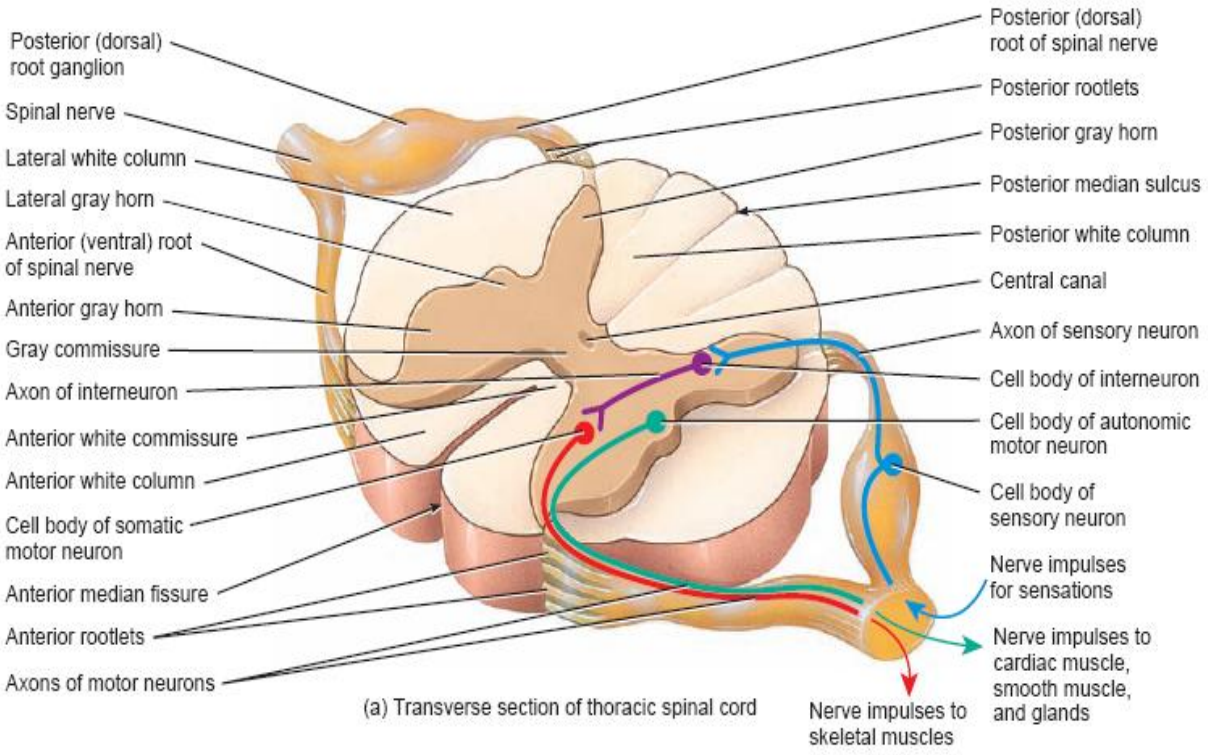
The **anterior (ventral) gray horns** contain *somatic motor nuclei*, which are clusters of cell bodies of somatic motor neurons that provide nerve impulses for contraction of skeletal muscles. Between the posterior and anterior gray horns are the **lateral gray horns,** which are present only in thoracic and upper lumbar segments of the spinal cord. The lateral gray horns contain *autonomic motor nuclei*, which are clusters of cell bodies of autonomic motor neurons that regulate the activity of cardiac muscle, smooth muscle, and glands.

The white matter of the spinal cord, like the gray matter, is organized into **regions.** The anterior and posterior gray horns divide the white matter on each side into three broad areas called **columns:** (1) **anterior (ventral) white columns,** (2) **posterior (dorsal) white**

columns, and (3) **lateral white columns**. Each column in turn contains **distinct bundles** of axons having a common origin or destination and carrying similar information.

These bundles, which may extend long distances up or down the spinal cord, are called **tracts.** Tracts are bundles of axons in the CNS, whereas nerves are bundles of axons in the PNS.

Sensory (ascending) tracts consist of axons that conduct nerve impulses toward the brain. Tracts consisting of axons that carry nerve impulses from the brain are called **motor (descending) tracts.** Sensory and motor tracts of the spinal cord are continuous with sensory and motor tracts in the brain.



Internal anatomy of the spinal cord: The organization of gray matter and white matter

The internal organization of the spinal cord allows sensory input and motor output to be processed by the spinal cord in the following way:

1. Sensory receptors detect a sensory stimulus.
2. Sensory neurons convey this sensory input in the form of nerve impulses along their axons, which extend from sensory receptors into the spinal nerve and then into the posterior root. From the posterior root, axons of sensory neurons may proceed along three possible paths: (see steps 3, 4, 5).

3. Axons of sensory neurons may extend into the white matter of the spinal cord and ascend to the brain as part of a sensory tract.
4. Axons of sensory neurons may enter the posterior gray horn and synapse with interneurons whose axons extend into the white matter of the spinal cord and then ascend to the brain as part of a sensory tract.
5. Axons of sensory neurons may enter the posterior gray horn and synapse with interneurons that in turn synapse with somatic motor neurons that are involved in spinal reflex pathways.
6. Motor output from the spinal cord to skeletal muscles involves somatic motor neurons of the anterior gray horn. Many somatic motor neurons are regulated by the brain. Axons from higher brain centers form motor tracts that descend from the brain into the white matter of the spinal cord. There they synapse with somatic motor neurons either directly or indirectly by first synapsing with interneurons that in turn synapse with somatic motor neurons.
7. When activated, somatic motor neurons convey motor output in the form of nerve impulses along their axons, which sequentially pass through the anterior gray horn and anterior root to enter the spinal nerve. From the spinal nerve, axons of somatic motor neurons extend to skeletal muscles of the body.
8. Motor output from the spinal cord to cardiac muscle, smooth muscle, and glands involves autonomic motor neurons of the lateral gray horn. When activated, autonomic motor neurons convey motor output in the form of nerve impulses along their axons, which sequentially pass through the lateral gray horn, anterior gray horn, and anterior root to enter the spinal nerve.
9. From the spinal nerve, axons of autonomic motor neurons from the spinal cord synapse with another group of autonomic motor neurons located in the peripheral nervous system (PNS). The axons of this second group of autonomic motor neurons in turn synapse with cardiac muscle, smooth muscle, and glands.

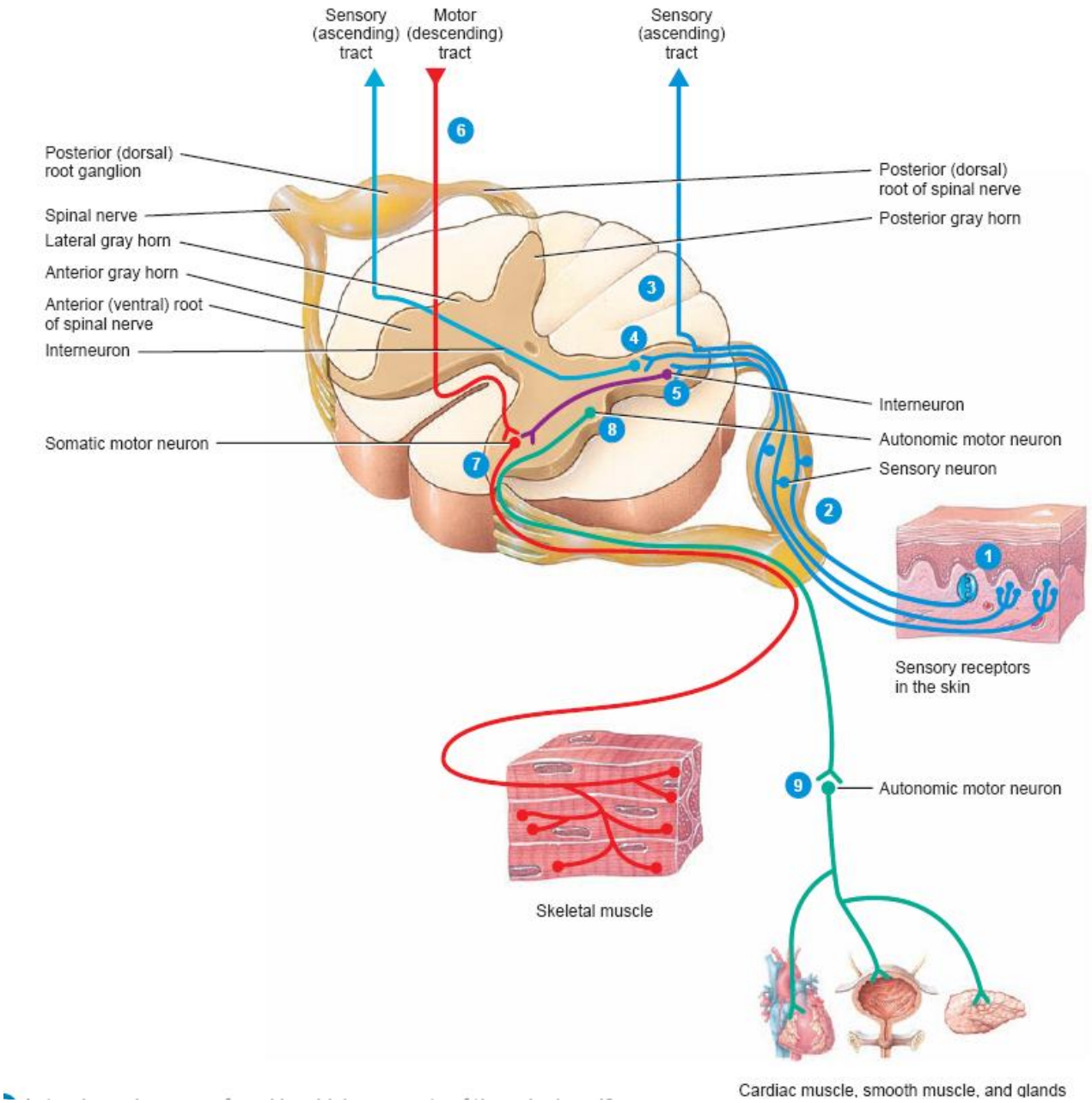


Figure: Processing of sensory input and motor output by the spinal cord.

SPINAL NERVES

Spinal nerves and the nerves that branch from them are part of the peripheral nervous system (PNS). They connect the CNS to sensory receptors, muscles, and glands in all parts of the body.

The 31 pairs of spinal nerves are named and numbered according to the region and level of the vertebral column from which they emerge.

As noted earlier, a typical spinal nerve has two connections to the cord: a posterior root and an anterior root.

The posterior and anterior roots unite to form a spinal nerve at the intervertebral foramen. Because the posterior root contains sensory axons and the anterior root contains motor axons, a spinal nerve is classified as a **mixed nerve.**

Distribution of spinal nerves.

Branches

A short distance after passing through its intervertebral foramen, a spinal nerve divides into several branches. These branches are known as **rami** (branches).

The **posterior (dorsal) ramus** serves the deep muscles and skin of the posterior surface of the trunk.

The **anterior (ventral) ramus** serves the muscles and structures of the upper and lower limbs and the skin of the lateral and anterior surfaces of the trunk.

In addition to posterior and anterior rami, spinal nerves also give off a **meningeal branch.** This branch reenters the vertebral cavity through the intervertebral foramen and supplies the vertebrae, vertebral ligaments, blood vessels of the spinal cord, and meninges.

Other branches of a spinal nerve are the **rami communicantes**, components of the autonomic nervous system.

Plexuses

Axons from the anterior rami of spinal nerves, except for thoracic nerves T2–T12, do not go directly to the body structures they supply. Instead, they form networks on both the left and right sides of the body by joining with various numbers of axons from anterior rami of adjacent nerves. Such a network of axons is called a **plexus** (braid or network). The principal plexuses are the **cervical plexus, brachial plexus, lumbar plexus,** and **sacral plexus.** A smaller **coccygeal plexus** is also present. Emerging from the plexuses are nerves bearing names that are often descriptive of the general regions they serve or the course they take. Each of the nerves in turn may have several branches named for the specific structures they innervate.

The anterior rami of spinal nerves T2–T12 are called **intercostal** or **thoracic nerves** and do not enter into the formation of plexuses.

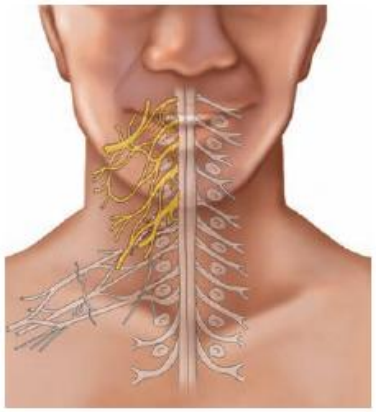
These nerves directly connect to the structures they supply

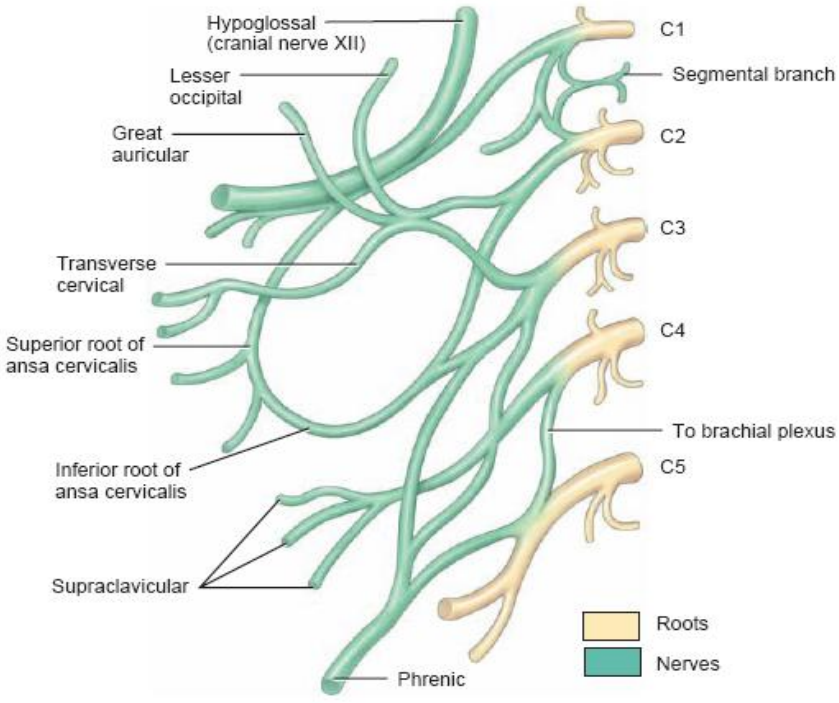
in the intercostal spaces. The anterior ramus of nerve **T2** innervates the intercostals muscles of the second intercostal space and supplies the skin of the axilla and posteromedial aspect of the arm. Nerves **T3–T6** extend along the costal grooves of the ribs and then to the intercostal muscles and skin of the anterior and lateral chest wall. Nerves **T7–T12** supply the intercostal muscles and abdominal muscles, along with the overlying skin. The **posterior rami** of the intercostal nerves supply the deep back muscles and skin of the posterior aspect of the thorax.

Cervical plexus

The **cervical plexus** (SER-vi-kul) is formed by the roots (anterior rami) of the first four cervical nerves (C1–C4), with contributions from C5. There is one on each side of the neck alongside the first four cervical vertebrae.

The cervical plexus supplies the skin and muscles of the head, neck, and superior part of the shoulders and chest. The phrenic nerves arise from the cervical plexuses and supply motor fibers to the diaphragm. Branches of the cervical plexus also run parallel to two cranial nerves, the accessory (XI) nerve and hypoglossal (XII) nerve.





Origin of cervical plexus

Brachial plexus

The roots (anterior rami) of spinal nerves C5–C8 and T1 form the **brachial plexus** which extends inferiorly and laterally on either side of the last four cervical and first thoracic vertebrae.

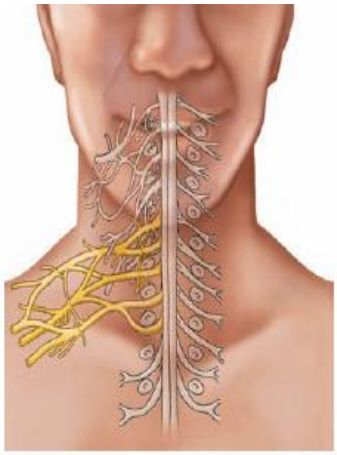
The roots of several spinal nerves unite to form **trunks** in the inferior part of the neck. These are the **superior, middle, and inferior trunks**. Posterior to the clavicles, the trunks divide into **divisions,** called the **anterior and posterior divisions.**

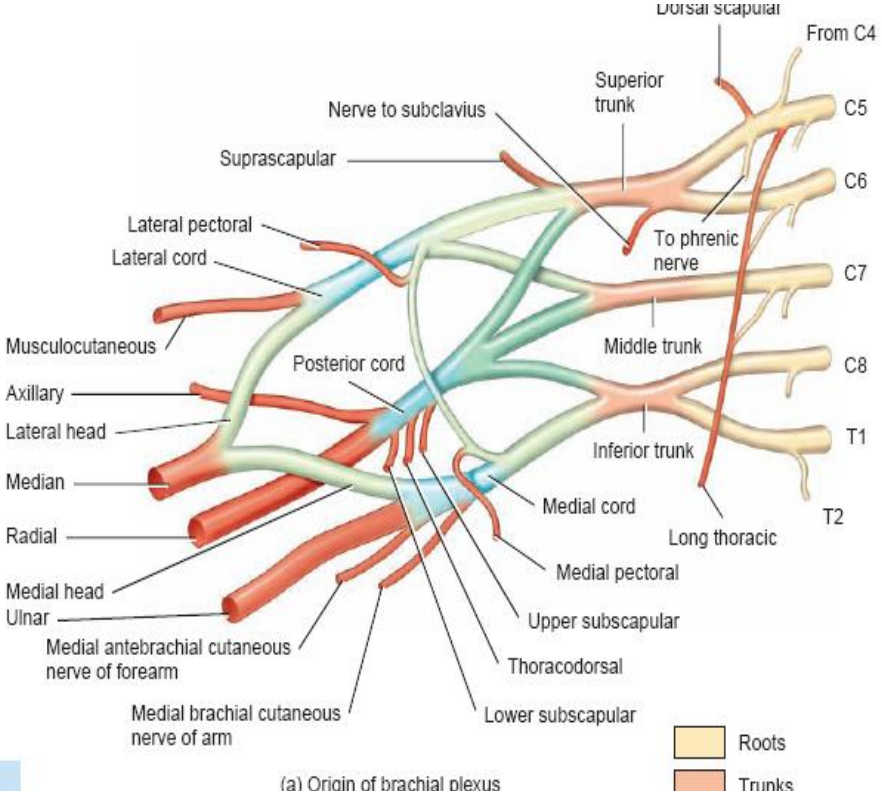
In the axillae, the divisions unite to form **cords** called the **lateral, medial, and posterior cords**.

The principal **nerves** of the brachial plexus branch from the cords.

The brachial plexus provides almost the entire nerve supply of the **shoulders and upper limbs**.

Five important nerves arise from the brachial plexus: (1) The **axillary nerve** supplies the deltoid and teres minor muscles. (2) The **musculocutaneous nerve** supplies the ante-rior muscles of the arm. (3) The **radial nerve** supplies the muscles on the posterior aspect of the arm and forearm. (4) The **median nerve** supplies most of the muscles of the anterior forearm and some of the muscles of the hand. (5) The **ulnar nerve** supplies the anteromedial muscles of the forearm and most of the muscles of the hand.

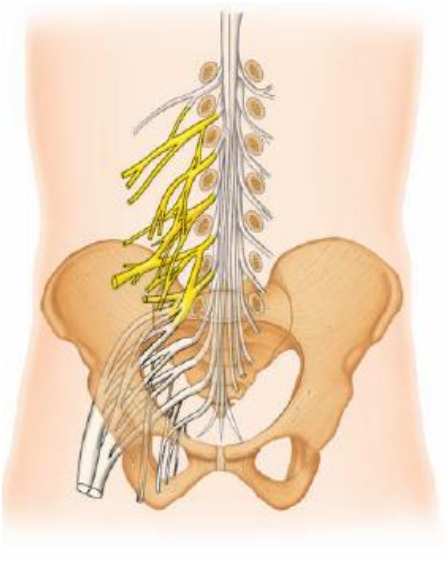


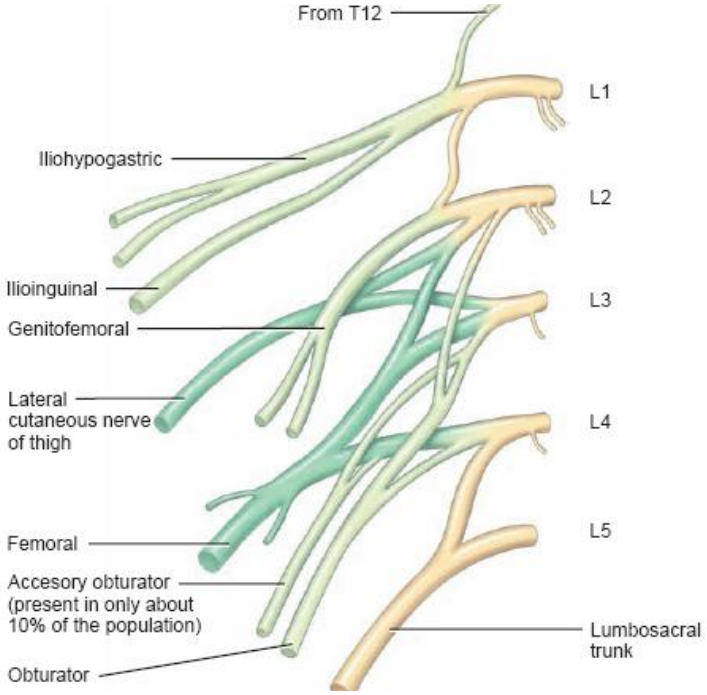


Lumbur plexus

The roots (anterior rami) of spinal nerves L1–L4 form the **lumbar plexus.**

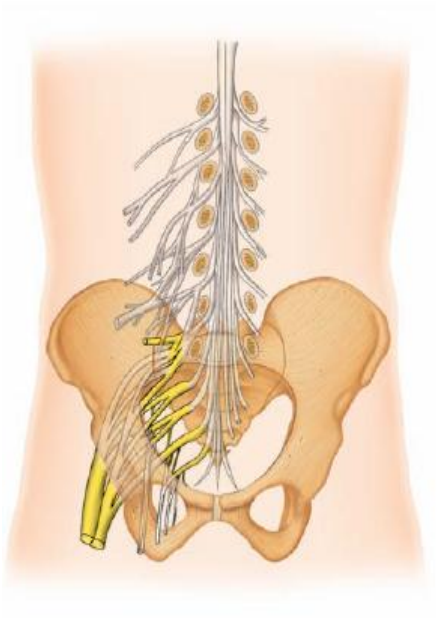
The lumbar plexus supplies the anterolateral abdominal wall, external genitals, and part of the lower limbs.

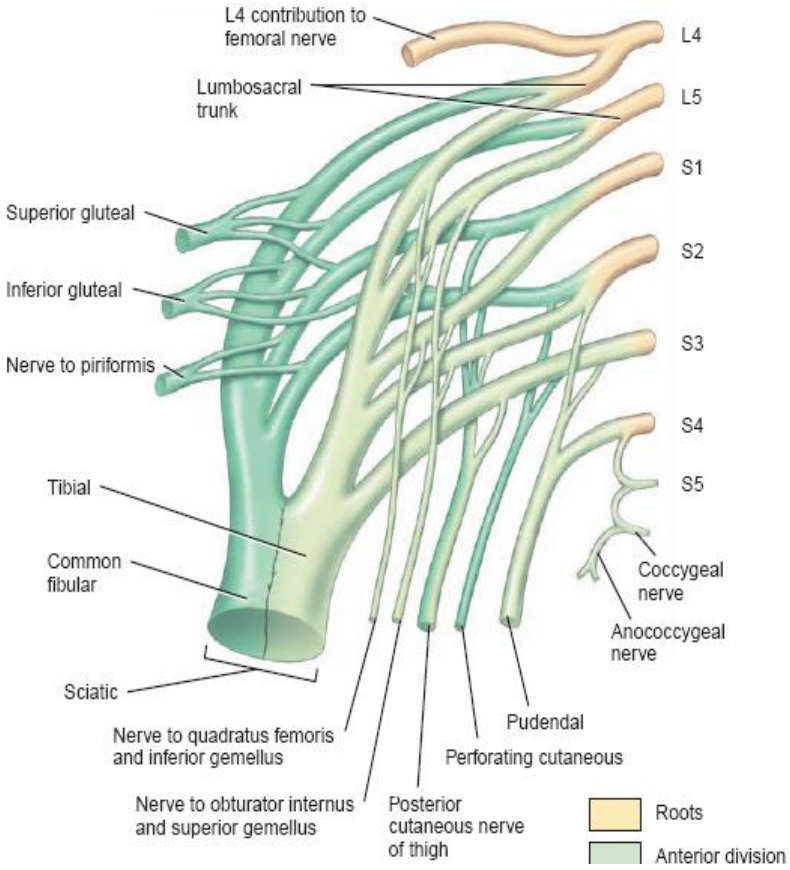




The roots (anterior rami) of spinal nerves L4–L5 and S1–S4 form the **sacral plexus**. This plexus is situated largely anterior to the sacrum. The sacral plexus supplies the buttocks, perineum, and lower limbs. The largest nerve in the body the sciatic nerve arises from the sacral plexus.

The roots (anterior rami) of spinal nerves S4–S5 and the coccygeal nerves form a small **coccygeal plexus,** which supplies a small area of skin in the coccygeal region.





Spinal cord physiology.

The spinal cord has **two principal functions** in maintaining homeostasis: **nerve impulse propagation and integration of information**. The *white matter tracts* in the spinal cord are highways for nerve impulse propagation. Sensory input travels along these tracts toward the brain (**ascending tracts**), and motor output travels from the brain along these tracts toward skeletal muscles and other effector tissues (**descending tracts**). By The *gray matter,* the spinal cord receives and integrates incoming and outgoing information.

Sensory and motor tracts

As noted previously, one of the ways the spinal cord promotes homeostasis is by conducting nerve impulses along tracts. Often, the name of a tract indicates its position in the white matter and where it begins and ends. For example, the anterior corticospinal tract is located in the *anterior* white column; it begins in the *cerebral cortex* (a region of the brain) and ends in the *spinal cord*. Notice that the location of the axon terminals comes last in the name. This

regularity in naming allows you to determine the direction of information flow along any tract named according to this convention.

The sensory information is integrated (processed) by interneurons in the spinal cord and brain. Responses to the integrative decisions are brought about by motor activities (muscular contractions and glandular secretions).

The cerebral cortex, the outer part of the brain, plays a major role in controlling precise voluntary muscular movements. Other brain regions provide important integration for regulation of automatic movements.

Motor output to skeletal muscles travels down the spinal cord in two types of descending pathways: **direct and indirect**.

The **direct pathways** convey nerve impulses that originate in the cerebral cortex and are destined to cause *voluntary* movements of skeletal muscles.

Indirect pathways convey nerve impulses from the brain stem to cause *automatic movements* that regulate muscle tone, posture, and balance, and orientation of the head and body.

Reflexes and reflexes arcs

The second way the spinal cord promotes homeostasis is by serving as an **integrating center** for some reflexes. A **reflex** is a fast, automatic, unplanned sequence of actions that occurs in response to a particular stimulus. Some reflexes are inborn, such as pulling your hand away from a hot surface before you even feel that it is hot. Other reflexes are learned or acquired.

When integration takes place in the spinal cord gray matter, the reflex is a **spinal reflex.** An **example** is the familiar patellar reflex (knee jerk). If integration occurs in the brain stem rather than the spinal cord, the reflex is called a **cranial reflex. An example** is the tracking movements of your eyes as you read this sentence.

They are probably most aware of **somatic reflexes,** which involve contraction of skeletal muscles.

The **autonomic (visceral) reflexes,** generally are not consciously perceived. They involve responses of smooth muscle, cardiac muscle, and glands. Body functions such as heart rate, digestion, urination, and defecation are controlled by the autonomic nervous system through autonomic reflexes.

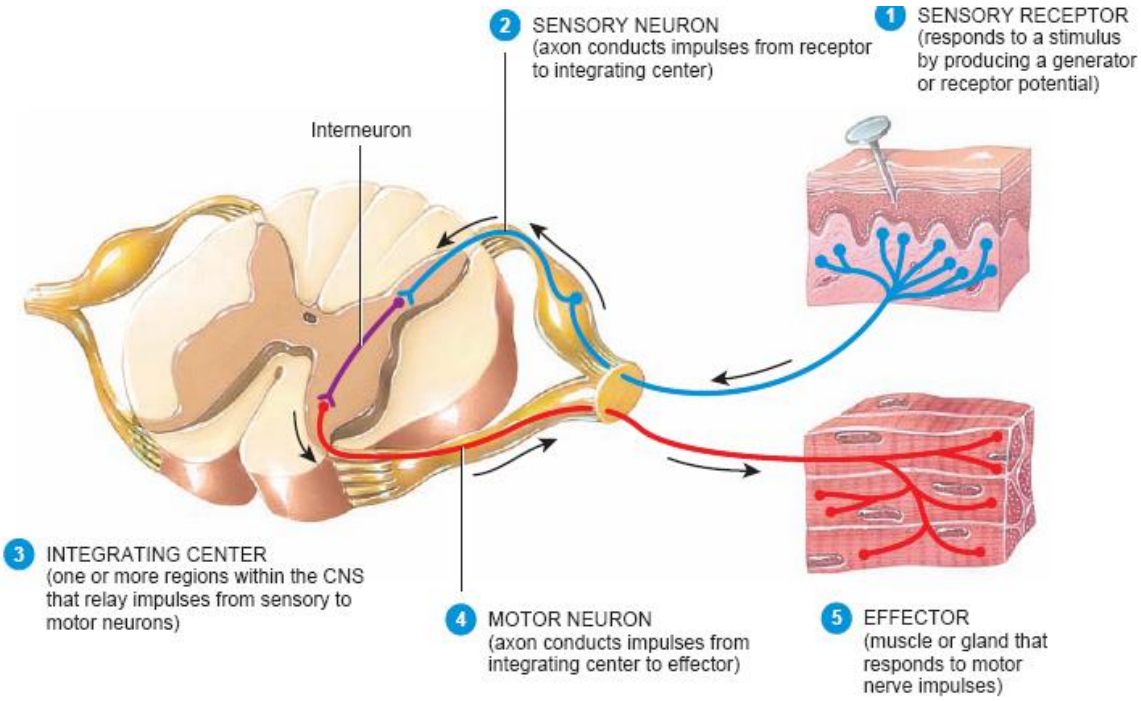
Nerve impulses propagating into, through, and out of the CNS follow specific pathways, depending on the kind of information, its origin, and its destination. The **pathway** followed by nerve impulses that produce a reflex is a **reflex arc (reflex circuit).**

A reflex arc includes the following five functional components

1. **Sensory receptor.** The distal end of a sensory neuron (dendrite) or an associated sensory structure serves as a sensory receptor. It responds to a specific **stimulus** which is a change in the internal or external environment by producing nerve impulse.
2. **Sensory neuron.** The nerve impulses propagate from the sensory receptor along the axon of the sensory neuron to the axon terminals, which are located in the gray matter of the spinal cord or brain stem.
3. **Integrating center.** One or more regions of gray matter within the CNS act as an integrating center. In the simplest type of reflex, the integrating center is a single synapse between a sensory neuron and a motor neuron. A reflex pathway having only one synapse in the CNS is termed a **monosynaptic reflex arc.** More often, the integrating center consists of one or more interneurons, which may relay impulses to other interneurons as well as to a motor neuron. A **polysynaptic reflex arc** involves more than two types of neurons and more than one CNS synapse.
4. **Motor neuron.** Impulses triggered by the integrating center propagate out of the CNS along a motor neuron to the part of the body that will respond.
5. **Effector.** The part of the body that responds to the motor nerve impulse, such as a muscle or gland, is the effector. Its action is called a reflex. If the effector is skeletal muscle, the reflex is a **somatic reflex.** If the effector is smooth muscle, cardiac muscle, or a gland, the reflex is an **autonomic (visceral) reflex.**

Because reflexes are normally so predictable, they provide useful information about the health of the nervous system and can greatly aid diagnosis of disease. Damage or disease anywhere along its reflex arc can cause a reflex to be absent or abnormal. For example, tapping the patellar ligament normally causes reflex extension of the knee joint. Absence of the patellar reflex could indicate damage of the sensory or motor neurons, or a spinal cord injury in the lumbar region. Somatic reflexes generally can be tested simply by tapping or stroking the body surface.

They are **four important somatic spinal reflexes**: the stretch reflex, the tendon reflex, the flexor (withdrawal) reflex, and the crossed extensor reflex.



General components of a reflex arc.

THE BRAIN AND CRANIAL NERVES

The brain contributes to homeostasis by receiving sensory input, integrating new and stored information, making decisions, and causing motor activities.

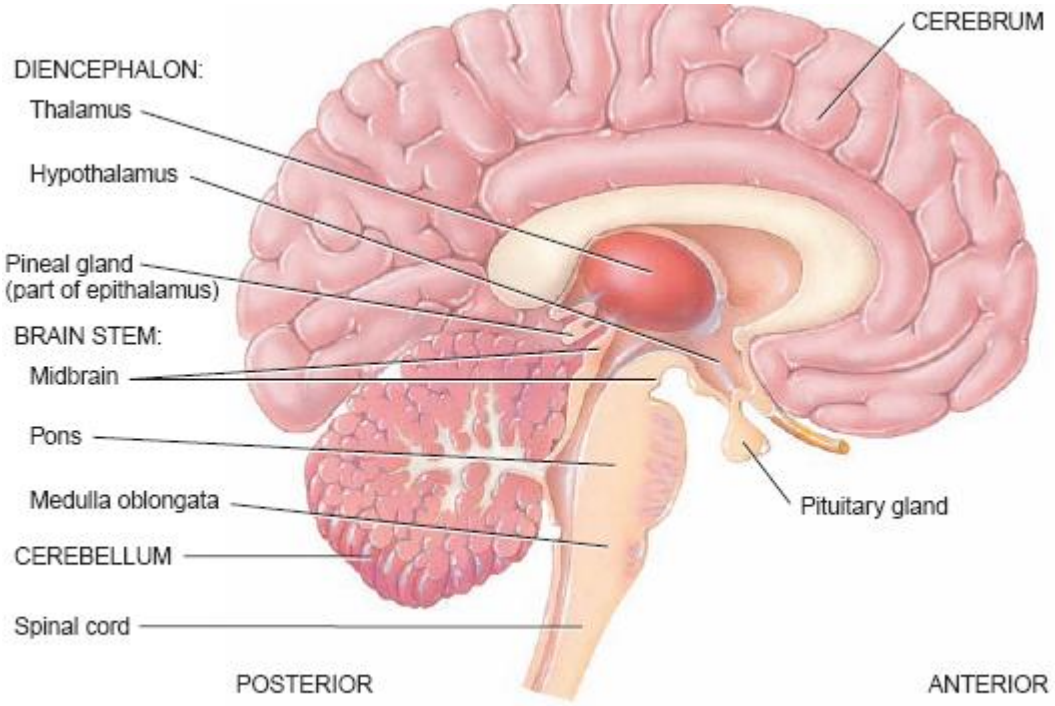
Major parts of the brain

The adult brain consists of four major parts: **brain stem, cerebellum, diencephalon, and cerebrum**.

The **brain stem** is continuous with the spinal cord and consists of the **medulla oblongata, pons, and midbrain.**

Posterior to the brain stem is the **cerebellum**.

Superior to the brain stem is the **diencephalon** which consists of the **thalamus, hypothalamus, and epithalamus**. Supported on the diencephalon and brain stem is the **cerebrum**, the largest part of the brain.



(a) Medial view of sagittal section

Protective coverings of the Brain

The cranium and the cranial meninges surround and protect the brain. The **cranial meninges** are continuous with the spinal meninges, have the same basic structure, and bear the same names: the outer **dura mater,** the middle **arachnoid mater,** and the inner **pia mater**

Three extensions of the dura mater separate parts of the brain. (1) The **falx cerebri** separates the two hemispheres (sides) of the cerebrum. (2) The **falx cerebelli** separates the two hemispheres of the cerebellum. (3) The **tentorium cerebelli** separates the cerebrum from the cerebellum.

Brain Blood Flow and the Blood–Brain Barrier

Blood flows to the brain mainly via the internal carotid and vertebral arteries; the internal jugular veins return blood from the head to the heart.

In an adult, the brain represents only 2% of total body weight, but consumes about 20% of the oxygen and glucose used even at rest. Neurons synthesize ATP almost exclusively from glucose via reactions that use oxygen. When activity of neurons and neuroglia increases in a region of the brain, blood flow to that area also increases. Even a brief slowing of brain blood flow may cause unconsciousness. Typically, an interruption in blood flow for 1 or 2 minutes

impairs neuronal function, and total deprivation of oxygen for about 4 minutes causes permanent injury.

The existence of a **blood–brain barrier (BBB)** protects brain cells from harmful substances and pathogens by preventing passage of many substances from blood into brain tissue.

A few water-soluble substances, such as glucose, cross the BBB by active transport.

Other substances, such as creatinine, urea, and most ions, cross the BBB very slowly. Still other substances, proteins and most antibiotic drugs, do not pass at all from the blood into brain tissue.

However, lipid-soluble substances, such as oxygen, carbon dioxide, alcohol, and most anesthetic agents, easily cross the blood–brain barrier. Trauma, certain toxins, and inflammation can cause a breakdown of the blood–brain barrier.

Cerebrospinal fluid.

Cerebrospinal fluid (CSF) is a clear, colorless liquid that protects the brain and spinal cord from **chemical and physical** injuries. It also carries oxygen, glucose, and other needed chemicals from the blood to neurons and neuroglia.

CSF continuously circulates through cavities in the brain and spinal cord and around the brain and spinal cord in the subarachnoid space.

Those cavities are **four** and are called **ventricles: two lateral ventricle, third ventricle and fourth ventricle.**

A **lateral ventricle** is located in each hemisphere of the cerebrum. The **third ventricle** is a narrow cavity along the midline superior to the hypothalamus and between the right and left halves of the thalamus. The **fourth ventricle** lies between the brain stem and the cerebellum.

The total volume of CSF is 80 to 150 mL in an adult. CSF contains glucose, proteins, lactic acid, urea, cations (Na_, K_, Ca2_, Mg2_), and anions (Cl_ and HCO3 _); it also contains some white blood cells.

The CSF contributes to homeostasis in **three main ways**:

1. ***Mechanical protection.*** CSF serves as a shock-absorbing medium that protects the delicate tissues of the brain and spinal cord from jolts that would otherwise cause them to hit the bony walls of the cranial cavity and vertebral canal. The fluid also buoys the brain so that it floats in the cranial cavity.

2. *Chemical protection.* CSF provides an optimal chemical environment for accurate neuronal signaling. Even minor changes in the ionic composition of CSF within the brain can seriously disrupt production of action potentials and postsynaptic potentials.

3. *Circulation.* CSF allows exchange of nutrients and waste products between the blood and nervous tissue.

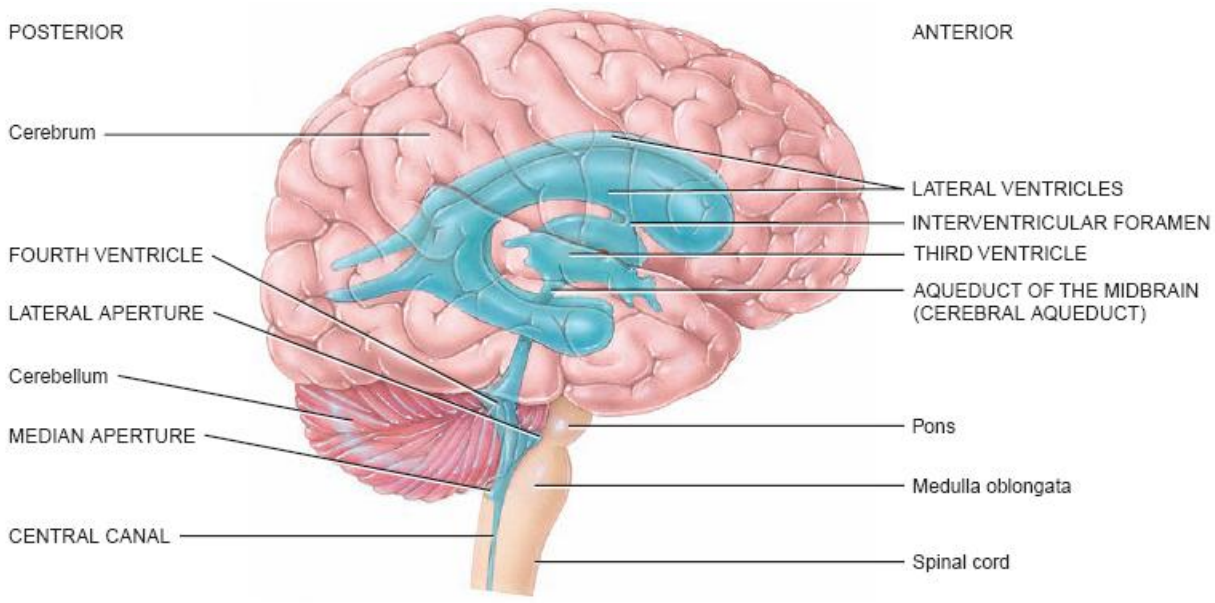
Formation of CSF in the ventricles

The sites of CSF production are the **choroid plexuses** (KO - royd - membrane like), networks of blood capillaries in the walls of the ventricles). The capillaries are covered by ependymal cells that form cerebrospinal fluid from blood plasma by filtration and secretion.

Because the ependymal cells are joined by tight junctions, materials entering CSF from choroid capillaries cannot leak between these cells; instead, they must pass through the ependymal cells. This **blood–cerebrospinal fluid barrier** permits certain substances to enter the CSF but excludes others, protecting the brain and spinal cord from potentially harmful bloodborne substances.

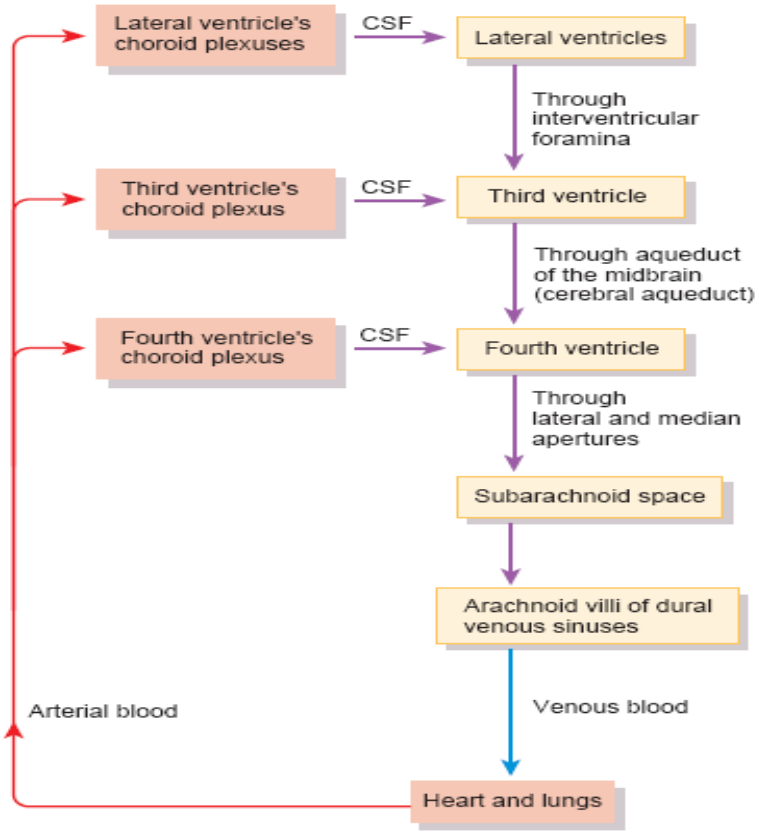
Circulation of CSF

The CSF formed in the choroid plexuses of each lateral ventricle flows into the third ventricle through two narrow, oval openings, the **interventricular foramina.** More CSF is added by the choroid plexus in the roof of the third ventricle. The fluid then flows through the **aqueduct of the midbrain (cerebral aqueduct),** which passes through the midbrain, into the fourth ventricle. The choroid plexus of the fourth ventricle contributes more fluid. CSF enters the subarachnoid space through three openings in the roof of the fourth ventricle: a **median aperture** and the paired **lateral apertures,** one on each side. CSF then circulates in the central canal of the spinal cord and in the subarachnoid space around the surface of the brain and spinal cord. CSF is gradually reabsorbed into the blood through **arachnoid villi,** fingerlike extensions of the arachnoid that project into the dural venous sinuses, especially the **superior sagittal sinus.**(A cluster of arachnoid villi is called an **arachnoid granulation.**) Normally, CSF is reabsorbed as rapidly as it is formed by the choroid plexuses, at a rate of about 20 mL/hr (480 mL/day). Because the rates of formation and reabsorption are the same, the pressure of CSF normally is constant.



Right lateral view of brain

Locations of ventricles within the brain. One interventricular foramen on each side connects a lateral ventricle to the third ventricle, and the aqueduct of the midbrain connects the third ventricle to the fourth ventricle.



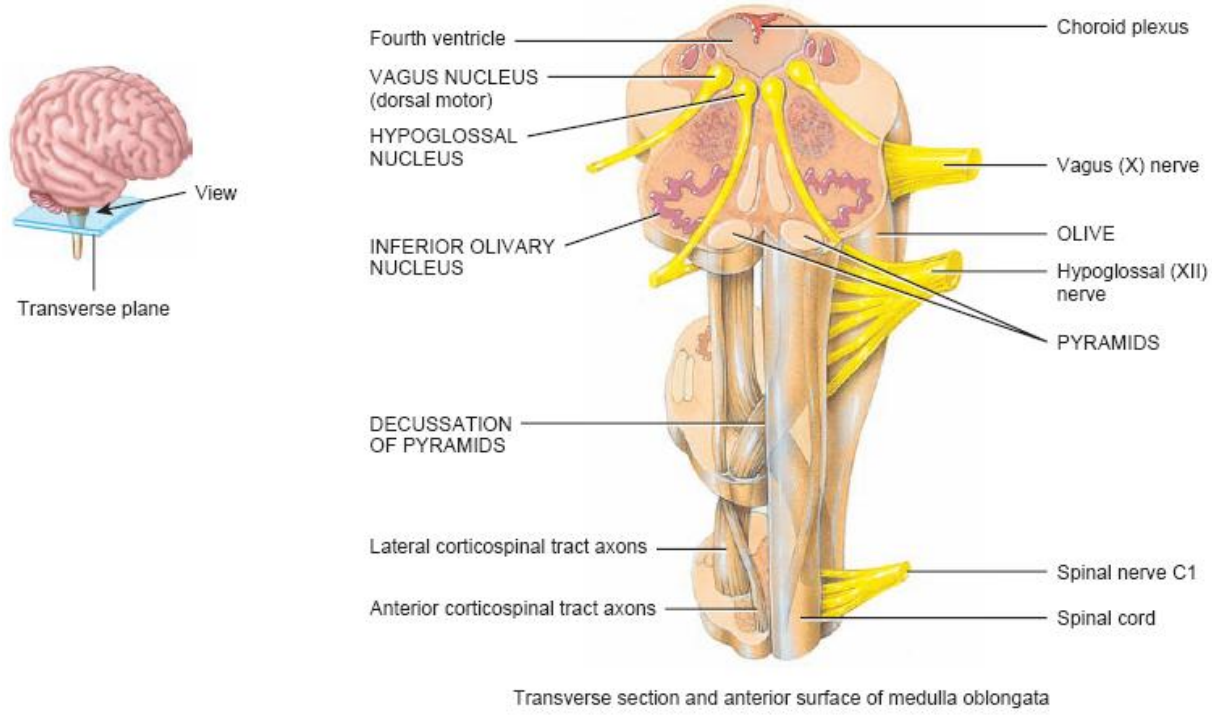
(d) Summary of the formation, circulation, and absorption of cerebrospinal fluid (CSF)

THE BRAIN STEM

The brain stem is the part of the brain between the spinal cord and the diencephalon. It consists of three structures: (1) **medulla oblongata, (2) pons, and (3) midbrain**. Extending through the brain stem is the reticular formation, a region of gray and white matter.

Medulla Oblongata

The **medulla oblongata** is continuous with the superior part of the spinal cord, it forms the inferior part of the brain stem. The medulla begins at the foramen magnum and extends to the inferior border of the pons.



Transverse section and anterior surface of medulla oblongata

Internal anatomy of the medulla oblongata

The medulla's white matter contains all sensory (ascending) tracts and motor (descending) tracts that extend between the spinal cord and other parts of the brain.

The medulla has some protrusions, called the **pyramids** formed by the large corticospinal tracts that control voluntary movements of the limbs and trunk.

Just superior to the junction of the medulla with the spinal cord, 90% of the axons in the left pyramid **cross t**o the right side, and 90% of the axons in the right pyramid **cross** to the left side. This crossing is called the **decussation of pyramids** and explains why each side of the brain controls voluntary movements on the **opposite** side of the body.

The medulla also contains several **nuclei**. (Recall that a nucleus is a collection of neuronal cell bodies within the CNS.)

Some of these nuclei control vital body functions. Examples of nuclei in the medulla that regulate vital activities include the **cardiovascular center** and the **medullary rhythmicity** area. The **cardiovascular center** regulates the rate and force of the heartbeat and the diameter of blood vessels. The **medullary rhythmicity area** of the **respiratory center** adjusts the basic rhythm of breathing.

Besides regulating heartbeat, blood vessel diameter, and the normal breathing rhythm, nuclei in the medulla also control reflexes for **vomiting, swallowing, sneezing, coughing, and hiccupping.**

Just lateral to each pyramid is an oval-shaped swelling called an **olive**. Within the olive is the **inferior olivary nucleus,** which receives input from the cerebral cortex, red nucleus of the midbrain, and spinal cord, it provides instructions that the cerebellum uses to make adjustments to muscle activity.

Nuclei associated with sensations of **touch, pressure, vibration, and conscious proprioception** are located in the posterior part of the medulla. These nuclei are the right and left **gracile nucleus** and **cuneate nucleus.**

The medulla also contains nuclei that are components of sensory pathways for gustation (taste), audition (hearing), and equilibrium (balance). Those are the **gustatory nucleus,** the **cochlear nuclei**, the **vestibular nuclei.**

Finally, the medulla contains nuclei associated with five pairs of cranial nerves vestibulocochlear (VIII) nerves, glossopharyngeal (IX) nerves, vagus (X) nerves, accessory (XI) nerves (cranial portion), and hypoglossal (XII) nerves.

Pons

The **pons** (bridge) lies directly superior to the medulla and anterior to the cerebellum. As its name implies, the pons is a **bridge** that connects different parts of the brain with one another. Like the medulla, the pons consists of **nuclei, sensory tracts, and motor tracts**. Signals for voluntary movements from motor areas of the cerebral cortex are relayed through several **pontine nuclei** into the cerebellum.

Along with the medulla, the pons contains **vestibular nuclei.**

Other nuclei in the pons are the **pneumotaxic area** and the **apneustic area** of the **respiratory center**. Together with the medullary rhythmicity area, the pneumotaxic and apneustic areas help control breathing.

The pons also contains nuclei associated with the following four pairs of cranial nerves: trigeminal (V) nerves, abducens (VI) nerves, facial (VII) nerves, and vestibulocochlear

(VIII) nerves.

Midbrain

The **midbrain** or **mesencephalon** extends from the pons to the diencephalon.

The aqueduct of the midbrain (cerebral aqueduct) passes through the midbrain, connecting the third ventricle above with the fourth ventricle below.

Like the medulla and the pons, the midbrain contains both **nuclei and tracts**.

The anterior part of the midbrain contains paired bundles of

axons known as the **cerebral peduncles** which consist of axons which conduct nerve impulses from motor areas in the cerebral cortex to the spinal cord, pons, and

medulla.

The posterior part of the midbrain, called the **tectum** (roof), contains four rounded elevations

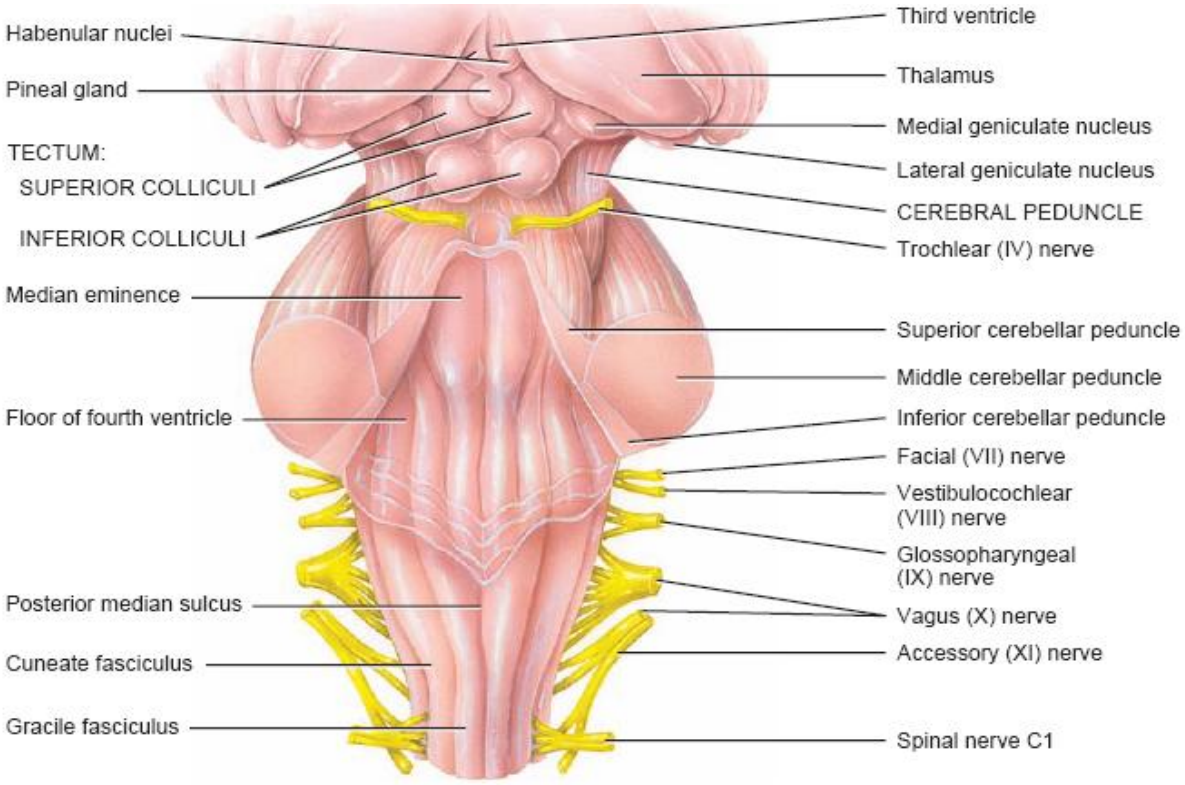
The two superior elevations, nuclei known as the **superior colliculi** serve as reflex centers for certain visual activities. The superior colliculi are also responsible for reflexes that govern movements of the head, eyes, and trunk in response to visual stimuli.

The two inferior elevations, the **inferior colliculi,** are part of the auditory pathway, relaying impulses from the receptors for hearing in the inner ear to the brain. These two nuclei are also reflex centers for the *startle reflex,* sudden movements of the head, eyes, and trunk that occur when you are surprised by a loud noise such as a gunshot.

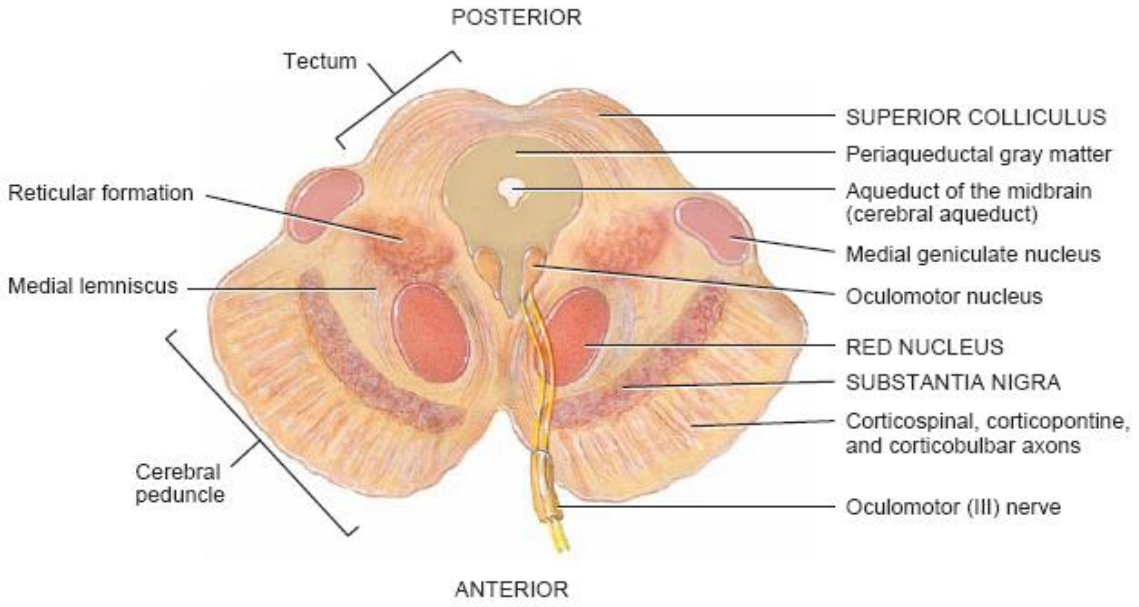
The midbrain contains several other nuclei, including the left and right **substantia nigra** which release dopamine and this help control subconscious muscle activities. Loss of these neurons is associated with **Parkinson disease**.

Also present are the left and right **red nuclei**. Axons from the cerebellum and cerebral cortex form synapses in the red nuclei, which help control some voluntary movements of the limbs.

Still other nuclei in the midbrain are associated with two pairs of cranial nerves: oculomotor (III) nerves and trochlear (IV) nerves.



(a) Posterior view of midbrain in relation to brain stem



(b) Transverse section of midbrain

Reticular formation

In addition to the well-defined nuclei already described, much of the brain stem consists of small clusters of neuronal cell bodies (gray matter) interspersed among small bundles of myelinated axons (white matter). The broad region where white matter and gray matter exhibit a netlike arrangement is known as the **reticular formation.**

It extends from the upper part of the spinal cord, throughout the brain stem, and into the lower part of the diencephalon. Neurons within the reticular formation have both ascending (sensory) and descending (motor) functions.

Part of the reticular formation, called the **reticular activating system (RAS),** consists of sensory axons that project to the cerebral cortex.

The RAS helps maintain consciousness and is active during awakening from sleep. For example, we awaken to the sound of an alarm clock, to a flash of lightning, or to a painful pinch because of RAS activity that arouses the cerebral cortex.

The reticular formation's **descending functions** are to help regulate posture and *muscle tone,* the slight degree of contraction in normal resting muscles.

9. List the functions of the reticular formation.

THE CEREBELLUM

The **cerebellum** occupies the inferior and posterior aspects of the cranial cavity.

The cerebellum is posterior to the medulla and pons and inferior to the posterior portion of the cerebrum.

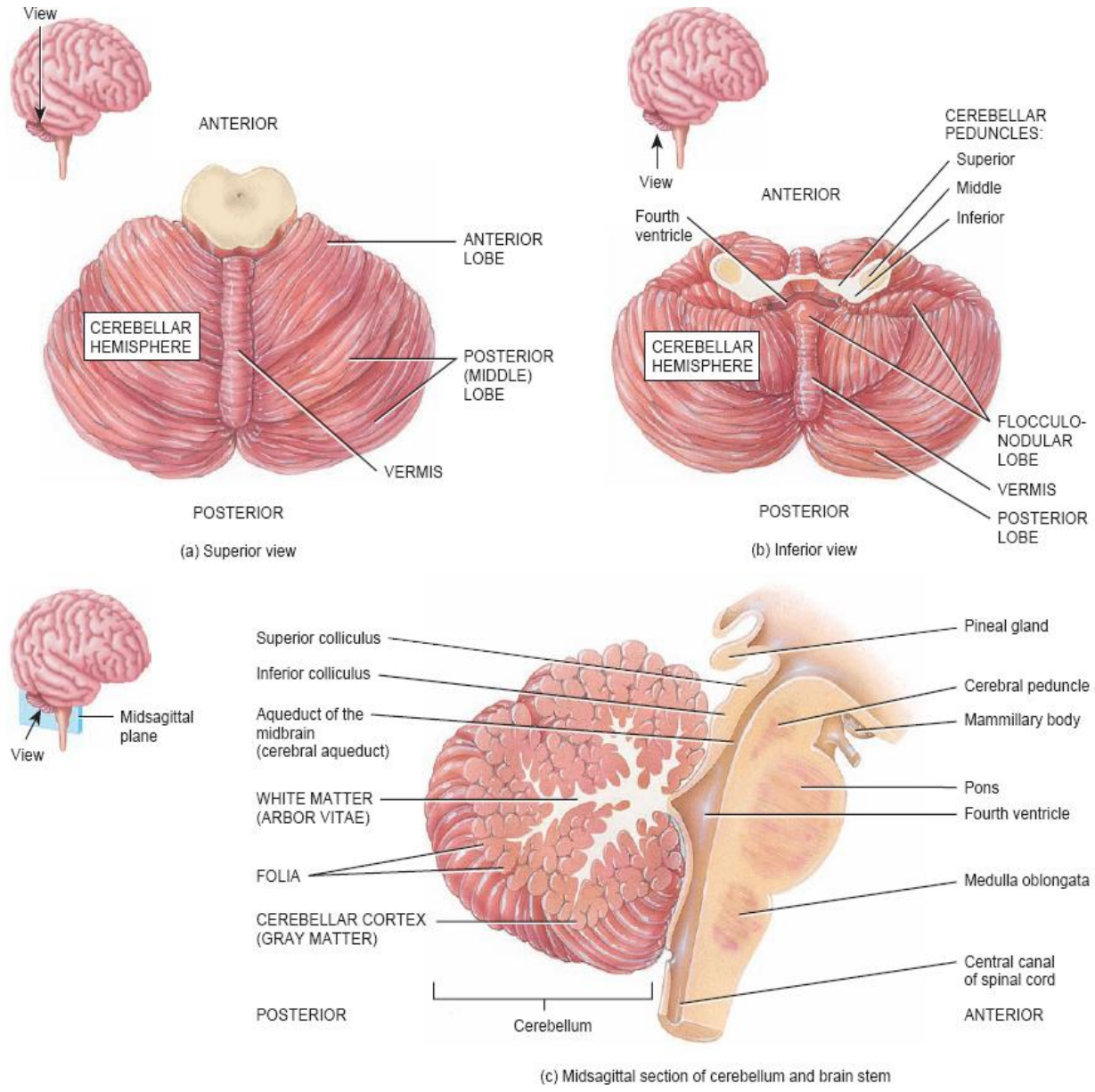
A deep groove known as the **transverse fissure,** separate the cerebellum from the cerebrum.

In superior or inferior views, the shape of the cerebellum resembles a butterfly. The central area is the **vermis** (worm), and the lateral areas are the **cerebellar hemispheres**.

Each hemisphere consists of lobes separated by deep and distinct fissures. The **anterior lobe** and **posterior lobe** govern subconscious aspects of skeletal muscle movements. The **flocculonodular lobe** on the inferior surface contributes to equilibrium and balance.

The superficial layer of the cerebellum, called the **cerebellar cortex,** consists of gray matter in a series of slender, parallel folds called **folia** (leaves). **Deep** to the gray matter are tracts of white matter called **arbor vitae** (tree of life). Even deeper, **within** the white matter, are the **cerebellar nuclei,** regions of gray matter that give rise to axons carrying impulses from the cerebellum to other brain centers.

Three paired **cerebellar peduncles** attach the cerebellum to the brain stem.



The **superior cerebellar peduncles, middle cerebellar peduncles** and **inferior cerebellar peduncles.** These bundles of white matter consist of axons that conduct impulses between the cerebellum and other parts of the brain.

The primary function of the cerebellum is to evaluate how movements initiated by motor areas in the cerebrum are actually being carried out. **HOW?** When movements initiated by the cerebral motor areas are not being carried out correctly, the cerebellum detects the discrepancies. It then sends feedback signals to motor areas of the cerebral cortex, via its connections to the thalamus. The feedback signals help correct the errors, smooth the movements, and coordinate complex sequences of skeletal muscle contractions.

Aside from this coordination of skilled movements, the cerebellum is the main brain region that regulates posture and balance. These aspects of cerebellar function make possible all

skilled muscular activities, from catching a baseball to dancing to speaking. The presence of reciprocal connections between the cerebellum and association areas of the cerebral cortex suggests that the cerebellum may also have nonmotor functions such as cognition (acquisition of knowledge) and language processing.

THE DIENCEPHALON

.

The **diencephalon** extends from the brain stem to the cerebrum and surrounds the third ventricle; it includes the **thalamus, hypothalamus, and epithalamus.**

Thalamus

The **thalamus** (inner chamber), consists of paired oval masses of gray matter organized into nuclei with interspersed tracts of white matter.

A bridge of gray matter called the **intermediate mass (interthalamic adhesion)** joins the right and left halves of the

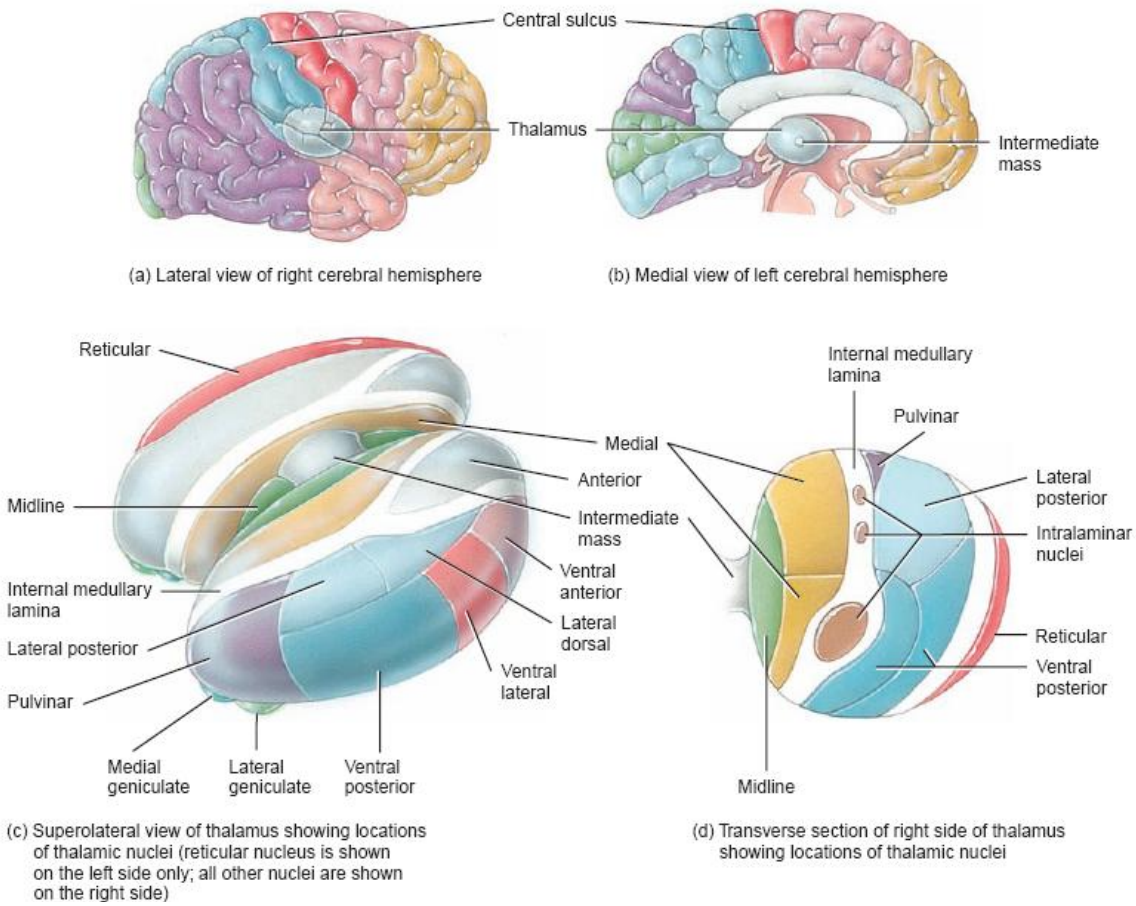
A vertical Y-shaped sheet of white matter called the **internal medullary lamina** divides the gray matter of the right and left sides of the thalamus. It consists of myelinated axons that enter and leave the various thalamic nuclei. Axons that connect the thalamus and cerebral cortex pass through the **internal capsule.**

The thalamus is the major relay station for most sensory impulses that reach the primary sensory areas of the cerebral cortex from the spinal cord and brain stem. In addition, the thalamus contributes to motor functions by transmitting information from the cerebellum and basal ganglia to the primary motor area of the cerebral cortex. The thalamus also relays nerve impulses between different areas of the cerebrum and plays a role in the maintenance of consciousness.

Based on their positions and functions, there are **seven major groups** of nuclei on each side of the thalamus.

1. The **anterior nucleus** It functions in emotions and memory.

2. The **medial nuclei.** They function in emotions, learning, memory, and cognition (thinking and knowing).



The thalamus is the main relay station for sensory impulses that reach the cerebral cortex from other parts of the brain and the spinal cord.

3. Nuclei in the l**ateral group**. The **lateral dorsal nucleus** functions in the expression of emotions. The **lateral posterior nucleus** and **pulvinar nucleus** help integrate sensory information.

4. Five nuclei are part of the **ventral group.** The **ventral anterior nucleus** plays a role in movement control. The **ventral lateral nucleus** also plays a role in movement control. The **ventral posterior nucleus** relays impulses for somatic sensations such as touch, pressure, vibration, itch, tickle, temperature, pain, and proprioception from the face and body to the cerebral cortex. The **lateral geniculate nucleus** relays visual impulses for sight from the retina to the primary visual area of the cerebral cortex. The **medial geniculate nucleus** relays auditory impulses for hearing from the ear to the primary auditory area of the cerebral cortex.

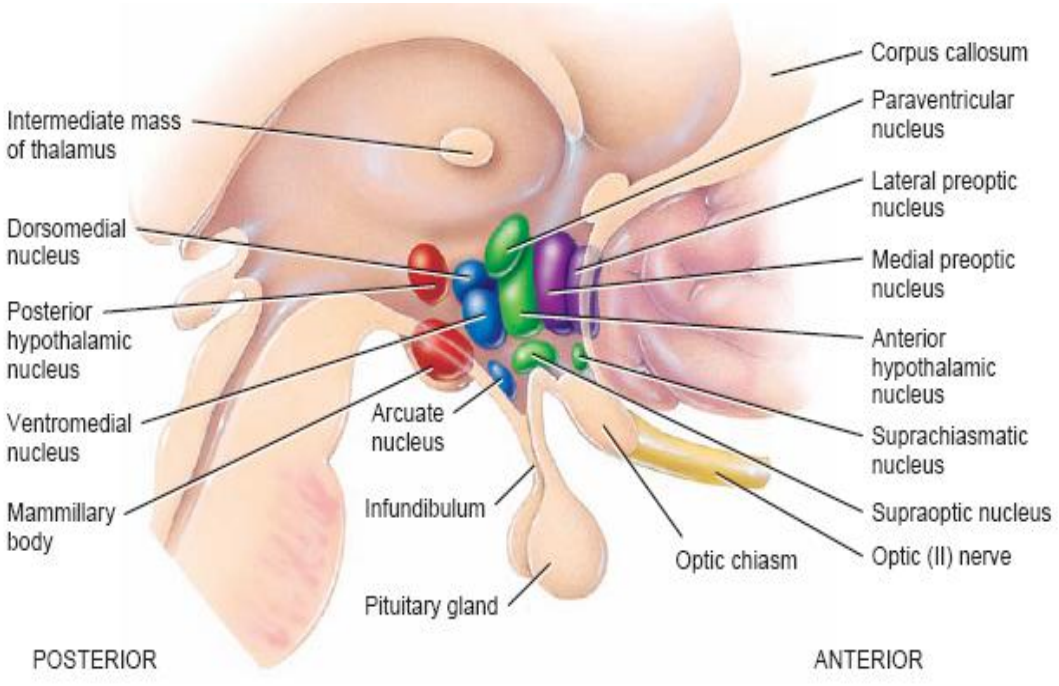
5. Intralaminar nuclei function in arousal (activation of the cerebral cortex from the brain stem reticular formation) and integration of sensory and motor information.

6. The **midline nucleus** has a supposed function in memory and olfaction.

7. The **reticular nucleus** monitors, filters, and integrates activities of other thalamic nuclei.

Hypothalamus

The **hypothalamus** (*hypo*- under) is a small part of the diencephalon located inferior to the thalamus. It is composed of nuclei in four major regions:



Sagittal section of brain showing hypothalamic nuclei

The hypothalamus controls many body activities and is an important regulator of homeostasis

1. The **mammillary region** includes the **mammillary bodies and posterior hypothalamic** *nuclei*. The mammillary bodies serve as relay stations for reflexes related to the sense of smell.

2. The **tuberal region,** the widest part of the hypothalamus, includes the **dorsomedial nucleus, ventromedial nucleus, and arcuate nucleus**, plus the **infundibulum** which connects the pituitary gland to the hypothalamus

The **median eminence** encircles the infundibulum.

3. The **supraoptic region** lies superior to the optic chiasm (point of crossing of optic nerves) and contains the **paraventricular nucleus, supraoptic nucleus, anterior hypothalamic nucleus, and suprachiasmatic nucleus.** Axons from the paraventricular and supraoptic nuclei form the hypothalamohypophyseal tract, which extends through the infundibulum to the posterior lobe of the pituitary**.**

4. The **preoptic region** anterior to the supraoptic region and it participates with the hypothalamus in regulating certain autonomic activities.

The preoptic region contains the **medial and lateral preoptic nuclei**

The hypothalamus controls many body activities and is one of the major regulators of homeostasis. Sensory impulses related to both somatic and visceral senses arrive at the hypothalamus, as do impulses from receptors for vision, taste, and smell. Other receptors within the hypothalamus itself continually monitor osmotic pressure, glucose level, certain hormone concentrations, and the temperature of blood. The hypothalamus has several very important connections with the pituitary gland and produces a variety of hormones.

Important functions of the hypothalamus include the following:

• ***Control of the ANS.*** The hypothalamus controls and integrates activities of the autonomic nervous system, which regulates contraction of smooth muscle and cardiac muscle and the secretions of many glands. Through the ANS, the hypothalamus is a major regulator of visceral activities, including regulation of heart rate, movement of food through the gastrointestinal tract, and contraction of the urinary bladder.

• ***Production of hormones.*** The hypothalamus produces several hormones and has **two types** of important connections with the pituitary gland.

First, hypothalamic hormones known as *releasing hormones* and *inhibiting hormones* are released into capillary networks, the bloodstream carries these hormones directly to the anterior lobe of the pituitary, where they stimulate or inhibit secretion of anterior pituitary hormones.

Second, axons extend from the paraventricular and supraoptic nuclei through the infundibulum into the posterior lobe of the pituitary. The cell bodies of these neurons make one of two hormones (*oxytocin* or *antidiuretic hormone*). Their axons transport the hormones to the posterior pituitary, where they are released.

• ***Regulation of emotional and behavioral patterns.*** Together with the limbic system, the hypothalamus participates in expressions of anger, aggression, pain, and pleasure, and the behavioral patterns related to sexual arousal.

• ***Regulation of eating and drinking.*** The hypothalamus regulates food intake. It contains a **feeding center,** which promotes eating, and a **satiety center,** which causes a sensation of fullness and cessation of eating. The hypothalamus also contains a **thirst center.**

When certain cells in the hypothalamus are stimulated by rising osmotic pressure of the extracellular fluid, they cause the sensation of thirst. The intake of water by drinking restores the osmotic pressure to normal, removing the stimulation and relieving the thirst.

• ***Control of body temperature.*** The hypothalamus also functions as the body's **thermostat.** If the temperature of blood flowing through the hypothalamus is above normal, the hypothalamus directs the autonomic nervous system to stimulate activities that promote heat loss. When blood temperature is below normal, by contrast, the hypothalamus generates impulses that promote heat production and retention.

• ***Regulation of circadian rhythms and states of consciousness.***

The suprachiasmatic nucleus of the hypothalamus serves as the body's internal biological clock because it establishes **circadian rhythms,** patterns of biological activity (such as the sleep–wake cycle) that occur on a circadian schedule (cycle of about 24 hours).

Epithalamus

The **epithalamus** (*epi-* above) is a small region superior and posterior to the thalamus. It consists of the **pineal gland and habenular nuclei**.

The pineal gland is considered part of the endocrine system because it secretes the hormone **melatonin.** Melatonin appears to contribute to the setting of the body's biological clock, which is controlled by the suprachiasmatic nucleus of the hypothalamus. As more melatonin is liberated during darkness than in light, this hormone is thought to promote sleepiness. In response to visual input from the eyes (retina), the suprachiasmatic nucleus stimulates the pineal gland to secrete the hormone melatonin in a rhythmic pattern, with low levels of melatonin secreted during the day and significantly higher levels secreted at night.

The **habenular nuclei** are involved in olfaction, especially emotional responses to odors

Circumventricular organs

Parts of the diencephalon, called **circumventricular** because they lie in the wall of the third ventricle, can monitor chemical changes in the blood because they lack a blood–brain barrier CVOs include part of the hypothalamus, the pineal gland, the pituitary gland, and a few other nearby structures. Functionally, these regions coordinate homeostatic activities of the endocrine and nervous systems, such as the regulation of blood pressure, fluid balance, hunger, and thirst. CVOs are also thought to be the sites of entry into the brain of HIV. Once in the brain, HIV may cause dementia (irreversible deterioration of mental state) and other neurological disorders.

THE CEREBRUM

The **cerebrum** is the "seat of intelligence." It provides us with the ability to read, write, and speak; to make calculations and compose music; and to remember the past, plan for the future, and imagine things that have never existed before. **The cerebrum consists of an outer cerebral cortex, an internal region of cerebral white matter, and gray matter nuclei deep within the white matter.**

Cerebral cortex

The **cerebral cortex** is a region of gray matter that forms the outer rim or circumference of the cerebrum.

The cortex has the folds called **gyri** or **convolutions**.

Between the folds are grooves. The deepest grooves are known as **fissures;** the shallower grooves are termed **sulci**.

The most prominent fissure, the **longitudinal fissure,** separates the cerebrum into **right and left** halves called **cerebral hemispheres.**

Within the longitudinal fissure between the cerebral hemispheres is the falx cerebri.

The cerebral hemispheres are connected internally by the **corpus callosum**

Lobes of the cerebrum

Each cerebral hemisphere can be further subdivided into four lobes. The lobes are named after the bones that cover them: **frontal, parietal, temporal, and occipital lobes**.

The **central sulcus** separates the **frontal lobe** from the **parietal lobe.** A major gyrus, the **precentral gyrus** located immediately anterior to the central sulcus contains the **primary motor area** of the cerebral cortex. Another major gyrus, the **postcentral gyrus,** which is located immediately posterior to the central sulcus, contains the **primary somatosensory** area of the cerebral cortex.

The **lateral cerebral sulcus (fissure)** separates the **frontal lobe** from the **temporal lobe.** The **parieto- occipital sulcus** separates the **parietal lobe** from the **occipital lobe.** A fifth part of the cerebrum, the **insula,** cannot be seen at the surface of the brain because it lies within the lateral cerebral sulcus, deep to the parietal, frontal, and temporal lobes

Cerebral white matter

The **cerebral white matter** consists primarily of myelinated axons in three types of tracts

1. Association tracts contain axons that conduct nerve impulses between gyri in the same hemisphere.

2. Commissural tracts contain axons that conduct nerve impulses from gyri in one cerebral hemisphere to corresponding gyri in the other cerebral hemisphere. Three important groups of commissural tracts are the **corpus callosum**, **anterior commissure,** and **posterior commissure.**

3. Projection tracts contain axons that conduct nerve impulses from the cerebrum to lower parts of the CNS (thalamus, brain stem, or spinal cord) or from lower parts of the CNS to the cerebrum.

Basal ganglia

Deep within each cerebral hemisphere are three nuclei that are collectively termed the **basal ganglia**

Recall that "ganglion" usually means a collection of neuronal cell bodies *outside* the CNS.

Two of the basal ganglia are side-by-side, just lateral to the thalamus. The **globus pallidus** and the **putamen**. Together, the

globus pallidus and putamen are referred to as the **lentiform nucleus**. The third basal ganglion is the **caudate nucleus**. Together, the lentiform and caudate nuclei are known as the **corpus striatum.**

A major function of the basal ganglia is to help initiate and terminate movements of the body. The basal ganglia also suppress unwanted movements and regulate muscle tone. In addition, the basal ganglia influence many aspects of cortical function, including sensory, limbic, cognitive, and linguistic functions.

The Limbic system

Encircling the upper part of the brain stem and the corpus callosum is a ring of structures on the inner border of the cerebrum and floor of the diencephalon that constitutes the **limbic system** (*limbic* border).

The limbic system is sometimes called the "emotional brain" because it plays a primary role in a range of emotions, including pleasure, pain, docility, affection, fear, and anger. It also is involved in olfaction (smell) and memory.

Functional organisation of cerebral cortex

Specific types of sensory, motor, and integrative signals are processed in certain regions of the cerebral cortex.

Generally, **sensory areas** receive sensory information and are involved in **perception,** the conscious awareness of a sensation; **motor areas** control the execution of voluntary movements; and **association areas** deal with more complex integrative functions such as memory, emotions, reasoning, will, judgment, personality traits, and intelligence.

Sensory areas

Sensory information arrives mainly in the posterior half of both cerebral hemispheres, in regions behind the central sulci. In the cerebral cortex, **primary sensory areas** receive sensory information that has been relayed from peripheral sensory receptors through lower regions of the brain. **Sensory association areas** often are adjacent to the primary areas. They usually receive input both from the primary areas and from other brain regions.

Sensory association areas integrate sensory experiences to generate meaningful patterns of recognition and awareness. **For example**, a person with damage in the *primary* visual area would blind in at least part of his visual field, but a person with damage to a visual *association* area might see normally yet be unable to recognize ordinary objects such as a lamp or a toothbrush just by looking at them.

The following are some important sensory areas

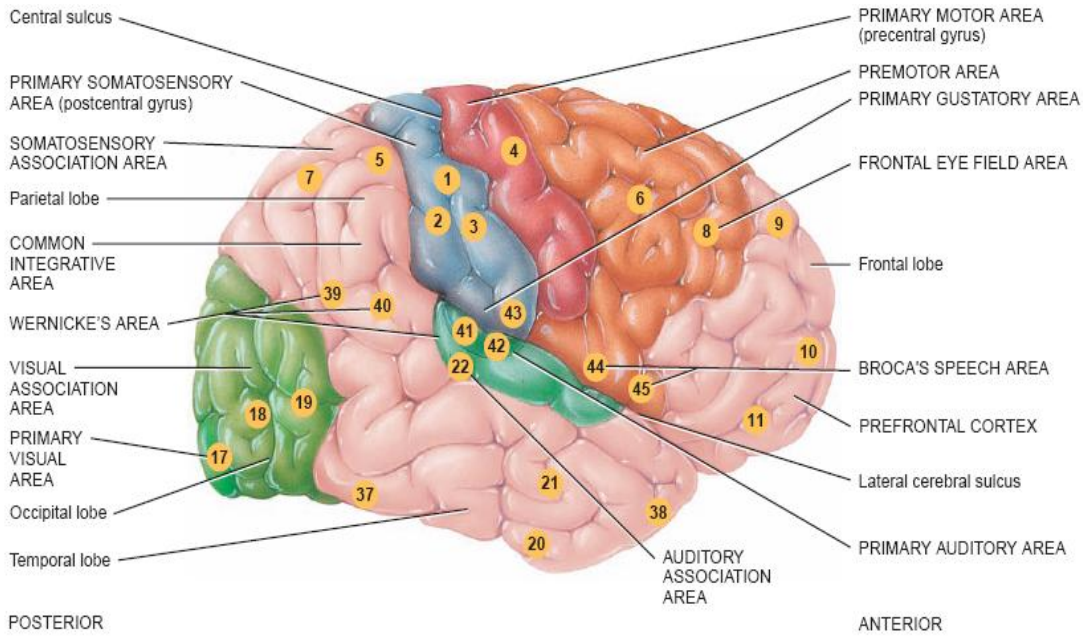
• The **primary somatosensory area** (areas 1, 2, and 3), located in parietal lobe, receives nerve impulses for touch, pressure, vibration, itch, tickle, temperature (coldness and warmth), pain, and proprioception (joint and muscle position) and is involved in the perception of these somatic sensations.

• The **primary visual area** (area 17) in occipital lobe, receives visual information and is involved in visual perception.

• The **primary auditory area** (areas 41 and 42), in temporal lobe, receives information for sound and is involved in auditory perception.

• The **primary gustatory area** (area 43), in parietal lobe, receives impulses for taste and is involved in gustatory perception and taste discrimination.

• The **primary olfactory area** (area 28), located in the temporal lobe ,receives impulses for smell and is involved in olfactory perception.



Lateral view of right cerebral hemisphere

Motor areas

Motor output from the cerebral cortex flows mainly from the anterior part of each hemisphere. Among the most important motor areas are the following:

• The **primary motor area** (area 4) is located in

frontal lobe. Each region in the primary motor area controls voluntary contractions of specific muscles or groups of muscles. Electrical stimulation of any point in the primary motor area causes contraction of specific skeletal muscle fibers on the opposite side of the body.

• **Broca's speech area** (areas 44 and 45), located in the frontal lobe, is involved in the articulation of speech. In most people, Broca's speech area is localized in the *left* cerebral hemisphere.

Association areas

The association areas of the cerebrum consist of large areas of the occipital, parietal, and temporal lobes and of the frontal lobes anterior to the motor areas. Association areas are connected with one another by association tracts and include the followi:

• The **somatosensory association area** (areas 5 and 7) is just posterior to and receives input from the primary somatosensory area, as well as from the thalamus and other parts of the brain. This area permits you to determine the exact shape and texture of an object by feeling it, to determine the orientation of one object with respect to another as they are felt, and to sense the relationship of one body part to another.

Another role of the somatosensory association area is the storage of memories of past somatic sensory experiences, enabling you to compare current sensations with previous experiences. For example, the somatosensory association area allows you to recognize objects such as a pencil and a paperclip simply by touching them.

• The **visual association area** (areas 18 and 19), located in the occipital lobe, receives sensory impulses from the primary visual area and the thalamus. It relates present and past visual experiences and is essential for recognizing and evaluating what is seen. For example, the visual association area allows you to recognize an object such as a spoon simply by looking at it.

• The **facial recognition area,** corresponding roughly to areas 20, 21, and 37 in the inferior temporal lobe, receives nerve impulses from the visual association area. This area stores information about faces, and it allows you to recognize people by their faces.

• The **auditory association area** (area 22), located inferior and posterior to the primary auditory area in the temporal cortex, allows you to recognize a particular sound as speech, music, or noise.

• The **orbitofrontal cortex,** corresponding roughly to area 11 along the lateral part of the frontal lobe, receives sensory impulses from the primary olfactory area. This area allows you to identify odors and to discriminate among different odors.

• **Wernicke's (posterior language) area** (area 22, and possibly areas 39 and 40), a broad region in the *left* temporal and parietal lobes, interprets the meaning of speech by recognizing spoken words. It is active as you translate words into thoughts. The regions in the *right* hemisphere that correspond to Broca's and Wernicke's areas in the left hemisphere also contribute to verbal communication by adding emotional content, such as anger or joy, to spoken words. Unlike those who have CVAs in Broca's area, people who suffer strokes in Wernicke's area can still speak, but cannot arrange words in a coherent fashion.

• The **common integrative area** (areas 5, 7, 39, and 40) is bordered by somatosensory, visual, and auditory association areas. It receives nerve impulses from these areas and from the primary gustatory area, primary olfactory area, the thalamus, and parts of the brain stem. This area integrates sensory interpretations from the association areas and impulses from other areas, allowing the formation of thoughts based on a variety of sensory inputs. It then transmits signals to other parts of the brain for the appropriate response to the sensory signals it has interpreted.

• The **prefrontal cortex (frontal association area)** is an extensive area in the anterior portion of the frontal lobe that is well-developed in primates, especially humans (areas 9, 10, 11, and 12). This area has numerous connections with other areas of the cerebral cortex, thalamus, hypothalamus, limbic system, and cerebellum. The prefrontal cortex is **concerned** with the makeup of a person's personality, intellect, complex learning abilities, recall of information, initiative, judgment, foresight, reasoning, conscience, intuition, mood, planning for the future, and development of abstract ideas. A person with bilateral damage to the prefrontal cortices typically becomes rude, inconsiderate, incapable of accepting advice, moody, inattentive, less creative, unable to plan for the future, and incapable of anticipating the consequences of rash or reckless words or behavior.

• The **premotor area** (area 6) is a motor association area that is immediately anterior to the primary motor area. The premotor area deals with learned motor activities of a complex and sequential nature. It generates nerve impulses that cause specific groups of muscles to contract in a specific sequence, as when you write your name. The premotor area also serves as a memory bank for such movements.

• The **frontal eye field area** (area 8) in the frontal cortex is sometimes included in the premotor area. It controls voluntary scanning movements of the eyes like those you just used in reading the sentence

Hemispheric lateralization

Although the two hemispheres share performance of many functions, each hemisphere also specializes in performing certain unique functions. This functional asymmetry is termed **hemispheric lateralization.**

In the most example of hemispheric lateralization, **the left hemisphere receives** somatic sensory signals from and controls muscles on **the right side of the body**, whereas the right hemisphere receives sensory signals from and controls muscles on the left side of the body.

In most people, the left hemisphere is more important for reasoning, numerical and scientific skills, spoken and written language, and the ability to use and understand sign language. Patients with damage in the left hemisphere, for example, often exhibit aphasia.

Conversely, the right hemisphere is more specialized for musical and artistic awareness; spatial and pattern perception; recognition of faces and emotional content of language; discrimination of different smells; and generating mental images of sight, sound, touch, taste, and smell to compare relationships among them. Patients with damage in right hemisphere

regions that correspond to Broca's and Wernicke's areas in the left hemisphere speak in a monotonous voice, having lost the ability to impart emotional inflection to what they say.

CRANIAL NERVES

The 12 pairs of **cranial nerves** are so named because they arise from the brain inside the cranial cavity and pass through various foramina in the bones of the cranium. Like the 31 pairs of spinal nerves, they are part of the peripheral nervous system (PNS). Each cranial nerve has both a number, designated by a roman numeral, and a name. The numbers indicate the order, from anterior to posterior, in which the nerves arise from the brain. The names designate a nerve's distribution or function.

Cranial nerves emerge from the nose (cranial nerve I), the eyes (cranial nerve II), the inner ear (cranial nerve VIII), the brain stem (cranial nerves I I I–XII), and the spinal cord (cranial nerve XI).

Three cranial nerves (I, II, and VIII) carry axons of sensory neurons and thus are called **sensory nerves.** Five cranial nerves (III, IV, VI, XI, and XII) contain only axons of motor neurons as they leave the brain stem and are called **motor nerves**. The other four cranial nerves (V, VII, IX, and X) are **mixed nerves** because they contain axons of both sensory and motor neurons.

The cell bodies of sensory neurons are located in ganglia outside the brain. The cell bodies of motor neurons lie in nuclei within the brain.

Cranial nerves III, VII, IX, and X include both somatic and autonomic motor axons. The somatic axons innervate skeletal muscles; the autonomic axons, which are part of the parasympathetic division, innervate glands, smooth muscle, and cardiac muscle.

Olfactory (I) nerve

The **olfactory (I) nerve** is entirely sensory; it contains axons that conduct nerve impulses for olfaction, the sense of smell. Axons in the olfactory tracts end in the primary olfactory area in the temporal lobe of the cerebral cortex.

Optic (II) nerve

The **optic (II) nerve** is entirely sensory; it contains axons that conduct nerve impulses for vision.

About 10 mm posterior to the eyeball, the two optic nerves merge to form the **optic chiasm**. Within the chiasm, axons from the medial half of each eye cross to the opposite side; axons

from the lateral half remain on the same side. Most axons in the optic tracts end in the lateral geniculate nucleus of the thalamus where they synapse with neurons whose axons extend to the primary visual area in the occipital lobe of the cerebral cortex.

Oculomotor (III) Nerve

The **oculomotor (III) nerve** is a motor cranial nerve. Its branches (**superior and inferior)** innervate the muscles which control movements of the eyeball and upper eyelid.

The inferior branch also provides parasympathetic innervation to intrinsic eyeball muscles, the **ciliary muscle** of the eyeball which adjusts the lens for near vision and the **circular muscles** of the iris to contract when bright light stimulates the eye, causing a decrease in the size of the pupil (constriction).

Trochlear (IV) nerve

The **trochlear (IV) nerve** is a motor cranial nerve. It innervate the superior oblique muscle of the eyeball, another extrinsic eyeball muscle that controls movement of the eyeball.

Trigeminal (V) nerve is a mixte cranial nerve. As indicated by its name, the trigeminal nerve has three branches: **ophthalmic, maxillary, and mandibular**.

Sensory axons in the trigeminal nerve carry nerve impulses for touch, pain, and thermal sensations. **The ophthalmic nerve** contains sensory axons from the skin over the upper eyelid, eyeball, lacrimal glands, upper part of the nasal cavity, side of the nose, forehead, and anterior half of the scalp. **The maxillary nerve** includes sensory axons from the mucosa of the nose, palate, part of the pharynx, upper teeth, upper lip, and lower eyelid. **The mandibular nerve** contains sensory axons from the anterior two-thirds of the tongue (not taste), cheek and mucosa deep to it, lower teeth, skin over the mandible and side of the head anterior to the ear, and mucosa of the floor of the mouth.

Somatic motor axons of the trigeminal nerve are part of the mandibular nerve and supply muscles of mastication (masseter, temporalis, medial pterygoid, lateral pterygoid, anterior belly of digastric, mylohyoid muscles, and tensor tympani muscle in the ear). These motor neurons control **chewing movements**.

Abducens (VI) nerve

The **abducens (VI) nerve** is a motor cranial nerve. The abducens nerve is so named because

nerve impulses cause abduction of the eyeball (lateral rotation). It innervates the lateral rectus muscle, an ixtrinsic eyeball muscle responsible in lateral movement (rotation) of eyeball.

Facial (VII) nerve

The **facial (VII) nerve** is a mixed cranial nerve.

Sensory function*:* Touch, pain, and temperature sensations, proprioception, and taste.

Somatic motor function*:* Facial expression.

Autonomic motor function *(parasympathetic):* Secretion of saliva and tears.

Vestibulocochlear (VIII) Nerve

The **vestibulocochlear (VIII) nerve** was formerly known as the **acoustic** or **auditory nerve.** It is a sensory cranial nerve and has two branches, the vestibular branch and the cochlear branch. The **vestibular branch** carries impulses for equilibrium; the **cochlear branch** carries impulses for hearing.

Glossopharyngeal (IX) nerve

The **glossopharyngeal (IX) nerve** (*glosso-* tongue; *-pharyngeal* - throat) is a mixed cranial nerve.

Sensory function: Taste and somatic sensations (touch, pain, temperature) from posterior third of tongue; proprioception in swallowing muscles; monitoring of blood pressure; monitoring of O2 and CO2 in blood for regulation of breathing rate and depth.

Somatic motor function: Elevates the pharynx during swallowing and speech.

Autonomic motor function (parasympathetic): Stimulates secretion of saliva by parotid salivary gland.

Vagus (X) nerve

The **vagus (X) nerve** is a mixed cranial nerve that is distributed from the head and neck into the thorax and abdomen. The nerve derives its name from its wide distribution.

Sensory function: Taste and somatic sensations (touch, pain, temperature, and proprioception) from epiglottis and pharynx;nmonitoring of blood pressure; monitoring of O2 and CO2 in blood for regulation of breathing rate and depth; sensations from visceral organs in thorax and abdomen.

Somatic motor function: Swallowing, coughing, and voice production.

Autonomic motor function (parasympathetic): Smooth muscle contraction and relaxation in organs of the GI tract; slowing of the heart rate; secretion of digestive fluids.

Accessory (XI) nerve

The **accessory (XI) nerve** (assisting) is a motor cranial nerve.

Function: Mediates movement of head and pectoral girdle by supplying sternocleidomastoid and trapezius muscles

Hypoglossal (XII) nerve

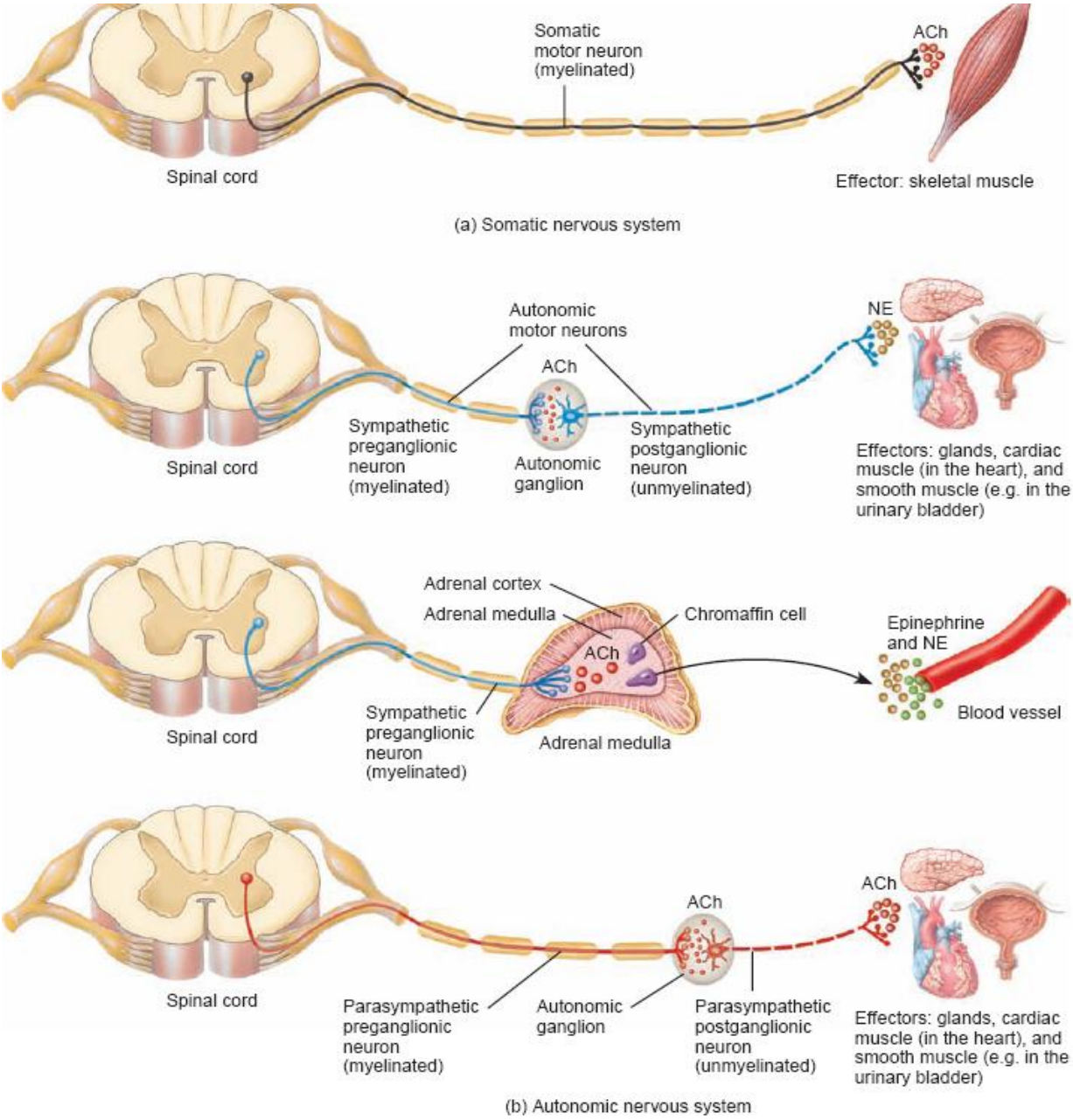
The **hypoglossal (XII) nerve** is a motor cranial nerve. Supply the muscles of the tongue necessary in movement of tongue during speech swallowing.

AUTONOMIC NERVOUS SYSTEM.

The autonomic nervous system contributes to homeostasis by responding to subconscious visceral sensations and exciting or inhibiting smooth muscle, cardiac muscle, and glands.

The ANS usually operates without conscious control. The system was originally named *autonomic* because it was thought to function autonomously or in a self-governing manner, without control by the CNS. However, centers in the hypothalamus and brain stem do regulate ANS reflexes.

Structurally, the ANS includes autonomic sensory neurons, integrating centers in the CNS, and autonomic motor neurons. A continual flow of nerve impulses from (1) *autonomic sensory neurons* in visceral organs and blood vessels propagate into (2) *integrating centers* in the central nervous system (CNS). Then, impulses in (3) *autonomic motor* neurons propagate to various effector tissues, thereby regulating the activity of smooth muscle, cardiac muscle, and many glands.



Motor neuron pathways in the (a) somatic nervous system and (b) autonomic nervous system (ANS). Note that autonomic motor neurons release either acetylcholine (ACh) or norepinephrine (NE); somatic motor neurons release ACh.

Somatic nervous system stimulation always excites its effectors (skeletal muscle fibers); stimulation by the autonomic nervous system either excites or inhibits visceral effectors.

Comparison of the somatic and autonomic nervous systems

	SOMATIC NERVOUS SYSTEM	AUTONOMIC NERVOUS SYSTEM
Sensory input	Somatic senses and special senses.	Mainly from interoceptors; some from somatic senses and special senses.
Control of motor output	Voluntary control from cerebral cortex,with contributions from basal ganglia, celebellum. brain stem, and spinal cord	Involuntary control from hypothalamus, limbic system, brain stem, and spinal cord; limited control from cerebral cortex
Motor neuron pathway	One-neuron pathway: Somatic motor neurons extending from CNS synapse directly with effector.	Usually two-neuron pathway: Preganglionic neurons extending from CNS synapse with postganglionic neurons in an autonomic ganglion, and postganglionic neurons. extending from ganglion synapse with a visceral effector. Alternatively, preganglionic neurons may extend from CNS to synapse with chromaffin cells of adrenal medullae.
Neurotransmitters and homones	All somatic motor neurons release ACh	All sympathetic and parasympathetic preganglionic neurons release acetylcholine (ACh). Most sympathetic postganglionic neurons release norepinephrine (NE); those to most sweat glands release ACh. All parasympathetic postganglionic neurons release ACh. Chromaffin cells of adrenal medullae release epinephrine and norepinephrine.
Effectors	Skeletal muscle	Smooth muscle, cardiac muscle, and glands
Responses	Contraction of skeletal muscle	Contraction or relaxation of smooth muscle; increased or decreased rate and force of contraction of cardiac muscle; increased or decreased secretions of glands.

Anatomical components

The first of the two motor neurons in any autonomic motor pathway is called a **preganglionic neuron.** Its cell body is in the brain or spinal cord, and its axon exits the CNS as part of a cranial or spinal nerve. The axon of a preganglionic extends to an autonomic ganglion, where it synapses with a **postganglionic neuron** which is the second neuron in the autonomic motor pathway.

The postganglionic neuron lies entirely outside the CNS. Its cell body and dendrites are located in an autonomic ganglion, where it forms synapses with one or more preganglionic axons.

Preganglionic neurons convey nerve impulses from the CNS to autonomic ganglia, and postganglionic neurons relay the impulses from autonomic ganglia to visceral effectors.

Preganglionic Neurons

In the **sympathetic division**, the preganglionic neurons have their cell bodies in the lateral horns of the gray matter in the 12 thoracic segments and the first two (and sometimes three) lumbar segments of the spinal cord. For this reason, the sympathetic division is also called the **thoracolumbar division**, and the axons of the sympathetic preganglionic neurons are known as the **thoracolumbar outflow.**

In the **parasympathetic division,** the cell bodies of preganglionic neurons are located in the nuclei of four cranial nerves in the brain stem (III, VII, IX, and X) and in the lateral gray matter of the second through fourth sacral segments of the spinal cord, that's why, the parasympathetic division is also known as the **craniosacral division** and the axons of the parasympathetic preganglionic neurons are referred to as the **craniosacral outflow.**

Autonomic Ganglia

There are two **major groups of autonomic ganglia**: (1) **sympathetic ganglia**, which are components of the sympathetic division of the ANS and (2) **parasympathetic ganglia**, which are components of the parasympathetic division of the ANS.

SYMPATHETIC GANGLIA The sympathetic ganglia are the sites of synapses between sympathetic preganglionic and postganglionic neurons. There are **two major types** of sympathetic ganglia: **sympathetic trunk ganglia** and **prevertebral ganglia**.

Sympathetic trunk ganglia (also called *vertebral chain ganglia* or *paravertebral ganglia*) lie in a vertical row on either side of the vertebral column. These ganglia extend from the base of the skull to the coccyx. Postganlionic axons from sympathetic trunk ganglia primarily innervate organs above the diaphragm. Sympathetic trunk ganglia in the neck have specific names. They are the **superior, middle,** and **inferior cervical ganglia**. The remaining sympathetic trunk ganglia do not have individual names.

The **prevertebral** (*collateral*) **ganglia,** lies anterior to the vertebral column and close to the large abdominal arteries. In general, postganglionic axons from prevertebral ganglia innervate organs below the diaphragm.

There are **five major** prevertebral ganglia: (1) the **celiac ganglion** is on either side of the celiac trunk, an artery that is just inferior to the diaphragm. (2) The **superior mesenteric ganglion** is near the beginning of the superior mesenteric artery in the upper abdomen. (3)

The **inferior mesenteric ganglion** is near the beginning of the inferior mesenteric artery in the middle of the abdomen. (4) The **aorticorenal ganglion** and (5) the **renal ganglion** are near the renal artery of each kidney.

PARASYMPATHETIC GANGLIA

Preganglionic axons of the parasympathetic division synapse with postganglionic neurons in **terminal** (*intramural*) **ganglia.** Most of these ganglia are located close to or actually within the wall of a visceral organ.

Terminal ganglia in the head have specific names. They are the **ciliary ganglion, pterygopalatine ganglion, submandibular ganglion,** and **otic ganglion** The remaining terminal ganglia do not have specific names.

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Postganglionic neurons

Once axons of sympathetic preganglionic neurons pass to sympathetic trunk ganglia, they may connect with postganglionic neurons in one of the following ways:

- An axon may synapse with postganglionic neurons in the ganglion it first reaches.
- An axon may ascend or descend to a higher or lower ganglion before synapsing with postganglionic neurons.
- An axon may continue, without synapsing, through the sympathetic trunk ganglion to end at a prevertebral ganglion and synapse with postganglionic neurons there.
- An axon may also pass, without synapsing, through the sympathetic trunk ganglion and a prevertebral ganglion and then extend to chromaffin cells of the adrenal medullae that are functionally similar to sympathetic postganglionic neurons.

A single sympathetic preganglionic fiber has many axon collaterals (branches) and may synapse with 20 or more postganglionic neurons. This pattern of projection is an example of divergence and helps explain why many sympathetic responses affect almost the entire body simultaneously. After exiting their ganglia, the postganglionic axons typically terminate in several visceral effectors.

Axons of preganglionic neurons of the parasympathetic division pass to terminal ganglia near or within a visceral effector.

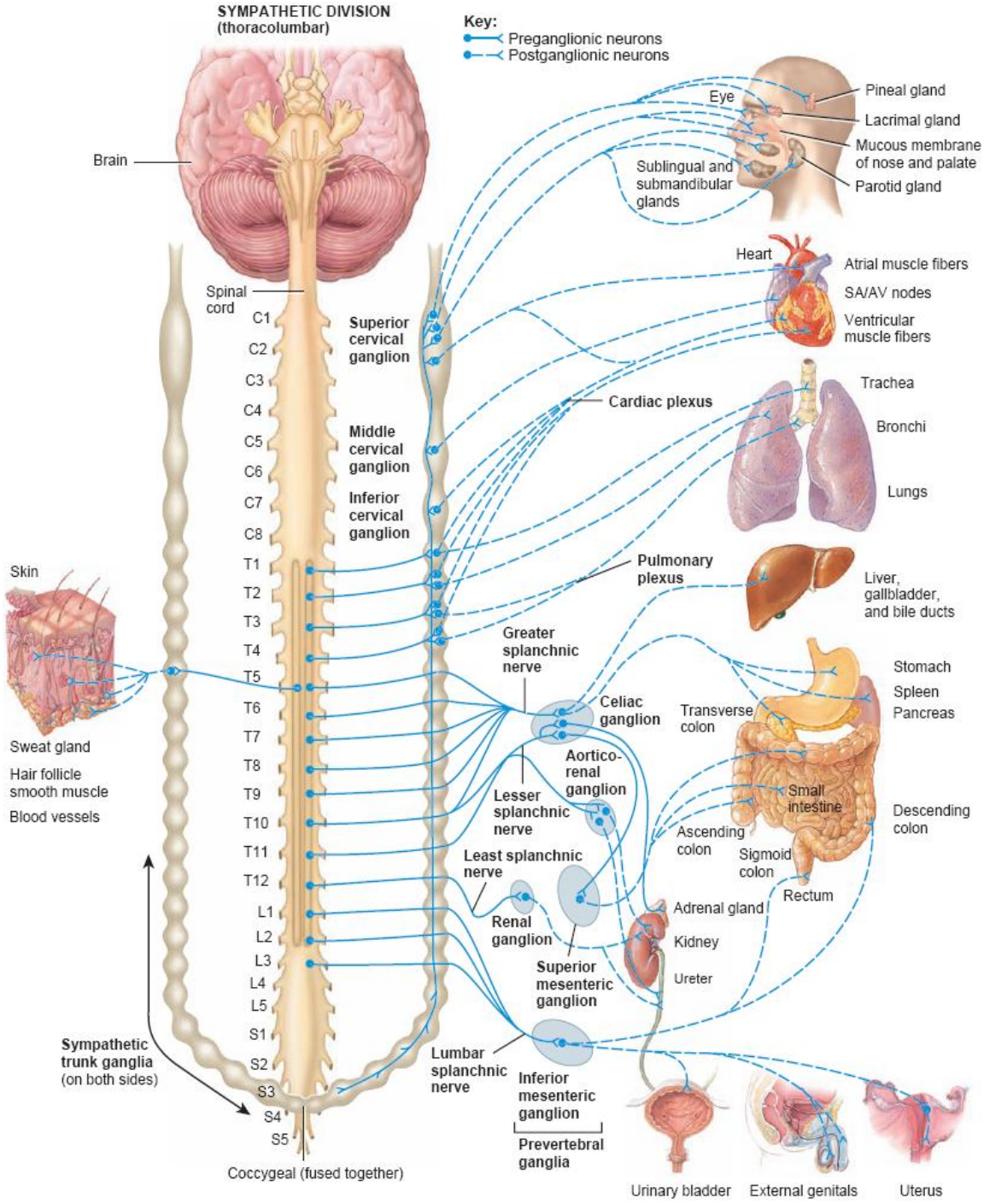
In the ganglion, the presynaptic neuron usually synapses with only four or five postsynaptic neurons, all of which supply a single visceral effector, allowing parasympathetic responses to be localized to a single effector.

Autonomic Plexuses

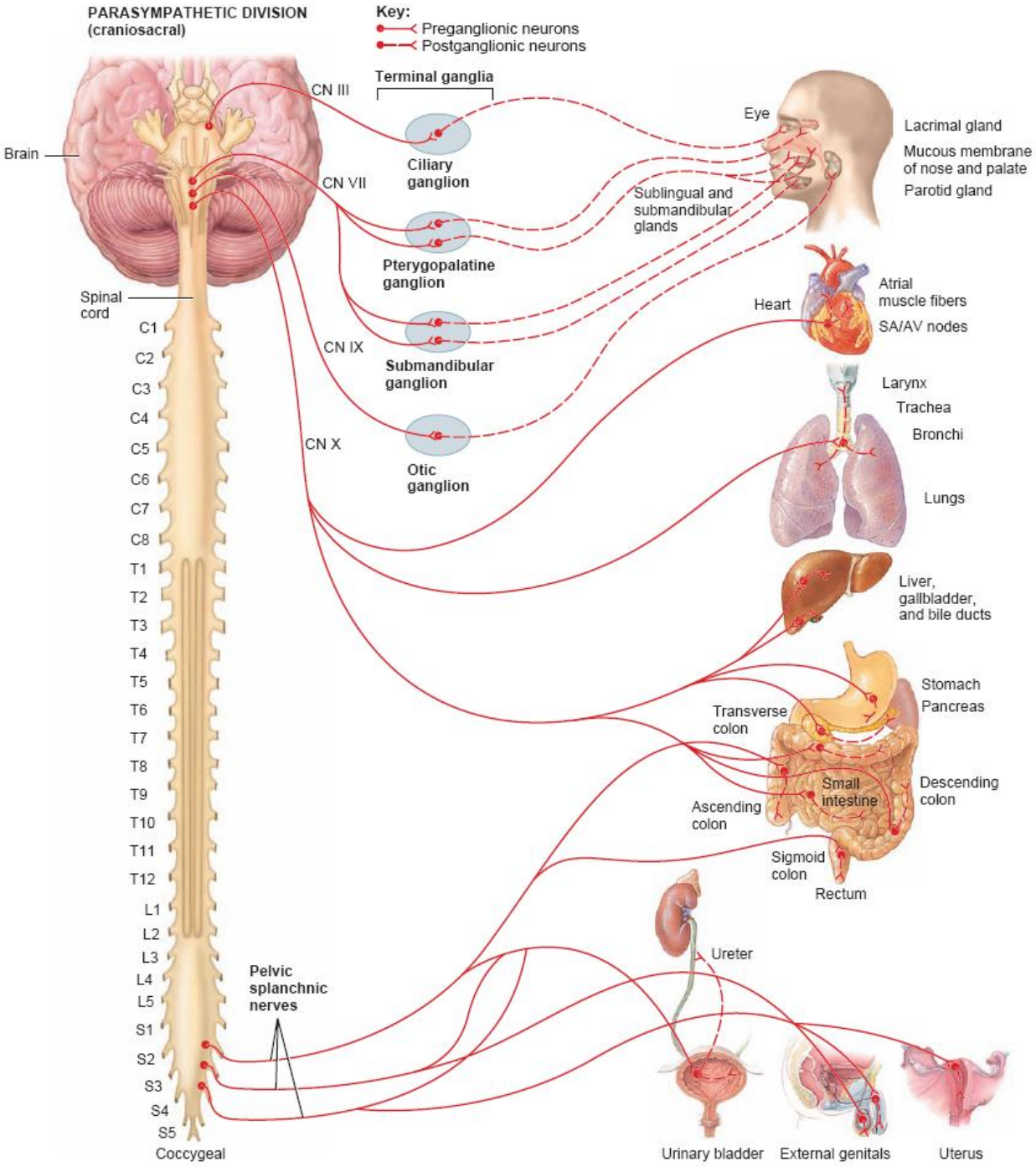
In the thorax, abdomen, and pelvis, axons of both sympathetic and parasympathetic neurons form tangled networks called **autonomic plexuses,** many of which lie along major arteries.

The autonomic plexuses also may contain sympathetic ganglia and axons of autonomic sensory neurons. The major plexuses in the thorax are the **cardiac plexus,** which supplies the heart, and the **pulmonary plexus,** which supplies the bronchial tree

The abdomen and pelvis also contain major autonomic plexuses and often the plexuses are named after the artery along which they are distributed. The **celiac** (*solar*) **plexus** is distributed to the stomach, spleen, pancreas, liver, gallbladder, and adrenal medullae. The **superior mesenteric plexus** contains the superior mesenteric ganglion and supplies the small intestine and proximal colon. The **inferior mesenteric plexus** contains the inferior mesenteric ganglion, which innervates the distal colon and rectum. The **hypogastric plexus,** supply the urinary bladder and genital organs. The **renal plexus** contains the renal ganglion and supplies the renal arteries within the kidneys and ureters.



Structure of the sympathetic division of the autonomic nervous system. Cell bodies of sympathetic preganglionic neurons are located in the lateral horns of gray matter in the 12 thoracic and first two lumbar segments of the spinal cord.



Structure of the parasympathetic division of the autonomic nervous system. Cell bodies of parasympathetic preganglionic neurons are located in brain stem nuclei and in the lateral gray matter in the second through fourth sacral segments of the spinal cord.

ANS neurotransmitters and receptors

Based on the neurotransmitter they produce and release, **autonomic neurons** are classified as either **cholinergic or adrenergic**.

The receptors for the neurotransmitters are integral membrane proteins located in the plasma membrane of the postsynaptic neuron or effector cell.

Cholinergic neurons and receptors

Cholinergic neurons release the neurotransmitter **acetylcholine (ACh).**

In the ANS, the cholinergic neurons include (1) all sympathetic and parasympathetic preganglionic neurons, (2) sympathetic postganglionic neurons that innervate most sweat glands, and (3) all parasympathetic postganglionic neurons.

ACh is stored in synaptic vesicles and released by exocytosis. It then diffuses across the synaptic cleft and binds with specific **cholinergic receptors,** integral membrane proteins in the *postsynaptic* plasma membrane.

The two types of cholinergic receptors, both of which bind ACh, are **nicotinic receptors** and **muscarinic receptors**.

Nicotinic receptors are present in the plasma membrane of dendrites and cell bodies of both sympathetic and parasympathetic postganglionic neurons, the plasma membranes of chromaffin cells of the adrenal medullae, and in the motor end plate at the neuromuscular junction. They are so named because nicotine mimics the action of ACh by binding to these receptors. (Nicotine, a natural substance in tobacco leaves, is not a naturally occurring substance in humans and is not normally present in nonsmokers.)

Muscarinic receptors are present in the plasma membranes of all effectors (smooth muscle, cardiac muscle, and glands) innervated by parasympathetic postganglionic axons. In addition, most sweat glands receive their innervations from *cholinergic* sympathetic postganglionic neurons and possess muscarinic receptors. These receptors are so named because a mushroom poison called muscarine mimics the actions of ACh by binding to them.

Acetylcholine is inactivated by the enzyme **acetylcholinesterase (AChE).**

Adrenergic neurons and receptors

In the ANS, **adrenergic neurons** release **norepinephrine (NE),** also known as **noradrenalin**. Most sympathetic postganglionic neurons are adrenergic.

Location and Responses of Adrenergic and Cholinergic Receptors

TYPE OF RECEPTOR	MAJOR LOCATIONS	EFFECTS OF RECEPTOR ACTIVATION
Cholinergic	Integral proteins in postsynaptic plasma membranes; activated by the neurotransmitter acetylcholine.	
Nicotinic	Plasma membrane of postganglionic sympathetic and parasympathetic neurons.	Excitation → impulses in postganglionic neurons.
	Chromaffin cells of adrenal medullae.	Epinephrine and norepinephrine secretion.
	Sarcolemma of skeletal muscle fibers (motor end plate).	Excitation → contraction.
Muscarinic	Effectors innervated by parasympathetic postganglionic neurons.	In some receptors, excitation; in others, inhibition.
	Sweat glands innervated by cholinergic sympathetic postganglionic neurons.	Increased sweating.
	Skeletal muscle blood vessels innervated by cholinergic sympathetic postganglionic neurons.	Inhibition → relaxation → vasodilation.
Adrenergic	Integral proteins in postsynaptic plasma membranes; activated by the neurotransmitter norepinephrine, and by the hormones norepinephrine and epinephrine.	
α_1	Smooth muscle fibers in blood vessels that serve salivary glands, skin, mucosal membranes, kidneys, and abdominal viscera; radial muscle in iris of eye; sphincter muscles of stomach and urinary bladder.	Excitation → contraction, which causes vasoconstriction, dilation of pupil, and closing of sphincters.
	Salivary gland cells.	Secretion of K^+ and water.
	Sweat glands on palms and soles.	Increased sweating.
α_2	Smooth muscle fibers in some blood vessels.	Inhibition → relaxation → vasodilation.
	Cells of pancreatic islets that secrete the hormone insulin (beta cells).	Decreased insulin secretion.
	Pancreatic acinar cells.	Inhibition of digestive enzyme secretion.
	Platelets in blood.	Aggregation to form platelet plug.
β_1	Cardiac muscle fibers.	Excitation → increased force and rate of contraction.
	Juxtaglomerular cells of kidneys.	Renin secretion.
	Posterior pituitary.	Secretion of antidiuretic hormone.
	Adipose cells.	Breakdown of triglycerides → release of fatty acids into blood.
β_2	Smooth muscle in walls of airways; in blood vessels that serve the heart, skeletal muscle, adipose tissue, and liver; and in walls of visceral organs, such as the urinary bladder.	Inhibition → relaxation, which causes dilation of airways, vasodilation, and relaxation of organ walls.
	Ciliary muscle in eye.	Inhibition → relaxation.
	Hepatocytes in liver.	Glycogenolysis (breakdown of glycogen into glucose).
β_3	Brown adipose tissue.	Thermogenesis (heat production).

Like ACh, NE is synthesized and stored in synaptic vesicles and released by exocytosis. Molecules of NE diffuse across the synaptic cleft and bind to specific adrenergic receptors on the postsynaptic membrane, causing either excitation or inhibition of the effector cell.

Adrenergic receptors bind both norepinephrine and epinephrine.

The norepinephrine can be either released as a neurotransmitter by sympathetic postganglionic neurons or released as a hormone into the blood by chromaffin cells of the adrenal medullae; epinephrine is released as a hormone.

The two main types of adrenergic receptors are **alpha receptors** and **beta receptors,** which are found on visceral effectors innervated by most sympathetic postganglionic axons. These receptors are further classified into **subtypes** *alpha*1 and *alpha*2, *beta*1, 2, and 3 based on the specific responses they elicit and by their selective binding of drugs that activate or block them. Although there are some exceptions, activation **of α_1 and β_1** receptors generally produces **excitation**, and activation of α_2 and β_2 receptors causes **inhibition of effector** tissues. β_3 receptors are present only on cells of brown adipose tissue, where their activation causes thermogenesis (heat production). Cells of most effectors contain either alpha or beta receptors; some visceral effector cells contain both. Norepinephrine stimulates alpha receptors more strongly than beta receptors; epinephrine is a potent stimulator of both alpha and beta receptors.

The activity of norepinephrine at a synapse is terminated either when the NE is taken up by the axon that released it or when the NE is enzymatically inactivated by either **catechol-*O*-methyltransferase (COMT)** or **monoamine oxidase (MAO).**

Physiology of the ANS

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Autonomic tone

Most body organs receive innervation from both divisions of the ANS, which typically work in opposition to one another. The **balance** between sympathetic and parasympathetic activity, called **autonomic tone,** is regulated by the hypothalamus. Typically, the hypothalamus turns up sympathetic tone at the same time it turns down parasympathetic tone, and vice versa. The two divisions can affect body organs differently because their postganglionic neurons release different neurotransmitters and because the effector organs possess different adrenergic and cholinergic receptors. A few structures receive **only sympathetic innervations** sweat glands, arrector pili muscles attached to hair follicles in the skin, the kidneys, the spleen, most blood vessels, and the adrenal medullae. In these structures there is no opposition from the parasympathetic division. Still, an increase in sympathetic tone has one effect, and a decrease in sympathetic tone produces the opposite effect.

Sympathetic responses

During physical or emotional stress, the sympathetic division dominates the parasympathetic division. High sympathetic tone favors body functions that can support vigorous physical

activity and rapid production of ATP. At the same time, the sympathetic division reduces body functions that favor the storage of energy.

Besides physical exertion, various emotions such as fear, embarrassment, or rage stimulate the sympathetic division.

Visualizing body changes that occur during "E situations" such as exercise, emergency, excitement, and embarrassment will help you remember most of the sympathetic responses.

Activation of the sympathetic division and release of hormones by the adrenal medullae set in motion a series of physiological responses collectively called the **fight-or-flight response,** which includes the following effects:

• The pupils of the eyes dilate.

• Heart rate, force of heart contraction, and blood pressure increase.

• The airways dilate, allowing faster movement of air into and out of the lungs.

• The blood vessels that supply the kidneys and gastrointestinal tract constrict, which decreases blood flow through these tissues. The result is a slowing of urine formation and digestive activities, which are not essential during exercise.

• Blood vessels that supply organs involved in exercise or fighting off danger, skeletal muscles, cardiac muscle, liver, and adipose tissue dilate, allowing greater blood flow through these tissues.

• Liver cells perform glycogenolysis and adipose tissue cells perform lipolysis.

• Release of glucose by the liver increases blood glucose level.

• Processes that are not essential for meeting the stressful situation are inhibited. For example, muscular movements of the gastrointestinal tract and digestive secretions slow down or even stop.

Parasympathetic responses

In contrast to the fight-or-flight activities of the sympathetic division, the parasympathetic division enhances **rest and digest** activities. Parasympathetic responses support body functions that conserve and restore body energy during times of rest and recovery. In the quiet intervals between periods of exercise, parasympathetic impulses to the digestive glands and the smooth muscle of the gastrointestinal tract predominate over sympathetic impulses. This allows energy-supplying food to be digested and absorbed. At the same time, parasympathetic responses reduce body functions that support physical activity.

The acronym ***SLUDD*** can be helpful in remembering five parasympathetic responses. It stands for salivation (S), lacrimation (L), urination (U), digestion (D), and defecation (D). All of these activities are stimulated mainly by the parasympathetic division.

Besides the increasing SLUDD responses, other important parasympathetic responses are "three decreases": decreased heart rate, decreased diameter of airways (bronchoconstriction), and decreased diameter (constriction) of the pupils.

Comparison of Sympathetic and Parasympathetic Divisions of the ANS

	SYMPATHETIC (THORACOLUMBAR)	PARASYMPATHETIC (CRANIOSACRAL)
Distribution	Wide regions of the body: skin, sweat glands, arrector pili muscles of hair follicles, adipose tissue, smooth muscle of blood vessels.	Limited mainly to head and to viscera of thorax, abdomen, and pelvis; some blood vessels.
Location of preganglionic neuron cell bodies and site of outflow	Cell bodies of preganglionic neurons are located in lateral gray horns of spinal cord segments T1–L2. Axons of preganglionic neurons constitute thoracolumbar outflow.	Cell bodies of preganglionic neurons are located in the nuclei of cranial nerves III, VII, IX , and X and the latera gray matter of spinal cord segments S2–S4. Axons of preganglionic neurons constitute craniosacral outflow.
Associated ganglia	Two types: sympathetic trunk ganglia and prevertebral ganglia.	One type: terminal ganglia.
Ganglia locations	Close to CNS and distant from visceral effectors.	Typically near or within wall of visceral effectors.
Axon length and divergence	Preganglionic neurons with short axons synapse with many postganglionic neurons with long axons that pass to many visceral effectors.	Preganglionic neurons with long axons usually synapse with four to five postganglionic neurons with short axons that pass to a single visceral effector.
Rami communicantes	Both present; white rami communicantes contain myelinated preganglionic axons, and gray rami communicantes contain unmyelinated postganglionic axons.	Neither present.
Neurotransmitters	Preganglionic neurons release acetylcholine (ACh), which is excitatory and stimulates postganglionic neurons; most postganglionic neurons release norepinephrine (NE); postganglionic neurons that innervate most sweat glands and some blood vessels in skeletal muscle release ACh.	Preganglionic neurons release acetylcholine (ACh), which is excitatory and stimulates postganglionic neurons; postganglionic neurons release ACh.
Physiological effects	Fight-or-flight responses.	Rest-and-digest activities.

Effects of Sympathetic and Parasympathetic Divisions of the ANS

VISCERAL EFFECTOR	EFFECT OF SYMPATHETIC STIMULATION (α OR β ADRENERGIC RECEPTORS, EXCEPT AS NOTED)*	EFFECT OF PARASYMPATHETIC STIMULATION (MUSCARINIC ACh RECEPTORS)
GLANDS		
Adrenal medullae	Secretion of epinephrine and norepinephrine (nicotinic ACh receptors).	No known effect.
Lacrimal (tear)	Slight secretion of tears (α).	Secretion of tears.
Pancreas	Inhibits secretion of digestive enzymes and the hormone insulin (α_2); promotes secretion of the hormone glucagon (β_2).	Secretion of digestive enzymes and the hormone insulin.
Posterior pituitary	Secretion of antidiuretic hormone (ADH) (β_1).	No known effect.
Pineal	Increases synthesis and release of melatonin (β).	No known effect.
Sweat	Increases sweating in most body regions (muscarinic ACh receptors); sweating on palms and soles (α_1).	No known effect.
Adipose tissue†	Lipolysis (breakdown of triglycerides into fatty acids and glycerol) (β_1); release of fatty acids into blood (β_1 and β_3).	No known effect.
Liver†	Glycogenolysis (conversion of glycogen into glucose); gluconeogenesis (conversion of noncarbohydrates into glucose); decreased bile secretion (α and β_2).	Glycogen synthesis; increased bile secretion.
Kidney, juxtaglomerular cells†	Secretion of renin (β_1).	No known effect.
CARDIAC (HEART) MUSCLE		
	Increased heart rate and force of atrial and ventricular contractions (β_1).	Decreased heart rate; decreased force of atrial contraction.
SMOOTH MUSCLE		
Iris, radial muscle	Contraction → dilation of pupil (α_1).	No known effect.
Iris, circular muscle	No known effect.	Contraction → constriction of pupil.
Ciliary muscle of eye	Relaxation for distant vision (β_2).	Contraction for close vision.
Lungs, bronchial muscle	Relaxation → airway dilation (β_2).	Contraction → airway constriction.
Gallbladder and ducts	Relaxation (β_2).	Contraction → increased release of bile into small intestine.
Stomach and intestines	Decreased motility and tone (α_1, α_2, β_2); contraction of sphincters (α_1).	Increased motility and tone; relaxation of sphincters.
Spleen	Contraction and discharge of stored blood into general circulation (α_1).	No known effect.
Ureter	Increases motility (α_1).	Increases motility (?).
Urinary bladder	Relaxation of muscular wall (β_2); contraction of sphincter (α_1).	Contraction of muscular wall; relaxation of sphincter.
Uterus	Inhibits contraction in nonpregnant women (β_2); promotes contraction in pregnant women (α_1).	Minimal effect.
Sex organs	In males : contraction of smooth muscle of ductus (vas) deferens, seminal vesicle, prostate → ejaculation of semen (α_1).	Vasodilation; erection of clitoris (females) and penis (males).
Hair follicles, arrector pili muscle	Contraction → erection of hairs (α_1).	No known effect.

VASCULAR SMOOTH MUSCLE		
Salivary gland arterioles	Vasoconstriction, which decreases secretion (α_1).	Vasodilation, which increases K^+ and water secretion.
Gastric gland arterioles	Vasoconstriction, which inhibits secretion (α_1).	Secretion of gastric juice.
Intestinal gland arterioles	Vasoconstriction, which inhibits secretion (α_1).	Secretion of intestinal juice.
Coronary (heart) arterioles	Relaxation → vasodilation (β_2); contraction → vasoconstriction (α_1, α_2); contraction → vasoconstriction (muscarinic ACh receptors).	Contraction → vasoconstriction.
Skin and mucosal arterioles	Contraction → vasoconstriction (α_1).	Vasodilation, which may not be physiologically significant.
Skeletal muscle arterioles	Contraction → vasoconstriction (α_1); relaxation → vasodilation (β_2); relaxation → vasodilation (muscarinic ACh receptors).	No known effect.
Abdominal viscera arterioles	Contraction → vasoconstriction (α_1, β_2).	No known effect.
Brain arterioles	Slight contraction → vasoconstriction (α_1).	No known effect.
Kidney arterioles	Constriction of blood vessels → decreased urine volume (α_1).	No known effect.
Systemic veins	Contraction → constriction (α_1); relaxation → dilation (β_2).	No known effect.

INTEGRATION AND CONTROL OF AUTONOMIC FUNCTIONS

Autonomic reflexes

Autonomic reflexes are responses that occur when nerve impulses pass through an autonomic reflex arc. These reflexes play a key role in regulating controlled conditions in the body, such as *blood pressure*, by adjusting heart rate, force of ventricular contraction, and blood vessel diameter; *digestion*, by adjusting the motility (movement) and muscle tone of the gastrointestinal tract; and *defecation* and *urination*, by regulating the opening and closing of sphincters.

The components of an autonomic reflex arc are as follows:

• **Receptor**: in an autonomic reflex arc is the distal end of a sensory neuron, which responds to a stimulus and produces a change that will ultimately trigger nerve impulses. Autonomic sensory receptors are mostly associated with interoceptors.

• **Sensory neuron.** Conducts nerve impulses from receptors to the CNS.

• **Integrating center.** Interneurons within the CNS relay signals from sensory neurons to motor neurons. The main integrating centers for most autonomic reflexes are located in the hypothalamus and brain stem. Some autonomic reflexes, such as those for urination and defecation, have integrating centers in the spinal cord.

• **Motor neurons.** Nerve impulses triggered by the integrating center propagate out of the CNS along motor neurons to an effector. In an autonomic reflex arc, two motor neurons connect the CNS to an effector: The preganglionic neuron conducts motor impulses from the

CNS to an autonomic ganglion, and the postganglionic neuron conducts motor impulses from an autonomic ganglion to an effector.

• **Effector.** In an autonomic reflex arc, the effectors are smooth muscle, cardiac muscle, and glands, and the reflex is called an autonomic reflex.

Autonomic control by higher centers

The hypothalamus is the major control and integration center of the ANS. The hypothalamus receives sensory input related to visceral functions, olfaction (smell), and gustation (taste), as well as changes in temperature, osmolarity, and levels of various substances in blood. It also receives input relating to emotions from the limbic system. Output from the hypothalamus influences autonomic centers in both the brain stem (such as the cardiovascular, salivation, swallowing, and vomiting centers) and the spinal cord (such as the defecation and urination reflex centers in the sacral spinal cord).

The posterior and lateral parts of the hypothalamus control the sympathetic division. Stimulation of these areas produces an increase in heart rate and force of contraction, a rise in blood pressure due to constriction of blood vessels, an increase in body temperature, dilation of the pupils, and inhibition of the gastrointestinal tract.

In contrast, the anterior and medial parts of the hypothalamus control the parasympathetic division. Stimulation of these areas results in a decrease in heart rate, lowering of blood pressure, constriction of the pupils, and increased secretion and motility of the gastrointestinal tract.

○ **Applications to the nursing care**

1. MULTIPLE SCLEROSIS

Multiple sclerosis (**MS**) is a demyelinating disease; that is, it involves deterioration of the myelin sheath of neurons in the central nervous system. Without the myelin sheath, the impulses of these neurons are short-circuited and do not reach their proper destinations, and the neuron axons are damaged and gradually die.

Multiple sclerosis is an **autoimmune** disorder that may be triggered by a virus or bacterial infection. Research has also uncovered a genetic component to some clusters of MS cases in families. Exactly how such genes would increase a person's susceptibility to an autoimmune disease is not yet known.

In MS, the autoantibodies destroy the oligodendrocytes, the myelin-producing neuroglia of the central nervous system, which results in the formation of scleroses, or plaques of scar tissue, that do not provide electrical insulation or protect the axon.

Because loss of myelin may occur in many parts of the central nervous system, the symptoms vary, but they usually include muscle weakness or paralysis, numbness or partial loss of sensation, double vision, and loss of spinal cord reflexes, including those for urination and defecation. The first symptoms usually appear between the ages of 20 and 40 years, and the disease may progress either slowly or rapidly. Some MS patients have **remissions**, periods of time when their symptoms diminish, but remissions and progression of the disease are not predictable. There is still no cure for MS, but therapies include suppression of the immune response, and interferon, which seems to prolong remissions in some patients.

The possibility of stimulating remyelination of neurons is also being investigated.

2. SHINGLES

Shingles is caused by the same virus that causes chickenpox: the herpes varicella-zoster virus. Varicella is chickenpox, which many of us probably had as children (there is now a vaccine). When a person recovers from chickenpox, the virus may survive in a dormant (inactive) state in the dorsal root ganglia of some spinal nerves. For most people, the immune system is able to prevent reactivation of the virus. With increasing age, however, the immune system is not as effective, and the virus may become active and cause zoster, or shingles.

The virus is present in sensory neurons, often those of the trunk, but the damage caused by the virus is seen in the skin over the affected nerve. The raised, red lesions of shingles are often very painful and follow the course of the nerve on the skin external to it.

Pain may continue even after the rash heals; this is postherpetic neuralgia. Occasionally the virus may affect a cranial nerve and cause facial paralysis called Bell's palsy (7th cranial) or extensive facial lesions, or, rarely, blindness. Although not a cure, some antiviral medications lessen the duration of the illness. A vaccine is being developed for adults. Though it may not completely prevent shingles, it is expected to lessen the chance of postherpetic neuralgia.

3. SPINAL CORD INJURIES

Injuries to the spinal cord are most often caused by auto accidents, falls, and gunshot wounds. The most serious injury is transection, or severing, of the spinal cord. If, for example, the spinal cord is severed at the level of the 8th thoracic segment, there will be paralysis and loss of sensation below that level. Another consequence is spinal shock, the at least- temporary loss of spinal cord reflexes. In this example, the spinal cord reflexes of the lower trunk and legs will not occur. The stretch reflexes and flexor reflexes of the legs will be at least temporarily abolished, as will the urination and defecation reflexes.

Although these reflexes do not depend directly on the brain, spinal cord neurons depend on impulses from the brain to enhance their own ability to generate impulses. As spinal cord neurons below the injury recover their ability to generate impulses, these reflexes, such as the patellar reflex, often return. Urination and defecation reflexes may also be reestablished, but the person will not have an awareness of the need to urinate or defecate.

Nor will voluntary control of these reflexes be possible, because inhibiting impulses from the brain can no longer reach the lower segments of the spinal cord. Potentially less serious injuries are those in which the spinal cord is crushed rather than severed, and treatment is aimed at preserving whatever function remains. Minimizing inflammation and stimulating the production of nerve growth factors are aspects of such treatment. Perhaps the most challenging research is the attempt to stimulate severed spinal cords to regenerate. Partial success has been achieved in rats and mice, with Schwann cells transplanted from their peripheral nerves and nerve growth factors produced by genetically engineered cells. The use of stem cells has also been successful in rats. The researchers caution, however, that it will take some time before their procedures will be tested on people.

4. CEREBROVASCULAR ACCIDENTS

A **cerebrovascular accident** (**CVA**), or **stroke**, is damage to a blood vessel in the brain, resulting in lack of oxygen to that part of the brain. Possible types of vessel damage are thrombosis or hemorrhage. A **thrombus** is a blood clot, which most often is a consequence of atherosclerosis, abnormal lipid deposits in cerebral arteries. The rough surface stimulates clot formation, which obstructs the blood flow to the part of the brain supplied by the artery.

The symptoms depend on the part of the brain affected and may be gradual in onset if clot formation is slow. Approximately 80% of CVAs are of this type. A hemorrhage, the result of arteriosclerosis or **aneurysm** of a cerebral artery, allows blood out into brain tissue, which destroys brain neurons by putting excessive pressure on them as well as depriving them of oxygen. Onset of symptoms in this type of CVA is usually rapid. If, for example, the CVA is in the left frontal lobe, paralysis of the right side of the body will occur.

Speech may also be affected if the speech areas are involved. Some CVAs are fatal because the damage they cause is very widespread or affects vital centers in the medulla or pons.

For CVAs of the thrombus type, a clot-dissolving drug may help reestablish blood flow. To be effective, however, the drug must be administered within 3 hours of symptom onset Recovery from a CVA depends on its location and the extent of damage, as well as other factors. One of these is the redundancy of the brain.

Redundancy means repetition or exceeding what is necessary; the cerebral cortex has many more neurons than we actually use in daily activities. The characteristic of plasticity means that these neurons are available for use, especially in younger people (less than 50 years of age). When a patient recovers from a disabling stroke, what has often happened is that the brain has established new pathways, with previously little-used neurons now carrying impulses “full time.” Such recovery is highly individual and may take months. Yet another important factor is that CVA patients be started on rehabilitation therapy as soon as their condition permits.

5. APHASIA

Our use of language sets us apart from other animals and involves speech, reading, and writing. Language is the use of symbols (words) to designate objects and to express ideas. Damage to the speech areas or interpretation areas of the cerebrum may impair one or more aspects of a person's ability to use language; this is called **aphasia**.

Aphasia may be a consequence of a cerebrovascular accident, or of physical trauma to the skull and brain such as a head injury sustained in an automobile accident. If the motor speech (Broca's) area is damaged, the person is still able to understand written and spoken words and knows what he wants to say, but he cannot say it. Without coordination and impulses from the motor speech area, the muscles used for speech cannot contract to form words properly. Auditory aphasia is "**word deafness**," caused by damage to an interpretation area.

The person can still hear but cannot comprehend what the words mean. Visual aphasia is "**word blindness**"; the person can still see perfectly well, but cannot make sense of written words (the person retains the ability to understand spoken words). Imagine how you would feel if wms qsbbcljw jmqr rfc yzgjgrw rm pcyb. Frustrating isn't it? You know that those symbols are letters, but you canno decode" them right away. Those "words" were formed by shifting the alphabet two letters (A _ C, B _ D, C _ E, etc.), and would normally be read as: "you suddenly lost the ability to read." That may give you a small idea of what word blindness is like.

6. ALZHEIMER'S DISEASE

The first symptoms, which usually begin after age 65, are memory lapses and slight personality changes. As the disease progresses, there is total loss of memory, reasoning ability, and personality, and those with advanced disease are unable to perform even the simplest tasks or self-care. Structural changes in the brains of Alzheimer's patients may be seen at autopsy. Neurofibrillary tangles are abnormal fibrous proteins found in cells of the cerebral cortex in areas important for memory and reasoning. Also present are plaques made of another protein called beta-amyloid that are damaging to neurons. A defective gene has been found in some patients who have late-onset Alzheimer's disease, the most common type.

Yet another gene seems to trigger increased synthesis of beta-amyloid. Some research is focused on the interaction of these genes and on inflammation as a contributing factor to this

type of brain damage. It is likely that the treatment of Alzheimer's disease will one day mean delaying its onset with a variety of medications, each targeted at a different aspect of this complex disease. Early diagnosis will be very important, and this is yet another avenue of research.

7. PARKINSON'S DISEASE

Parkinson's disease is a disorder of the basal ganglia whose cause is unknown, and though there is a genetic component in some families, it is probably not the only factor. The disease usually begins after the age of 60. Neurons in the basal ganglia that produce the neurotransmitter dopamine begin to degenerate and die, and the deficiency of dopamine causes specific kinds of muscular symptoms.

Tremor, or involuntary shaking, of the hands is the most common symptom. The accessory movements regulated by the basal ganglia gradually diminish, and the affected person walks slowly without swinging the arms.

A mask-like face is characteristic of this disease, as the facial muscles become rigid. Eventually all voluntary movements become slower and much more difficult, and balance is seriously impaired. Dopamine itself cannot be used to treat Parkinson's disease because it does not cross the blood–brain barrier. A substance called L-dopa does cross and can be converted to dopamine by brain neurons.

Unfortunately, L-dopa begins to lose its therapeutic effectiveness within a few years. Other medications in use do not provide a cure. Some researchers suggest that implants of stem cells may offer the best hope of meaningful therapy.

8. LUMBAR PUNCTURE

A **lumbar puncture** (spinal tap) is a diagnostic procedure that involves the removal of cerebrospinal fluid to determine its pressure and constituents. As the name tells us, the removal, using a syringe, is made in the lumbar area. Because the spinal cord ends between the 1st and 2nd lumbar vertebrae, the needle is usually inserted between the 4th and 5th

lumbar vertebrae. The meningeal sac containing cerebrospinal fluid extends to the end of the lumbar vertebrae, permitting access to the cerebrospinal fluid with little chance of damaging the spinal cord.

Cerebrospinal fluid is a circulating fluid and has a normal pressure of 70 to 200 mmH_2O. An abnormal pressure usually indicates an obstruction in circulation, which may be caused by infection, a tumor, or mechanical injury. Other diagnostic tests would be needed to determine the precise cause. Perhaps the most common reason for a lumbar puncture is suspected **meningitis**, which may be caused by several kinds of bacteria.

If the patient does have meningitis, the cerebrospinal fluid will be cloudy rather than clear and will be examined for the presence of bacteria and many white blood cells. A few WBCs in CSF is normal, because WBCs are found in all tissue fluid. Another abnormal constituent of cerebrospinal fluid is red blood cells. Their presence indicates bleeding somewhere in the central nervous system.

There may be many causes, and again, further testing would be necessary.