Introduction

- The nervous system, along with the endocrine system, helps control and integrate all body activities.
- In humans, the nervous system serves three basic functions:
  - Sensing changes (sensory)
  - Interpreting those changes (integrative)
  - Reacting to those changes (motor)
- The branch of medical science that deals with the normal functioning and disorders of the nervous system is called neurology.

Nervous System Divisions

- The central nervous system (CNS) consists of the brain and spinal cord.
- The peripheral nervous system (PNS) consists of cranial and spinal nerves; it has sensory (afferent) and motor (efferent) components.
  - The sensory system includes a variety of different receptors as well as sensory neurons.
  - The motor system conducts nerve impulses from the CNS to muscles and glands.

Nervous System Divisions

- The PNS is also subdivided into somatic (voluntary) and autonomic (involuntary) nervous systems.
  - The somatic nervous system (SNS) consists of neurons that conduct impulses from cutaneous and special sense receptors to the CNS, and motor neurons that conduct impulses from the CNS to skeletal muscle tissue.
  - The autonomic nervous system (ANS) contains sensory neurons from visceral organs and motor neurons that convey impulses from the CNS to smooth muscle tissue, cardiac muscle tissue, and glands.

Histology Of Nervous Tissue

Neuroglia

- Neuroglia (or glia) are specialized tissue cells that support neurons, attach neurons to blood vessels, produce the myelin sheath around axons, and carry out phagocytosis.
- Neuroglia include astrocytes, oligodendrocytes, microglia, ependymal cells, neurolemmocytes (Schwann cells), and satellite cells (Exhibit 12.1).  
  - Two types of neuroglia produce myelin sheaths; oligodendrocytes myelinate axons in the CNS and neurolemmocytes (Schwann cells) myelinate axons in the PNS.

Histology Of Nervous Tissue

Neurons

- Most neurons, or nerve cells, consist of a cell body (soma), many dendrites, and usually a single axon. The dendrites conduct impulses from receptors or other neurons to the cell body.
  - The axon conducts nerve impulses from the neuron to the dendrites or cell body of another neuron or to an effector organ of the body (muscle or gland).
  - A nerve fiber is a general term for any neuronal process--dendrite or axon (usually an axon and its sheaths); the processes of neurons are arranged into bundles called nerves in the PNS and tracts in the CNS. Nerve cell bodies in the PNS form clusters called ganglia.

Histology Of Nervous Tissue

Neurons

- Axonal transport, a natural mechanism of intracellular transport in neurons, is exploited by certain microorganisms (such as the herpes and rabies viruses and the tetanus bacterium’s toxin) to reach other parts of the nervous system; genetically altered viruses that are able to utilize the fast axonal transport system may become a tool for treating genetic disorders of the CNS someday.
- On the basis of the number of processes extending from the cell body (structure), neurons are classified as multipolar, bipolar, and unipolar.
Histology Of Nervous Tissue

- On the basis of the direction in which they transmit nerve impulses (function), afferent (sensory) neurons conduct impulses from receptors to the CNS; association (interneurons or connecting) neurons conduct impulses to other neurons, including motor neurons; and efferent (motor) neurons conduct impulses to effectors (muscles or glands).

Histology Of Nervous Tissue

Gray and White Matter

- White matter is composed of aggregations of myelinated processes whereas gray matter contains nerve cell bodies, dendrites, and axon terminals or bundles of unmyelinated axons and neuroglia.
- In the spinal cord, gray matter forms an H-shaped inner core, surrounded by white matter; in the brain a thin outer shell of gray matter covers the cerebral hemispheres.
- A nucleus is a mass of nerve cell bodies and dendrites inside the CNS.

Neurophysiology

Ion Channels

- The two basic types of ion channels are leakage (nongated) and gated.
- Leakage (nongated) channels are always open.
- Gated channels open and close in response to some sort of stimulus.
  - There are four types of gated channels: voltage-gated, chemically gated, mechanically gated, and light-gated.
  - Voltage-gated ions channels in nerve and muscle plasma membranes gives these cells excitability (irritability).
  - The presence of chemically, mechanically, or light-gated ion channels in a membrane permits the appropriate stimulus to cause a graded potential.

Resting Membrane Potential

- The membrane of a nonconducting neuron is positive outside and negative inside owing to the distribution of different ions across the membrane and the relative permeability of the membrane toward Na$^+$ and K$^+$.
- A typical value for the resting membrane potential (RMP) is -70 mV, and the membrane is said to be polarized.
- The sodium-potassium pumps compensate for slow leakage of Na$^+$ into the cell by pumping it back out.

Graded Potentials

- Graded potentials are produced by the opening and closing of chemically gated channels in response to chemicals called neurotransmitters or physical changes.
- Flow of ions through a particular channel may cause either depolarization or hyperpolarization relative to the resting membrane potential, depending on the charge of the ion and the direction of flow.

Action Potential (impulse)

- During an action potential (impulse), voltage-gated Na$^+$ and K$^+$ channels open in sequence. This results first in depolarization, the loss and then reversal of membrane polarization (from -70 to 0 to +30 mV), and then in repolarization, the recovery of the RMP (from+30 to -70 mV).
- During the refractory period, another impulse cannot be generated at all (absolute refractory period) or can be triggered only by a suprathreshold stimulus (relative refractory period).
Neurophysiology

Action Potential (impulse)
- An action potential conducts or propagates (travels) from point to point along the membrane; the traveling action potential is a nerve impulse.
- Local anesthetics prevent opening of voltage-gated Na+ channels so nerve impulses cannot pass the obstructed region.
- According to the all-or-none principle, if a stimulus is strong enough to generate an action potential, the impulse travels at a constant and maximum strength for the existing conditions; a stronger stimulus will not cause a larger impulse.

Neurophysiology

Action Potential (impulse)
- Nerve impulse conduction in which the impulse jumps from neurofibral node to node is called saltatory conduction.
- The propagation speed of a nerve impulse is not related to stimulus strength.
  - Larger-diameter fibers conduct impulses faster than those with smaller diameters.
  - Myelinated fibers conduct impulses faster than unmyelinated fibers.
  - Nerve fibers conduct impulses faster when warmed and slower when cooled.
- The intensity of a stimulus is coded in the rate of impulse production, i.e., the frequency of action potentials.

Neurophysiology

Transmission at Synapses
- A synapse is the functional junction between one neuron and another or between a neuron and an effector such as a muscle or gland.
  - At an electrical synapse, ionic current spreads directly from one cell to another through gap junctions they are faster than chemical synapses and they can synchronize the activity of a group of neurons or muscle fibers.
  - At a chemical synapse, there is only one-way information transfer from a presynaptic neuron to a postsynaptic neuron.

Neurophysiology

Transmission at Synapses
- An excitatory neurotransmitter is one that can depolarize or make less negative the postsynaptic neuron’s membrane, bringing the membrane potential closer to threshold.
  - A depolarizing postsynaptic potential (PSP) is called an excitatory postsynaptic potential (EPSP).
  - Although a single EPSP normally does not initiate a nerve impulse, the postsynaptic neuron does become more excitable; it is already partially depolarized and thus more likely to reach threshold when the next EPSP occurs. This effect is called summation.

Neurophysiology

Transmission at Synapses
- An inhibitory neurotransmitter hyperpolarizes the membrane of the postsynaptic neuron, making the inside more negative and generation of a nerve impulse more difficult; a hyperpolarizing PSP is inhibitory and is termed an inhibitory postsynaptic potential (IPSP).
- Neurotransmitter is removed from the synaptic cleft in three ways: diffusion, enzymatic degradation, and uptake into cells (neurons and glia).

Neurophysiology

Transmission at Synapses
- Certain synapses can modify the quantity of neurotransmitter released at other synapses.
  - Presynaptic facilitation increases the amount of neurotransmitter released by a presynaptic neuron whereas presynaptic inhibition decreases it.
  - Presynaptic facilitation and inhibition may last for several minutes or hours and may be important in learning and memory.
Transmission at Synapses

- There are important differences between action potentials (APs) and postsynaptic potentials (PSPs) relating to propagation distance, amplitude, and refractory periods.
- If several presynaptic end bulbs release their neurotransmitter at about the same time, the combined effect may generate a nerve impulse due to summation; summation may be spatial or temporal.
- The postsynaptic neuron is an integrator, receiving and integrating signals, then responding.

Neurotransmitters

- Both excitatory and inhibitory neurotransmitters are present in the CNS and PNS; the same neurotransmitter may be excitatory in some locations and inhibitory in others.
- Important neurotransmitters include acetylcholine (ACh), glutamate, aspartate, gamma aminobutyric acid (GABA), glycine, norepinephrine, epinephrine, and dopamine.
- Strychnine binds to and blocks glycine receptors in the spinal cord, obstructing normal inhibition of skeletal muscle activity and producing massive tetanic contractions.

Alteration of Impulse Conduction and Synaptic Transmission

- A neuron’s chemical and physical environment influences both impulse conduction and synaptic transmission.
- Chemical synaptic transmission may be stimulated or blocked by affecting neurotransmitter synthesis, release, removal, or the receptor site.
- Alkalosis, acidosis, mechanical pressure, hypnotics, tranquilizers, anesthetics, caffeine, benzedrine, nicotine, botulinum toxin, neostigmine, physostigmine, disopropyl fluorophosphate, and curare may all modify impulse conduction and/or synaptic transmission.

Neuronal Circuits

- Neurons in the central nervous system are organized into definite patterns called neuronal pools; each pool differs from all others and has its own role in regulating homeostasis. A neuronal pool may contain thousands or even millions of neurons.
- Neuronal pools are organized into circuits. These include simple series, diverging, converging, reverberating (oscillatory), and parallel after-discharge circuits.

Regeneration Of Nervous Tissue

- Around 6 months of age, the neuronal cell body loses its mitotic apparatus and is no longer able to divide; a neuron destroyed is permanently lost, and only some types of damage may be repaired.
- In the PNS, damage to myelinated axons and dendrites may be repaired if the cell body remains intact and if the neurolemmocytes (Schwann cells) that perform the myelination remain active; the neurolemmina forms a tube that appears to aid regeneration.
- In the CNS, injury to the brain or spinal cord usually is permanent.
- Large and distinct research efforts are directed at using electrical stimulation and nerve growth factor (or similar substances) to promote regrowth of damaged neurons.
Regeneration Of Nervous Tissue

Damage and Repair of Peripheral Neurons
● When there is damage to an axon, usually there are changes, called chromatolysis, which occur in the cell body of the affected cell; this causes swelling of the cell body and peaks between 10 and 20 days after injury.
● By the third to fifth day, degeneration of the distal portion of the neuronal process and myelin sheath (Wallerian degeneration) occurs; afterward, macrophages phagocytize the remains. Retrograde degeneration of the proximal portion of the fiber extends only to the first neurofibral node.
● Regeneration follows chromatolysis; synthesis of RNA and protein accelerates, favoring rebuilding of the axon and often taking several months.
● Function is never completely restored after a nerve is severed.

Regeneration Of Nervous Tissue

Epilepsy
● The second most common neurological disorder after stroke is epilepsy, which affects 1% of the population; it is characterized by shod, recurrent, periodic attacks of motor, sensory, or psychological malfunction called epileptic seizures.
● These seizures are initiated by abnormal synchronous electrical discharges from millions of neurons in the brain, perhaps resulting from abnormal reverberating circuits.

Regeneration Of Nervous Tissue

Epilepsy
● Epilepsy has many causes, including brain damage at birth, the most common cause; metabolic disturbances, infections, toxins, vascular disturbances, head injuries, and tumors and abscesses of the brain. Most epileptic seizures, however, are idiopathic (i.e., they have no demonstrable cause).
● Epileptic seizures can be eliminated or alleviated by drugs that depress neuronal excitability, such as valproic acid, phenytoin, and phenobarbital.
Introduction

- The brain is the center for registering sensations, correlating them with one another and with stored information, making decisions, and taking action.
  - It is also the center for intellect, emotions, behavior, and memory.
- In this chapter we will consider the principal parts of the brain, how the brain is protected and nourished, and how it is related to the spinal cord and to the 12 pairs of cranial nerves.

Brain

- During embryological development, brain vesicles (prosencephalon, mesencephalon, and rhombencephalon) are formed and serve as forerunners of various parts of the brain.
- The diencephalon develops into the thalamus and hypothalamus, the telencephalon forms the cerebrum, the mesencephalon develops into the midbrain, the myelencephalon forms the medulla, and the metencephalon develops into the pons and cerebellum.
- The principal parts of the brain are the brain stem, diencephalon, cerebrum, and cerebellum.

Protection and Coverings of the Brain

- The brain is protected by cranial bones, meninges, and cerebrospinal fluid.
- The cranial meninges are continuous with the spinal meninges and are named dura mater, arachnoid, and pia mater.

Cerebrospinal Fluid

- Cerebrospinal fluid (CSF) is formed by filtration from networks of capillaries called choroid plexuses (found in the ventricles) and circulates through the subarachnoid space, ventricles, and central canal.

Cerebrospinal Fluid

- Cerebrospinal fluid provides mechanical protection, chemical protection, and circulation of nutrients and waste products.
- Materials entering CSF from the choroid capillaries cannot leak between the surrounding ependymal cells; these constitute the blood-cerebrospinal fluid barrier, which permits certain substances to enter the fluid but excludes others and protects the brain and spinal cord from harmful elements.

Cerebrospinal Fluid

- Most of the fluid is absorbed by the arachnoid villi of the superior sagittal blood sinus; this absorption normally occurs at the same rate at which CSF is produced in the choroid plexuses, thereby maintaining a relatively constant CSF volume and pressure.
- If CSF cannot circulate or drain properly due to some obstruction in the ventricles or subarachnoid space, a condition called hydrocephalus develops. The fluid buildup causes increased pressure on the brain, either internally or externally, depending on where the blockage is present. Surgically draining the ventricles and diverting the flow of CSF by an implanted shunt can positively and dramatically affect the individual’s prognosis.
Blood Supply of the Brain

- The blood supply to the brain is via the cerebral arterial circle (circle of Willis) (see figures and exhibits in Chapter 21).
- Although the brain comprises only about 2% of the total body weight, it utilizes about 20% of the oxygen used by the entire body. The brain is one of the most metabolically active organs of the body, and the amount of oxygen it uses varies with the degree of mental activity.
- Any interruption of the oxygen supply to the brain can result in weakening, permanent damage, or death of brain cells. Interruption of the mother’s blood supply to a child during childbirth before it can breathe may result in paralysis, mental retardation, epilepsy, or death.
- Because carbohydrate storage in the brain is limited, the supply of glucose to the brain must be continuous. Glucose deficiency may produce mental confusion, dizziness, convulsions, and unconsciousness.
- The blood-brain barrier (BBB) is a concept that explains the differential rates of passage of certain materials from the blood into the brain.
  - The blood-brain barrier functions as a selective barrier to protect brain cells from harmful substances.
  - An injury to the brain due to trauma, inflammation, or toxins causes a breakdown of the BBB, permitting the passage of normally restricted substances into brain tissue. The BBB may also prevent entry of drugs that could be used as therapy for brain cancer or other CNS disorders, so research is exploring ways to transport drugs past the BBB.

Brain Stem: Anatomy and Physiology

- Medulla
  - The medulla oblongata, or just medulla, is continuous with the upper part of the spinal cord and contains portions of both motor and sensory tracts.
  - It contains nuclei that are reflex centers for regulation of heart rate, respiratory rate, vasoconstriction, swallowing, coughing, vomiting, sneezing, and hiccuping; the first three are considered vital reflexes.
  - It also contains the nuclei of origin for cranial nerves VIII (cochlear and vestibular branches) through XII.
  - It also contains olivary and vestibular nuclei.

Brain Stem: Anatomy and Physiology: Pons

- The pons is located superior to the medulla. It connects the spinal cord with the brain and links parts of the brain with one another by way of tracts.
- It relays nerve impulses related to voluntary skeletal movements from the cerebral cortex to the cerebellum.
- It contains the nuclei for cranial nerves V through VII and the vestibular branch of VIII.
- The pons also contains the pneumotaxic and apneustic areas, which help control respiration along with the respiratory center in the medulla.

Brain Stem: Anatomy and Physiology: Midbrain

- The midbrain, or mesencephalon, connects the pons and diencephalon. It conveys motor impulses from the cerebrum to the cerebellum and spinal cord, sends sensory impulses from the spinal cord to the thalamus, and regulates auditory and visual reflexes.
- It also contains the red nucleus and the nuclei of origin for cranial nerves III and IV.

Brain Stem: Anatomy and Physiology: Reticular Formation

- A large portion of the brain stem (medulla, pons, and midbrain), called the reticular formation, consists of small areas of gray matter interspersed among fibers of white matter; it has both sensory and motor functions.
- It helps regulate muscle tone, alerts the cortex to incoming sensory signals (reticular activating system, or RAS), and is responsible for maintaining consciousness and awakening from sleep.
Nervous Tissue: Anatomy and Physiology 121:

**Cerebellum**
- The cerebellum occupies the inferior and posterior aspects of the cranial cavity. It consists of two hemispheres and a central, constricted vermis.
- It is attached to the brain stem by three pairs of cerebellar peduncles.
- The cerebellum functions in the coordination of skeletal muscle contractions and in the maintenance of normal muscle tone, posture, and balance.

**Diencephalon: (Thalamus and Hypothalamus)**
- The pineal gland secretes melatonin to influence diurnal cycles in conjunction with the hypothalamus.
- **Thalamus**
  - The thalamus is located superior to the midbrain and contains nuclei that serve as relay stations for all sensory impulses, except smell, to the cerebral cortex
  - It also registers conscious recognition of pain and temperature and some awareness of light touch and pressure.
- **Hypothalamus**
  - The hypothalamus is found inferior to the thalamus, has four major regions (mammillary, tuberal, supraoptic, and preoptic), controls many body activities, and is one of the major regulators of homeostasis.
  - The hypothalamus has a great number of functions; the chief ones include the following:
    - It controls and integrates the autonomic nervous system, which regulates contraction of smooth muscle, cardiac muscle, and secretions of many glands.
  - The hypothalamus has a great number of functions; the chief ones include the following:
    - It is the principal intermediary between the nervous system and the endocrine system--the two major control systems of the body. When the hypothalamus detects certain changes in the body, it releases a variety of chemicals called regulating hormones (or factors) that stimulate or inhibit specific cells in the anterior pituitary gland.
    - It functions in feelings of rage and aggression
    - It aids in controlling body temperature.
  - The hypothalamus has a great number of functions; the chief ones include the following:
    - It regulates food intake through two centers, the feeding (hunger) center and the satiety center.
    - It contains a thirst center that initiates drinking when extracellular fluid osmotic pressure rises above normal.
    - It is one of the centers that maintains the waking state and sleep patterns.

**Cerebrum**
- The cerebrum is the largest part of the brain.
  - The surface layer, the cerebral cortex, is 2-4 mm thick and is composed of gray matter. The cortex contains billions of neurons.
  - The cortex contains gyri (convolutions), deep grooves called fissures, and shallower sulci.
  - Beneath the cortex lies the cerebral white matter, tracts that connect parts of the brain with itself and other parts of the nervous system.
- The cerebrum is nearly separated into right and left halves, called hemispheres, by the longitudinal fissure. Internally it remains connected by the corpus callosum, a bundle of transverse white fibers.

**Cerebrum: Lobes**
- Each cerebral hemisphere is further subdivided into four lobes by sulci or fissures.
- The cerebral lobes are named the frontal, parietal, temporal, and occipital.
- A fifth part of the cerebrum, the insula, lies deep to the parietal, frontal, and temporal lobes and cannot be seen in an external view of the brain.
Nervous Tissue: Anatomy and Physiology 121:

Cerebrum: White Matter
- The white matter is under the cortex and consists of myelinated axons running in three principal directions.
- Association fibers connect and transmit nerve impulses between gyri in the same hemisphere.
- Commissural fibers connect gyri in one cerebral hemisphere to the corresponding gyri in the opposite hemisphere.
- Projection fibers form ascending and descending tracts that transmit impulses from the cerebrum to other parts of the brain and spinal cord.

Basal Ganglia: (Cerebral Nuclei)
- The basal ganglia (cerebral nuclei) are paired masses of gray matter in each cerebral hemisphere.
- They are responsible for helping to control muscular movements.

Limbic System
- The limbic system is found in the cerebral hemispheres and diencephalon.
- It functions in emotional aspects of behavior and memory, and is associated with pleasure and pain.

Brain Injuries
- Lapse in memory is one of many effects resulting from brain injuries; brain injuries are commonly associated with head injuries and result in part from displacement and distortion of neuronal tissue at the moment of impact and in part from the release of disruptive chemicals from injured brain cells.
- Various degrees of brain injury are described by the terms concussion, contusion, and laceration.

Functional Areas of the Cerebral Cortex
- Specific types of sensory, motor, and integrative signals are processed in certain cerebral regions.
- The sensory areas of the cerebral cortex are concerned with the reception and interpretation of sensory impulses.
- The motor areas are the regions that govern muscular movement.
- The association areas are concerned with complex integrative functions such as memory, emotions, reasoning, will, judgment, personality traits, and intelligence.

Electroencephalogram (EEG)
- Brain waves generated by the cerebral cortex are recorded as an electroencephalogram (EEG).
- An EEG may be used to diagnose epilepsy and other seizure disorders, infectious diseases, tumors, trauma, hematomas, metabolic abnormalities, degenerative diseases, and periods of unconsciousness and confusion; it may also provide useful information regarding sleep and wakefulness.
- An EEG may also be one criterion in confirming brain death (complete absence of brain waves in two EEGs taken 24 hours apart).

Brain Lateralization
- The two hemispheres of the brain are not bilaterally symmetrical, either anatomically or functionally.
- The left hemisphere is more important for right-handed control, spoken and written language, and numerical and scientific skills.
- The right hemisphere is more important for left-handed control, musical and artistic awareness, space and pattern perception, insight, imagination, and generating mental images of sight, sound, touch, taste, and smell.
Neurotransmitters In The Brain

- About 50 substances are either known or strongly suspected neurotransmitters in the brain, which can facilitate, excite, or inhibit postsynaptic neurons (Exhibit 14.2).
- B. Examples of neurotransmitters include acetylcholine (ACh), amino acids (e.g., gamma aminobutyric acid [GABA] and glycine), biogenic amines (e.g., norepinephrine [NE], dopamine [DA], and serotonin [5-HT]), neuropeptides, and recently recognized nitric oxide and perhaps even carbon monoxide (Exhibit 14.3).

Cranial Nerves

- Twelve pairs of cranial nerves originate from the brain.
- The pairs are named primarily on the basis of distribution and numbered by order of attachment to the brain; a summary of cranial nerves and clinical applications related to dysfunction is presented in Exhibit 14.4.
- Some cranial nerves (I, II, and VIII) contain only sensory fibers and are called sensory nerves. The rest are mixed nerves because they contain both sensory and motor fibers.

Aging And The Nervous System

- Age-related effects involve loss of neurons and decreased capacity for sending nerve impulses to and from the brain; processing of information also diminishes.
- Other effects include decreased conduction velocity, slowing of voluntary motor movements, and increased reflex time.
- Degenerative changes and disease states involving the sense organs can alter vision, hearing, taste, smell, and touch.

Developmental Anatomy Of The Nervous System

- The development of the nervous system begins with a thickening of ectoderm called the neural plate.
- The parts of the brain develop from primary and secondary vesicles.

Disorders: Homeostatic Imbalances

- The most common brain disorder is a cerebrovascular accident (CVA, or stroke).
  - CVAs are classified into two principal types: ischemic (the most common type), due to a decreased blood supply, or hemorrhagic, due to a blood vessel in the brain that bursts.
  - Common causes of CVAs are intracerebral hemorrhage, emboli, and atherosclerosis.
  - CVAs are characterized by abrupt onset of persisting neurological symptoms that arise from destruction of brain tissue (infarction).
- A transient ischemic attack (TIA) is an episode of temporary cerebral dysfunction caused by impaired blood flow to the brain.
  - Symptoms include dizziness, weakness, numbness, or paralysis in a limb or in half of the body; drooping of one side of the face; headache; slurred speech or difficulty understanding speech; or a partial loss of vision or double vision.
  - Onset is sudden and a TIA usually persists for only a few minutes, rarely lasting as long as 24 hours.
  - Causes of the impaired blood flow include blood clots, atherosclerosis, and certain blood disorders; TIAS commonly are forerunners of future CVAs.
- Alzheimer’s disease (AD) is a disabling neurological disorder that afflicts about 11% of the population over age 65.
  - Its causes are unknown, its effects are irreversible and devastating, and it has no cure at the present time.
  - It involves widespread intellectual impairment, personality changes, sometimes delirium, and culminates in dementia, the loss of reason and ability to care for oneself.
  - A person with AD usually dies of some complication that affects bedridden patients, such as pneumonia.
Disorders: Homeostatic Imbalances

- Brains of AD victims show three distinct structural abnormalities:
  - Great loss of neurons in specific regions (e.g., hippocampus and cerebral cortex).
  - Plaques of abnormal proteins deposited outside neurons (amyloid plaques).
  - Tangled protein filaments within neurons (neurofibrillary tangles).

- A brain tumor refers to any benign or malignant growth within the cranium.
  - The symptoms include headaches, altered consciousness, vomiting, seizures, visual problems, cranial nerve abnormalities, hormonal syndromes, personality changes, dementia, and sensory or motor deficits that often signal the presence of a tumor result from the increased intracranial pressure from the growing tumor or accompanying edema.

- Cerebral palsy (CP) refers to a group of motor disorders resulting in muscular incoordination and loss of muscle control. It is caused by damage to the motor areas of the brain (parts of the cerebral cortex, cerebellum, or basal ganglia) during fetal life, birth, or infancy. This damage may result from German measles infection of the mother during the first trimester, radiation during gestation, temporary lack of oxygen during birth, or hydrocephalus during infancy.

- Parkinson’s disease (PD), or parkinsonism, is a progressive disorder of the CNS that typically affects victims around age 60.
  - The cause is unknown, but toxic environmental factors are suspected; pathological changes occur in the substantia nigra and basal ganglia and the degeneration of dopamine-producing neurons brings about a shortage of dopamine (DA). The imbalance between coexisting levels of dopamine and acetylcholine (ACh) is thought to bring about most of the symptoms.
  - Unnecessary skeletal muscle contractions result, which often interfere with voluntary movement. Tremor, rigidity, and bradykinesia (slowed movement) are examples of other manifestations of the disorder.

- Multiple sclerosis (MS) is the progressive destruction of myelin sheaths of neurons in the CNS. Impulse transmission is disrupted, often temporarily and repeatedly, although a minority of individuals become totally disabled. The cause of MS is unknown.
Introduction

- The spinal cord and nerves mediate interactions between the central nervous system and the receptors and effectors of the periphery, as well as the site of many reflexes.

Spinal Cord Anatomy

- Protection and Coverings
  - The spinal cord is protected by the vertebral column, meninges, cerebrospinal fluid, and vertebral ligaments.
  - The meninges are three coverings that run continuously around the spinal cord and brain.
    - The outermost layer is the dura mater
    - The middle layer is the arachnoid.
    - The innermost meninx is the pia mater, a thin, transparent connective tissue layer that adheres to the surface of the spinal cord and brain.
  - Inflammation of the meninges is known as meningitis.

External Anatomy of the Spinal Cord

- The spinal cord begins as a continuation of the medulla oblongata and terminates at about the second lumbar vertebra in an adult.
- It contains cervical and lumbar enlargements that serve as points of origin for nerves to the extremities.
- The tapered portion of the spinal cord is the conus medullaris, from which arise the filum terminale and cauda equina.
  - The spinal cord is partially divided into right and left sides by the anterior median fissure and posterior median sulcus
  - Removal of cerebrospinal fluid from the subarachnoid space is called a spinal tap (lumbar puncture). The procedure is used to diagnose pathologies and to introduce antibiotics, contrast media, anesthetics, and chemotherapeutic drugs

Internal Anatomy of the Spinal Cord

- The gray matter of the spinal cord is shaped like the letter H or a butterfly and is surrounded by white matter; the gray matter is divided into horns and the white matte’ into columns.
- In the center of the spinal cord is the central canal, which runs the length of the spinal cord and contains cerebrospinal fluid.

- Parts of the spinal cord observed in cross section are the gray commissure; central canal; anterior, posterior, and lateral gray horns; anterior, posterior, and lateral white columns; and ascending and descending tracts.
- The spinal cord conveys sensory and motor information by way of the ascending and descending tracts, respectively.
Spinal Cord Physiology

- Sensory and Motor Tracts
  - A major function of the spinal cord is to convey nerve impulses from the periphery to the brain (sensory tracts) and to conduct motor impulses from the brain to the periphery (motor tracts).
  - Sensory information from receptors travels up the spinal cord to the brain along two main routes on each side of the cord: the spinothalamic tracts and the posterior column tract.
  - Motor information travels from the brain down the spinal cord to effectors (muscles and glands) along two main descending tracts: the pyramidal tracts and the extrapyramidal tracts.

Reflexes

- The second principal function of the spinal cord is to serve as an integrating center for spinal reflexes; this occurs in the gray matter.
- A reflex is a fast, predictable, automatic response to changes in the environment that helps to maintain homeostasis.
- Reflexes may be spinal, cranial, somatic, or autonomic.

Reflex Arc and Homeostasis

- A reflex arc is the simplest type of pathway; pathways are specific neuronal circuits and thus include at least one synapse.
- The five functional components of a reflex arc are the receptor, sensory neuron, integrating center, motor neuron, and effector.

Reflex Arc and Homeostasis

- Reflexes help to maintain homeostasis by permitting the body to make exceedingly rapid adjustments to homeostatic imbalances.
- Somatic spinal reflexes include the stretch (myostatic) reflex, tendon reflex, flexor (withdrawal) reflex, and crossed extensor reflex; all exhibit reciprocal innervation.
  - A two-neuron or monosynaptic reflex arc contains one sensory neuron and one motor neuron. A stretch reflex, such as the patellar reflex, is an example.
  - The stretch (myostatic) reflex is ipsilateral and is important in maintaining muscle tone and muscle coordination during exercise.
- A polysynaptic reflex arc contains a sensory neuron, an association neuron, and motor neuron. The tendon reflex, flexor (withdrawal) reflex, and crossed extensor reflexes are examples.
- The tendon reflex is ipsilateral and prevents damage to muscles and tendons as a result of stretching.
- The flexor (withdrawal) reflex is ipsilateral and is a protective withdrawal reflex that moves a limb to avoid pain.
- The crossed extensor reflex, which is contralateral, helps to maintain balance during the flexor reflex.
Reflexes are often used for diagnosing disorders of the nervous system and locating injured tissue.

- If a reflex is absent, or abnormal, the damage may be somewhere along a particular conduction pathway.
- Among the clinically important somatic reflexes are the patellar reflex (knee jerk), the Achilles reflex (ankle jerk), the Babinski sign, and the abdominal reflex.

**Spinal Nerves**

**Names**

- The 31 pairs of spinal nerves are named and numbered according to the region and level of the spinal cord from which they emerge.
- There are 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves, and 1 pair of coccygeal nerves.

**Composition and Coverings of Spinal Nerves**

- Spinal nerve axons are grouped within connective tissue sheathes (Figs. 13.11)
  - a fiber is a single axon, within an endoneurium,
  - a fascicle is a bundle of fibers within a perineurium, and
  - a nerve is a bundle of fascicles within an epineurium.

- Roots are the two points of attachment that connect each spinal nerve to a segment of the spinal cord.
  - The posterior, or dorsal (sensory) root contains sensory nerve fibers and conducts nerve impulses from the periphery into the spinal cord; the posterior root ganglion contains the cell bodies of the sensory neurons from the periphery.
  - The anterior, or ventral (motor) root contains motor neuron axons and conducts impulses from the spinal cord to the periphery; the cell bodies of motor neurons are located in the gray matter of the cord.

**Distribution of Spinal Nerves**

- Shortly after passing through its intervertebral foramen, a spinal nerve divides into several branches; these branches are known as rami.
- Branches of a spinal nerve include the dorsal ramus, ventral ramus, meningeal branch, and rami communicantes.
- The ventral rami of spinal nerves, except for T2-T12, form networks of nerves called plexuses.
  - Emerging from the plexuses are nerves bearing names that are often descriptive of the general regions they supply or the course they take.
● The cervical plexus supplies the skin and muscles of the head, neck, and upper part of the shoulders; connects with some cranial nerves; and supplies the diaphragm.
  • Damage to the spinal cord above the origin of the phrenic nerves (C3-C5) causes respiratory arrest.
  • Breathing stops because the phrenic nerves no longer send impulses to the diaphragm.
● The brachial plexus constitutes the nerve supply for the upper extremities and anumber of neck and shoulder muscles.
  • A number of nerve disorders may result from injury to the brachial plexus.
  • Among these injuries are Saturday night palsy, radial nerve damage, median nerve damage, carpal tunnel syndrome, and ulnar nerve damage.
● The lumbar plexus supplies the anterolateral abdominal wall, external genitals, and part of the lower extremities.
  • The largest nerve arising from the lumbar plexus is the femoral nerve.
  • Injury to the femoral nerve is indicated by an inability to extend the leg and by loss of sensation in the skin over the anteromedial aspect of the thigh.
● The sacral plexus supplies the buttocks, perineum, and part of the lower extremities.
  • The largest nerve arising from the sacral plexus (and the largest nerve in the body) is the sciatic nerve.
  • Injury to the sciatic nerve (common peroneal portion) and its branches results in pain from the buttock down the back of the leg, foot drop, an inability to dorsiflex the foot, and loss of sensation over the leg and foot.
● Ventral rami of nerves T2-T12 do not form plexuses and are called intercostal (thoracic) nerves. They are distributed directly to the structures they supply in intercostal spaces.

Dermatomes
● The skin over the entire body is supplied by spinal nerves that carry somatic sensory nerve impulses into the spinal cord.
● All spinal nerves except C1 innervate specific, constant segments of the skin; the skin segments are called dermatomes.
● Knowledge of dermatomes helps a physician to determine which segment of the spinal cord or which spinal nerve is malfunctioning.
Disorders: Homeostatic Imbalances

- Spinal cord injury may result in paralysis (the total loss of voluntary motor function that results from damage to nervous or muscle tissue), which may be classified as monoplegia, diplegia, paraplegia, hemiplegia, or quadriplegia.
  - Transection (partial or complete severing of the spinal cord) is followed by a period of spinal shock that is accompanied by a loss of reflex activity called areflexia.
  - Persons with spinal cord injury may have an improved outcome if they are given an antiinflammatory drug (methylprednisolone) within eight hours of the injury.
- Inflammation of one or several nerves is known as neuritis; it can have many causes.
  - Neuritis of the sciatic nerve and its branches is called sciatica; the most common cause is a herniated (slipped) intervertebral disc.
  - Shingles is an acute infection of the peripheral nerves by the herpes zoster virus; the virus migrates down peripheral nerves, causing pain, skin discoloration, and a characteristic line of skin blisters.
  - Poliomyelitis (infantile paralysis, or polio) is a viral infection characterized by fever, headache, stiff neck and back, deep pain and weakness, and loss of certain somatic reflexes. Paralysis is produced when the virus destroys motor neuron cell bodies.
Introduction

- The inumerable components of the brain interact to realize three basic functions:
  - Receiving sensory input,
  - Integrating, associating, and storing information, and
  - Transmitting motor impulses that result in movement or secretion
- To accomplish the primary functions of the nervous system there are neural pathways to transmit impulses from receptors to the circuitry of the brain, which manipulates the circuitry to form directives that are transmitted via neural pathways to effectors as a response.

Sensation

- Levels of Sensation and Perception
  - Sensation is a conscious or unconscious awareness of external and internal stimuli.
  - Perception is the conscious awareness and interpretation of sensations.
- Modality
  - Modality is the property by which one sensation is distinguished from another.
  - In general, a given sensory neuron carries only one modality.

Components of Sensation

- For a sensation to arise, four events must occur.
- These are stimulation, transduction, conduction, and translation.
  - A stimulus, or change in the environment, capable of initiating a nerve impulse by the nervous system must be present.
  - A sensory receptor or sense organ must pick up the stimulus and transduce (convert) it to a nerve impulse by way of a generator potential.
  - The impulse(s) must be conducted along a neural pathway from the receptor or sense organ to the brain.
  - A region of the brain or spinal cord must translate the impulse into a sensation.

Sensory Receptors

- Sensory receptors are selective, i.e., they respond vigorously to one particular kind of stimulus and weakly or not at all to others.
- In terms of simplicity or complexity, simple receptors are associated with general senses, and complex receptors are associated with special senses.
- According to location, receptors are classified as exteroceptors, interoceptors (visceroceptors), and proprioceptors.
- On the basis of type of stimulus detected, receptors are classified as mechanoreceptors, thermoreceptors, nociceptors, photoreceptors, and chemoreceptors.
- Generator and receptor potentials are graded, local potentials; generator potentials trigger action potentials whereas receptor potentials do not.
- A characteristic of many sensations is adaptation, i.e., a change in sensitivity (usually a decrease) to a long-lasting stimulus; the receptors involved are important in signaling information regarding steady states of the body.
Somatic Senses: Cutaneous Sensations

- Cutaneous sensations include tactile sensations (touch, pressure, vibration), thermoreceptive sensations (cold and heat), and pain.
  - The receptors for these sensations are located in the skin, in connective tissue under the skin, in mucous membranes, and at the ends of the gastrointestinal tract.
  - Nerve impulses generated by cutaneous receptors pass along somatic afferent neurons in spinal and cranial nerves, through the thalamus, to the somatosensory area of the parietal lobe of the cortex.
  - Crude touch refers to the ability to perceive that something has simply touched the skin; discriminative touch refers to the ability to recognize exactly what point of the body is touched.
    - Receptors for touch include corpuscles of touch (Meissner’s corpuscles) and hair root plexuses; these are rapidly adapting receptors.
    - Type I cutaneous mechanoreceptors (tactile or Merkel discs) and type II cutaneous mechanoreceptors (end organs of Ruffini) are slowly adapting receptors for touch.
  - Pressure sensations generally result from stimulation of tactile receptors in deeper tissues and are longer lasting and have less variation in intensity than touch sensations; pressure is a sustained sensation that is felt over a larger area than touch.
    - Receptors for pressure are type II cutaneous mechanoreceptors and lamellated (Pacinian) corpuscles. Like corpuscles of touch, lamellated corpuscles adapt rapidly.
  - Vibration sensations result from rapidly repetitive sensory signals from tactile receptors; the receptors for vibration sensations are corpuscles of touch and lamellated corpuscles, which detect low-frequency and high-frequency vibrations, respectively.
  - Itch and tickle receptors are free nerve endings.
  - Thermoreceptors are free nerve endings; separate thermoreceptors respond to hot and cold stimuli.
  - Pain is a vital sensation because it provides us with information about tissue-damaging stimuli and with signs that may be used for diagnosis of disease or injury.
    - Pain receptors (nociceptors) are free endings that are located in nearly every body tissue; adaptation is slight if it occurs at all.
  - Two kinds of pain are recognized in the parietal lobe of the cortex: somatic (superficial and deep) and visceral; visceral pain, unlike somatic pain, is usually felt in or just under the skin that overlies the stimulated organ—the pain may also be felt in a surface area far from the stimulated organ in a phenomenon known as referred pain.
    - Phantom pain is the sensation of pain in a limb that has been amputated; the brain interprets nerve impulses arising in the remaining proximal portions of the sensory nerves as coming from the nonexistent (phantom) limb.
  - Anesthesia blocks sensations while still maintaining the stability of the patient’s organ systems.

Somatic Senses: Proprioceptive Sensations

- Receptors located in skeletal muscles, in tendons, in and around joints, and in the internal ear convey nerve impulses related to muscle tone, movement of body parts, and body position. This awareness of the activities of muscles, tendons, and joints and of balance or equilibrium is provided by the proprioceptive or kinesthetic sense.
  - The receptors include muscle spindles, tendon organs (Golgi tendon organs), and joint kinesthetic receptors.

Somatic Sensory Pathways
Sensory information from all parts of the body terminates in a specific area of the somato-sensory cortex (primary somatosensory or general sensory area).

In the posterior column-medial lemniscus pathway and spinothalamic (anterolateral) pathways, there are first-order, second-order, and third-order neurons.

- Impulses along this pathway are concerned with discriminative touch, stereognosis (the ability to recognize by feel” the size, shape, and texture of an object), proprioception, weight discrimination, and vibratory sensations.
- The neural pathway for pain and temperature is the lateral spinothalamic tract.
- Pain may be classified based on speed of onset, quality of the sensation, and duration.
  - Acute pain is fast, sharp, and not felt in deeper tissues of the body.
  - Chronic pain is slow, gradually increases in intensity, and occurs both in the skin and deeper tissues or in internal organs.
- Pain impulses may often be inhibited by pain-reducing drugs. Surgery may be required to control severe pain (e.g., cordotomy, rhizotomy).

The neural pathway for tickle, itch, crude touch, and pressure is the anterior spinothalamic pathway.

Areas of the somatosensory cortex (postcentral gyrus) that receive sensory information from different parts of the body have been mapped out, as shown in.

The pathways to the cerebellum are the anterior and posterior spinocerebellar tracts, which are involved in transmitting impulses for subconscious muscle and joint sense; sensory inputs along these two pathways are critical for cerebellar regulation of posture and balance and coordination of skilled movements.

**Integrative Functions**

- Sensory input keeps the CNS informed of changes in the environment.
- Incoming sensory information is integrated at many stations along the CNS, at both conscious and subconscious levels.
- A motor response to make a muscle contract or a gland secrete can be initiated at any of these stations or levels.
  - As the location of the sensory-motor linkage climbs to higher levels in the central nervous system, additional contributions are introduced that enrich the growing inventory of motor responses.
  - When the input reaches the highest center, the process of sensory-motor integration occurs. This involves not only the utilization of information contained within that center, but also the information impinging on that center that is delivered from other centers within the central nervous system.

**Somatic Motor Pathways**

- The motor cortex (primary motor area or precentral gyrus) is the major control region for initiation of voluntary movements. The adjacent premotor area and even the somatosensory cortex also contribute fibers to the descending motor pathways.
  - Different muscles are not represented equally in the motor cortex, as seen in.
  - The degree of representation is proportional to the number of motor units in a particular muscle of the body.
times.

- The axons of the corticospinal tracts, for example, do not become fully myelinated until the second year of life, explaining why infants and young children follow patterns of developmental activity.

- Indirect (extrapyramidal) pathways involve the motor cortex, basal ganglia, thalamus, cerebellum, reticular formation, and nuclei in the brain stem.
  - Muscle tone, posture, coordination, and equilibrium are all contributed to by nerve impulses carried by the extrapyramidal tracts.
  - Major indirect tracts are the rubrospinal, tectospinal, vestibulospinal, and reticulospinal tracts.

- The major sensory and motor pathways and tracts in the spinal cord are summarized in Exhibit 15.1.

**Integrative Functions**

- Memory is the ability to recall thoughts and is generally classified into two kinds based on how long the memory persists: short-term and long-term memory.
  - A memory trace in the brain is called an encephlagram (a change in the brain that represents the experience).
  - Short-term memory lasts only seconds or hours and is the ability to recall bits of information; it is related to electrical and chemical events.
  - Long-term memory lasts from days to years and is related to anatomical and biochemical changes at synapses.

- Sleep and wakefulness are integrative functions that are controlled by the reticular activating system (RAS).
  - The RAS can maintain a general state of wakefulness (consciousness) and also initiate the increased cortical activity seen in arousal from deep sleep.
  - A number of factors can noticeably alter the state of consciousness, e.g., amphetamines, alcohol, and other drugs; meditation; anesthetics; and a diseased or damaged nervous system.
  - Coma is the final stage of brain failure that is characterized by total unresponsiveness to all external stimuli.

- During sleep, a state of altered consciousness or partial unconsciousness from which an individual can be aroused by different stimuli, activity in the RAS is very low.
  - Normal sleep consists of two types: non-rapid eye movement sleep (NREM) and rapid eye movement sleep (REM)
    - Non-rapid eye movement (NREM) or slow wave sleep consists of four stages, each of which gradually merges into the next. Each stage has been identified by BEG recordings.
    - Most dreaming occurs during rapid eye movement (REM) sleep.
Somatic Motor Pathways

- Voluntary motor impulses are propagated from the motor cortex to somatic efferent neurons (voluntary motor neurons) that innervate skeletal muscles via the direct or (pyramidal) pathways. The simplest pathways consist of upper and lower motor neurons.
  - The direct pathways include the lateral and anterior corticospinal tracts and corticobulbar tracts.
  - The various tracts of the pyramidal system convey impulses from the cerebral cortex that result in precise muscular movement.

Integrative Functions

- The neurotransmitters that affect sleep are serotonin (5-HT) and norepinephrine (NE).

Disorders: Homeostatic Imbalances

- Spinal cord injury can be due to damage in a number of ways, such as compression or transection, and the location and extent of damage determines the type and degree of loss in neural abilities.
  - Cord damage caused by anything from tumors to trauma can compress neurons and either permanently or temporarily diminish capacity, depending on the type of nerves compromised.
    - Sensory nerve damage leads to the loss of the particular sensation that normally travels along the injured route, below the level of incident.

Disorders: Homeostatic Imbalances

- Motor pathway injury leads to paralysis that is described by the extent of motor control loss, below the level of incident, such as
  - monoplegia,
  - diaplegia,
  - paraplegia,
  - hemiplegia, and
  - quadraplegia.

- Damage to the cord, particularly transection, results in spinal cord shock, described as the loss of spinal reflexes, such as with incontinence.

Cerebral Palsy

- This condition entails loss of muscle control due to problems during development that impact the motor control areas of the brain.
  - The conditions are non-progressive, but permanent.

Parkinson’s Disease is a progressive degeneration of CNS neurons of the basal nuclei region due to unknown causes that decreases dopamine neurotransmitter production.

- This condition produces motor coordination problems of involuntary tremor, and/or rigidity.
- Motor performance can be described as bradykinesia (slow), and hypokinesia (limited).
- Limited treatment is provided with L-dopa, as precursor to dopamine, or through acetylcholine inhibitors.
Introduction

- The autonomic nervous system (ANS) regulates the activity of smooth muscle, cardiac muscle, and certain glands.
  - Operation of the ANS to maintain homeostasis, however, depends on a continual flow of sensory afferent input, from receptors in organs, and efferent motor output to the same effector organs.
  - Functionally, the ANS usually operates without conscious control.
    - However, it is regulated by centers in the brain, mainly the hypothalamus and medulla oblongata, which receives input from the limbic system and other regions of the cerebrum.

Comparison Of Somatic and Autonomic Nervous System

- Sensory neurons of the somatic nervous system receive input from the special senses, general somatic senses, and proprioceptors; sensory neurons of the ANS receive input from the special senses, general visceral senses, and general somatic senses.
- The somatic nervous system operates under conscious control; the ANS operates without conscious control.
- The axons of the motor neurons of the somatic nervous system extend from the CNS synapse directly to an effector and release acetylcholine; autonomic pathways consist of sets of two motor (efferent) neurons.
  - The axon of the first motor neuron of the ANS extends from the CNS and synapses in a ganglion with the second neuron.
  - The second neuron synapses on an effector. Preganglionic fibers release acetylcholine and postganglionic fibers release acetylcholine or norepinephrine.
- Somatic nervous system effectors are skeletal muscles; ANS effectors include cardiac and smooth muscle, and glands.
- The somatic nervous system responds to neurotransmitters as excitation; the ANS response to neurotransmitters is excitation or inhibition.
- A summary of the similarities of and differences between the somatic and autonomic nervous systems is presented in Exhibit 17.1.
- The output (efferent) part of the ANS is divided into two principal parts: the sympathetic and the parasympathetic. Organs that receive impulses from both sympathetic and parasympathetic fibers are said to have dual innervation.

Anatomy Of Autonomic Motor Pathways

- Overview
  - Preganglionic neurons are myelinated; postganglionic neurons are unmyelinated.
  - The first of two autonomic motor neurons is called a preganglionic neuron (Exhibit 17.1).
    - Its cell body is in the brain or spinal cord.
    - Its myelinated axon, called a preganglionic fiber, passes out of the CNS as part of a cranial or spinal nerve, later separating from the nerve and extending to an autonomic ganglion where it synapses with the postganglionic neuron.
  - The postganglionic neuron, the second neuron in the autonomic motor pathway, lies entirely outside the CNS.
    - Its cell body and dendrites are located in an autonomic ganglion, where it makes synapses with one or more preganglionic fibers.
    - The axon of a postganglionic neuron, the postganglionic fiber, is unmyelinated and terminates in a visceral effector.
  - The cell bodies of sympathetic preganglionic neurons are in the lateral gray horns of the
  - 12 thoracic and first 2 or 3 lumbar segments; the cell bodies of parasympathetic preganglionic neurons are in cranial nerve nuclei (111, VII, DC, and X) in the brain stem and lateral gray horns of the second through fourth sacral segments of the cord.
Overview

Autonomic ganglia are classified as sympathetic trunk (vertebral chain) ganglia (on both sides of spinal column), prevertebral (collateral) ganglia (anterior to spinal column), and terminal (intramural) ganglia (near or inside visceral effectors) (Figs. 17.1. 17.2).

In addition to autonomic ganglia, the ANS contains autonomic plexuses.

Sympathetic and Parasympathetic Divisions

Sympathetic preganglionic neurons synapse with postganglionic neurons in ganglia of the sympathetic trunk or prevertebral ganglia.

Parasympathetic preganglionic neurons synapse with postganglionic neurons in terminal ganglia.

The salient anatomical features of the sympathetic and parasympathetic divisions are compared in Exhibit 17.2.

Physiological Effects Of The ANS

Most body structures receive dual innervation, that is fibers from both the sympathetic and parasympathetic divisions. Usually one division causes excitation and one causes inhibition.

Cholinergic neurons release acetylcholine (ACh); adrenergic neurons release norepinephrine (noradrenaline) or epinephrine (adrenalin).

The effects of sympathetic stimulation are longer-lasting and more widespread than those of parasympathetic stimulation.

Two types of cholinergic receptors are nicotinic and muscarinic.

Two types of adrenergic receptors are alpha and beta.

The parasympathetic division regulates activities that conserve and restore body energy (energy conservation-restorative system); the sympathetic division prepares the body for emergency situations (fight-or-flight response).

Exhibit 17.3 summarizes the responses of glands, smooth muscle, and cardiac muscle to stimulation by the sympathetic and parasympathetic branches of the ANS.

Autonomic Reflexes

A visceral autonomic reflex adjusts the activity of a visceral effector, often unconsciously.

A visceral autonomic reflex arc consists of a receptor, sensory neuron, association neuron, autonomic motor neurons, and visceral effector.

Control By Higher Centers

The hypothalamus controls and integrates the autonomic nervous system. It is connected to both the sympathetic and the parasympathetic divisions.

Control of the ANS by the cerebral cortex occurs primarily during emotional stress.

Achalasia: An Example Of Autonomic Dysfunction

Disrupted function of the autonomic nerves (specifically, the myenteric plexus, or plexus of Auerbach), which innervate the smooth muscle of the lower end of the esophagus, can cause constriction of those muscles, inhibiting passage of food from the esophagus into the stomach. This disorder, known as achalasia, causes pain and discomfort upon swallowing and may result in accumulation of food in the distended lower end of the esophagus.

Treatment may involve mechanical stretching with a balloon device that is inflated after being passed into the lower end of the esophagus; this may only temporarily alleviate symptoms. If the disorder persists, surgery to cut some of the smooth muscles surrounding the entrance to the stomach may be required, a procedure referred to as cardiomyotomy.
Nervous Tissue: Anatomy and Physiology 121:

Introduction
- The special senses allow us to detect specific changes in our environment through a richer experience via smell, taste, vision, hearing, and equilibrium.

Olfactory Sensations: Smell
- The receptors for olfaction, which are bipolar neurons, are in the nasal epithelium in the superior portion of the nasal cavity.
- Substances to be smelled must be volatile, water-soluble, and lipid-soluble.
- In olfactory reception, a generator potential develops and triggers one or more nerve impulses.
- Adaptation to odors occurs quickly, and the threshold of smell is low; only a few molecules of certain substances need be present in air to be smelled.
- Olfactory receptors convey nerve impulses to olfactory (I) nerves, olfactory bulbs, olfactory tracts, and the cerebral (prepyriform) cortex and limbic system.

Gustatory Sensations: Taste
- The receptors for gustation, the gustatory receptor cells, are located in taste buds.
- Substances to be tasted must be in solution in saliva.
- Receptor potentials developed in gustatory hairs cause the release of neurotransmitter that gives rise to nerve impulses.
- The four primary tastes are sour, salty, bitter, and sweet.

Gustatory Sensations: Taste
- The senses of smell and taste are very closely associated; impaired ability to smell significantly affects one’s gustatory sensations.
- Adaptation to taste occurs quickly; the threshold varies with the taste involved.
- Gustatory receptor cells convey nerve impulses to cranial nerves V, VII, IX, and X, the medulla, the thalamus, and the parietal lobe of the cerebral cortex.

Visual Sensations
- Introduction
  - The study of the structure, function, and diseases of the eye is known as ophthalmology; a physician who specializes in diagnosis and treatment of eye disorders with drugs, surgery, and corrective lenses is known as an ophthalmologist.
  - An optometrist is a specialist with a doctorate in optometry who is licensed to examine and test the eyes and treat visual defects by prescribing corrective lenses; an optician is a technician who fits, adjusts, and dispenses corrective lenses prescribed by an ophthalmologist or optometrist.

Visual Sensations
- Accessory Structures of the Eye
  - Accessory structures of the eyes include the eyebrows, eyelids (palpebrae), eyelashes, lacrimal apparatus, and extrinsic eye muscles.
  - The conjunctiva is a thin mucous membrane that lines the inner aspect of the eyelids and is reflected onto the anterior surface of the eyeball.
  - The lacrimal apparatus consists of structures that produce and drain tears.
  - “Watery” eyes occur when the normal drainage system for the lacrimal glands is overwhelmed or obstructed.

Anatomy of the Eyeball
- The eye is constructed of three layers
  - The fibrous tunic is the outer coat of the eyeball. It can be divided into two regions: the posterior sciera and the anterior cornea. At the junction of the sciera and cornea is an opening known as the scleral venous sinus or canal of Schlemm. The sciera, the ‘white’ of the eye, is a white coat of dense fibrous tissue that covers all the eyeball, except the most anterior portion,
the iris; the sciera gives shape to the eyeball and protects its inner parts. Its posterior surface is pierced by the optic (II) nerve.

- The cornea is a nonvascular, transparent, fibrous coat through which the iris can be seen; the cornea acts in refraction of light.
- Corneal transplants are the most common organ transplant operation, and they are considered to be the most successful type of transplant since they are rarely rejected. This is because the cornea is avascular, and antibodies that might cause rejection do not circulate there (the cornea receives nourishment from tears and aqueous humor).

**Anatomy of the Eyeball**

- The vascular tunic, or uvea (2nd Layer), is the middle layer of the eyeball and is composed of three portions: choroid, ciliary body, and iris.
  - The choroid absorbs light rays so that they are not reflected and scattered within the eyeball; it also provides nutrients to the posterior surface of the retina.
  - The ciliary body consists of the ciliary processes and ciliary muscle.
  - The ciliary processes consist of protrusions or folds on the internal surface of the ciliary body where epithelial lining cells secrete aqueous humor.
  - The ciliary muscle is a smooth muscle that alters the shape of the lens for near or far vision.

**Anatomy of the Eyeball**

- The iris is the colored portion seen through the cornea and consists of circular iris and radial iris smooth muscle fibers (cells) arranged to form a doughnut-shaped structure.
  - The black hole in the center of the iris is the pupil, the area through which light enters the eyeball.
- A principal function of the iris is to regulate the amount of light entering the posterior cavity of the eyeball.

**Anatomy of the Eyeball**

- The third and inner coat of the eye, the retina (nervous tunic), lines the posterior three-quarters of the eyeball and is the beginning of the visual pathway.
- The primary function of the retina is image formation.
- The retina consists of a pigment epitheliurn (nonvisual portion) and a neural portion (visual portion).
  - The pigment epitheliurn aids the choroid in absorbing stray light rays.
  - The neural portion contains three zones of neurons that are named in the order in which they conduct nerve impulses: photoreceptor neurons, bipolar neurons, and ganglion neurons.

**Anatomy of the Eyeball**

- The photoreceptor neurons are called rods or cones because of the differing shapes of their outer segments.
  - Rods are specialized for black-and-white vision in dim light; they also allow us to discriminate between different shades of dark and light and permit us to see shapes and movement.
  - Cones are specialized for color vision and sharpness of vision (high visual acuity) in bright light; cones are most densely concentrated in the central fovea, a small depression in the center of the macula lutea. (a)The macula lutea is in the exact center of the posterior portion of theretina, corresponding to the visual axis of the eye.
Anatomy of the Eyeball

- The fovea is the area of sharpest vision because of the high concentration of cones.
- Rods are absent from the fovea and macula and increase in density toward the periphery of the retina.
- Detachment of the retina may occur in trauma, such as a blow to the head, or may be secondary to various intraocular disorders. The retina may be reattached by laser beams or cryosurgery (exposure to extreme cold). Boxing is one sport where routine blows to the head commonly result in retinal detachment.

Anatomy of the Eyeball

- The eyeball contains the nonvascular lens, just behind the pupil and iris.
  - The lens fine-tunes focusing of light rays for clear vision.
  - A loss of transparency of the lens known as a cataract is the leading cause of blindness. It is associated with aging but may also occur because of injury, exposure to ultraviolet rays, certain medications, or complications of diseases such as diabetes.

Anatomy of the Eyeball

- The interior of the eyeball is a large space divided into two cavities by the lens: the anterior cavity and the vitreous chamber.
  - The anterior cavity is subdivided into the anterior chamber (which lies behind the cornea and in front of the iris) and the posterior chamber (which lies behind the iris and in front of the suspensory ligaments and lens).
    - The anterior cavity is filled with a watery fluid called the aqueous humor that is continually secreted by the ciliary processes behind the iris.
    - The aqueous humor flows forward from the posterior chamber through the pupil into the anterior chamber and drains into the scleral venous sinus (canal of Schlemm) and then into the blood.

Anatomy of the Eyeball

- The pressure in the eye, called intraocular pressure, is produced mainly by the aqueous humor. The intraocular pressure, along with the vitreous body, maintains the shape of the eyeball and keeps the retina smoothly applied to the choroid so the retina will form clear images.
  - Excessive intraocular pressure, called glaucoma, results in degeneration of the retina and blindness.

Anatomy of the Eyeball

- The second, and larger, cavity of the eyeball is the vitreous chamber (posterior cavity). It lies between the lens and the retina and contains a gel called the vitreous body.
  - This substance contributes to intraocular pressure, helps to prevent the eyeball from collapsing, and holds the retina flush against the internal portions of the eyeball.
  - The vitreous body, unlike the aqueous humor, does not undergo constant replacement. It is formed during embryonic life and is not replaced thereafter.
- A summary of the structures associated with the eyeball is presented in Exhibit 16.1.

Image Formation

Page 26 - © - Dr. Jaeson T. Fournier
Image formation on the retina involves refraction of light rays by the cornea and lens, accommodation of the lens, and constriction of the pupil.

**Image Formation**

The bending of light rays at the interface of two different media is called refraction; the anterior and posterior surfaces of the cornea and of the lens refract entering light rays so they come into exact focus on the retina.

- Images are focused upside-down (inverted) on the retina and also undergo milTor reversal; these inverted images are rearranged by the brain to produce perception of images in their actual orientation.
- Abnormalities of refraction are due to improper shape of the eyeball or to irregularities in the surface of the lens or cornea; these abnormalities are illustrated and explained in.

**Image Formation**

Accommodation is an increase in the curvature of the lens, initiated by ciliary muscle contraction, which allow the lens to focus on near objects. To focus on far objects, the ciliary muscle relaxes and the lens flattens.

- Constriction of the pupil means narrowing the diameter of the hole through which light enters the eye; this occurs simultaneously with accommodation of the lens and functions to prevent light rays from entering the eye through the periphery of the lens.
- In convergence, the eyeballs move medially so they are both directed toward an object being viewed; the coordinated action of the extrinsic eye muscles brings about convergence.

**Physiology of Vision**

The first step in vision transduction is the absorption of light by photopigments (visual pigment) in rods and cones (photoreceptors).

- Photopigments are colored proteins that undergo structural changes upon light absorption.
- The single type of photopigment in rods is called rhodopsin. A cone contains one of three different kinds of photopigments so there are three types of cones; most forms of colorblindness (inability to distinguish certain colors) result from an inherited absence of or deficiency in one of the three cone photopigments and are more common in males.

**Physiology of Vision**

Bleaching and regeneration of the photopigments accounts for much but not all of the sensitivity change during light and dark adaptation.

Once receptor potentials develop in rods and cones, they release neurotransmitters that induce graded potentials in bipolar cells and horizontal cells.

**Visual Pathway**

- Horizontal cells transmit inhibitory signals to bipolar cells; bipolar or amacrine cells transmit excitatory signals to ganglion cells, which depolarize and initiate nerve impulses.
- Impulses from ganglion cells are conveyed through the retina to the optic (II) nerve, the optic chiasma, the optic tract, the thalamus, and the cortex (occipital lobes).

**Auditory Sensations**

**And Equilibrium**

The ear consists of three anatomical subdivisions.
The external (outer) ear collects sound waves and passes them inwards; it consists of the auricle (pinna), external auditory canal (meatus), and tympanic membrane (eardrum).

- Ceruminous glands in the external auditory canal secrete cerumen (earwax) to help prevent dust and foreign objects from entering the ear; excess cerumen may become impacted, causing temporary partial hearing loss before it is removed.
- A perforated eardrum is a hole in the tympanic membrane that reduces sound transmission. Causes of perforated eardrums include compressed air (explosion, scuba diving), trauma (skull fracture or wounds from objects such as ear swabs), or acute middle ear infections. If the condition does not resolve itself, surgery may be required.

The middle ear (tympanic cavity) is a small, air-filled cavity in the temporal bone that is lined by epithelium. It contains the auditory (Eustachian) tube, auditory ossicles (middle ear bones, the malleus, incus, and stapes), the oval window, and the round window.

The internal (inner) ear is also called the labyrinth because of its complicated series of canals. Structurally, it consists of two main divisions: an outer bony labyrinth that encloses an inner membranous labyrinth.

- The bony labyrinth is a series of cavities in the petrous portion of the temporal bone.
  - It can be divided into three areas named on the basis of shape: the semicircular canals and vestibule, both of which contain receptors for equilibrium, and the cochlea, which contains receptors for hearing.

The membranous labyrinth is a series of sacs and tubes lying inside and having the same general form as the bony labyrinth.

- The membranous labyrinth is lined with epithelium.
- It contains a fluid called endolymph, chemically similar to intracellular fluid.
- The vestibule constitutes the oval central portion of the bony labyrinth. The membranous labyrinth in the vestibule consists of two sacs called the utricle and saccule.

Projecting upward and posteriorly from the vestibule are the three bony semicircular canals. Each is arranged at approximately right angles to the other two.

- The anterior and posterior semicircular canals are oriented vertically; the lateral semicircular canal is oriented horizontally.
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- One end of each canal enlarges into a swelling called the aipulla.
- The portions of the membranous labyrinth that lie inside the semicircular canals are called the semicircular ducts (membranous semicircular canals).

Auditory Sensations
And Equilibrium

- Anterior to the vestibule is the cochlea, which consists of a bony spiral canal that makes almost three turns around a central bony core.
- Cross sections through the cochlea show that it is divided into three channels by partitions that together have the shape of the letter Y.
  - The channel above the bony partition is the scala vestibuli, which ends at the oval window.

Auditory Sensations
And Equilibrium

- Cross sections through the cochlea show that it is divided into three channels by partitions that together have the shape of the letter Y.
  - The channel below is the scala tympani, which ends at the round window. The scala vestibuli and scala tympani both contain perilymph and are completely separated except at an opening at the apex of the cochlea called the helicotrema.
  - The third channel (between the wings of the Y) is the cochlear duct (scala media). The vestibular membrane separates the cochlear duct from the scala vestibuli, and the basilar membrane separates the cochlear duct from the scala tympani.

Auditory Sensations
And Equilibrium

- Resting on the basilar membrane is the spiral organ (organ of Corti), the organ of hearing.
  - Hair cells of the spiral organ are easily damaged by continual exposure to high-intensity sounds and may degenerate, producing deafness.
  - Cochlear implants (artificial ears) are devices that translate sounds into electronic signals that can be interpreted by the brain. They take the place of hair cells of the spiral organ, which normally convert sound waves into electrical signals carried to the brain. The implants are used for individuals with sensorineural deafness, i.e., deafness due to disease or injury that has destroyed hair cells of the spiral organ.

Auditory Sensations
And Equilibrium

- Projecting over and in contact with the hair cells of the spiral organ is the tectorial membrane, a delicate and flexible gelatinous membrane.

Auditory Sensations
And Equilibrium

- Sound waves result from the alternate compression and decompression of air molecules.
  - The sounds heard most acutely by human ears are from sources that vibrate at frequencies between 1000 and 4000 Hertz (Hz; cycles per second).
  - The frequency of a sound vibration is its pitch; the greater the intensity (size) of the vibration, the louder the sound (as measured in decibels, dB).

Auditory Sensations
And Equilibrium

- The events involved in hearing are as follows.
  - The auricle directs sound waves into the external auditory canal.
  - Sound waves strike the tympanic membrane, causing it to vibrate back and forth.
  - The vibration conducts from the tympanic membrane through the ossicles (through the malleus to the incus and then to the stapes).
  - The stapes moves back and forth, pushing the membrane of the oval window in and out.
• The movement of the oval window sets up fluid pressure waves in the perilymph of the cochlea (scala vestibuli).

Auditory Sensations
And Equilibrium

• The events involved in hearing are as follows:
  • Pressure waves in the scala vestibuli are transmitted to the scala tympani and eventually to the round window, causing it to bulge outward into the middle ear.
  • As the pressure waves deform the walls of the scala vestibuli and scala tympani, they push the vestibular membrane back and forth and increase and decrease the pressure of the endolymph inside the cochlear duct.

Auditory Sensations
And Equilibrium

• Differences in pitch are related to differences in the width and stiffness of the basilar membrane and sound waves of various frequencies that cause specific regions of the basilar membrane to vibrate more intensely than others.
  • High-frequency or high-pitched sounds cause the basilar membrane to vibrate near the base of the cochlea.
  • Low-frequency or low-pitched sounds cause the basilar membrane to vibrate near the apex of the cochlea.

Auditory Sensations
And Equilibrium

• Hair cells convert a mechanical force (stimulus) into an electrical signal (receptor potential); hair cells release neurotransmitter, which initiates nerve impulses.
• Nerve impulses from the cochlear branch of the vestibulocochlear (VIII) nerve pass to the cochlear nuclei in the medulla. Here, most impulses cross to the opposite side and then travel to the midbrain, to the thalamus, and finally to the auditory area of the temporal lobe of the cerebral cortex.

Auditory Sensations
And Equilibrium

• Static equilibrium refers to the maintenance of the position of the body (mainly the head) relative to the force of gravity. The maculae of the utricle and saccule are the sense organs of static equilibrium; they also contribute to some aspects of dynamic equilibrium.
• Dynamic equilibrium is the maintenance of body position (mainly the head) in response to sudden movements, such as rotation, acceleration, and deceleration. The cristae in the semicircular ducts are the primary sense organs of dynamic equilibrium.

Auditory Sensations
And Equilibrium

• Most vestibular branch fibers of the vestibulocochlear (VIII) nerve enter the brain stem and terminate in the medulla; the remaining fibers enter the cerebellum.
• A summary of the structures of the ear related to hearing and equilibrium is presented in Exhibit 16.2.

Disorders:
Homeostatic Imbalances

• Glaucoma is abnormally high intraocular pressure, due to a buildup of aqueous humor inside the eyeball, which destroys neurons of the retina. It is the second most common cause of blindness (after cataracts), especially in the elderly.

Disorders:
Homeostatic Imbalances

• Senile macular degeneration (SMD) results from the growth of new blood vessels over the macula lutea. The effect ranges from distorted vision to blindness. SMD accounts for nearly all new cases
of blindness in people over age 65. Its cause is unknown. Laser beam treatment has been used effectively in arresting blood vessel proliferation and restoring normal vision in some cases.

Disorders: Homeostatic Imbalances

- Deafness is significant or total hearing loss. It is classified as sensorineural (caused by impairment of the cochlea or cochlear branch of the vestibulocochlear [VIII] nerve) or conduction (caused by impairment of the external and middle ear mechanisms for transmitting sounds to the cochlea).
- Meniere’s syndrome is a malfunction of the inner ear that may cause deafness and loss of equilibrium.

Disorders: Homeostatic Imbalances

- Otitis media is an acute infection of the middle ear, primarily by bacteria. It is characterized by pain, malaise, fever, and reddening and outward bulging of the eardrum, which may rupture unless prompt treatment is given. Children are more susceptible than adults.

Disorders: Homeostatic Imbalances

- Motion sickness is a functional disorder precipitated by repetitive angular, linear, or vertical motion and characterized primarily by nausea and vomiting. Preventative measures are more effective than trying to treat symptoms once they have developed.