CHAPTER 39 NEURONS AND NERVOUS SYSTEMS

Chapter Outline

39.1 Evolution of the Nervous System

A. Invertebrate Nervous Organization
   1. Comparative study shows the evolutionary steps leading to the centralized nervous system of vertebrates.
   2. Even primitive sponges, with only a cellular level of organization, respond by closing the osculum.
   3. Hydra (cnidarians) possess two cell layers separated by mesoglea.
      a. The hydra can contract, extend, and move tentacles to capture prey and even turn somersaults.
      b. A simple nerve net extends throughout the hydra body within the mesoglea.
      c. The hydra **nerve net** is composed of **neurons** in contact with one another and with contractile epitheliomuscular cells.
      d. The more complex cnidaria (sea anemones and jellyfish) may have two nerve nets.
         1) A fast-acting nerve net enables major responses, particularly in times of danger.
         2) Another nerve net coordinates slower and more delicate movements.
   4. The planarian nervous system is **bilaterally symmetrical**.
      a. It has two lateral nerve cords that allow rapid transfer of information from anterior to posterior.
      b. The nervous system of planaria exhibits **cephalization**; at their anterior end, planaria have a simple brain composed of a cluster of neurons or ganglia.
      c. Cerebral ganglia receive input from photoreceptors in eyespots and sensory cells in auricles.
      d. The transverse nerve fibers between the sides of the ladderlike nerve cords keep the movement on both sides of a planarian body coordinated.
      e. Bilateral symmetry plus cephalization are important trends in nervous system development.
      f. The organization of the planarian nervous system foreshadows both the central and peripheral system of vertebrates.
   5. The annelids, arthropods, and molluscs are complex animals with true nervous systems.
      a. The nerve cord has a **ganglion** in each segment of body that controls muscles of that segment.
      b. The brain still receives sensory information and controls the activity of the ganglia so the entire animal is coordinated.
      c. The presence of a brain and other ganglia indicate an increased number of neurons among invertebrates.

B. Vertebrate Nervous Organization
   1. Vertebrate nervous systems exhibit cephalization and bilateral symmetry.
      a. The vertebrate nervous system is composed of both central and peripheral nervous systems.
         1) The central nervous system develops a brain and spinal cord from the embryonic dorsal nerve cord.
         2) The peripheral nervous system consists of paired cranial and spinal nerves.
      b. Paired eyes, ears, and olfactory structures gather information from environment.
      c. A vast increase in number of neurons accompanied evolution of the vertebrate nervous system; an insect may have one million neurons while vertebrates may contain a thousand to a billion times more.
   2. The Vertebrate Brain
      a. The vertebrate brain is at the anterior end of the dorsal tubular nerve cord.
      b. The vertebrate brain is customarily divided into the hindbrain, midbrain, and forebrain.
         1) A well-developed hindbrain regulates organs below a level of consciousness; in humans it regulates lung and heart function even when we sleep, and coordinates motor activity.
         2) The optic lobes are part of a midbrain which was originally a center for coordinating reflex responses to visual input.
         3) The forebrain receives sensory input from the other two sections and regulates their output.
         4) The cerebrum is highly developed in mammals and is associated with conscious control; the outer layer, called the cerebral cortex, is large and complex.

C. The Human Nervous System

1. Three specific functions of the nervous system are to:
   a. receive sensory input,
   b. perform integration, and
   c. generate motor output to muscles and glands.
2. The **central nervous system** (**CNS**) is located in the midline of the body and integrates sensory information and controls the body.
3. The **peripheral nervous system** (**PNS**) lies outside the CNS and contains the **cranial** and **spinal nerves**.
4. The peripheral nervous system is divided into the somatic and autonomic systems.
   a. The somatic system controls the skeletal muscles.
   b. The autonomic system controls the smooth muscles, cardiac muscles, and glands.
5. The CNS and PNS of the human nervous system are connected and work together to perform the functions of a nervous system.

39.2 Nervous Tissue

A. Nervous tissue is made up of **neurons** and **neuroglia**, which supports and nourishes the neurons.

B. Neurons

1. **Neurons** vary in size and shape but they all have three parts.
   a. A **cell body** contains the nucleus and other organelles.
   b. **Dendrites** receive information and conduct impulses toward the cell body.
   c. Single **axon** conducts impulses away from cell body to stimulate or inhibit a neuron, muscle, or gland.
2. Myelination
   a. A long axon is called a nerve fiber.
   b. The long-axons are covered by a white myelin sheath.
   c. The **myelin sheath** is formed by membranes of tightly spiraled neuroglial cells.
   d. In the PNS, the neuroglial **neurolemmocyte** cell performs this function, leaving gaps called **neurofibril nodes**.

C. Types of Neurons

1. **Motor neurons** have many dendrites and a single axon; they conduct impulses from the CNS to muscle fibers or glands.
2. Sensory neurons are unipolar.
   a. The process that extends from the cell body divides into two processes, one goes to the CNS and one to periphery.
   b. It conducts impulses from the periphery toward the CNA.
3. **Interneurons** are multipolar
   a. They have highly-branched dendrites within the CNS.
   b. Interneurons convey messages between the various parts of the CNS.
   c. They form complex brain pathways accounting for thinking, memory, language, etc.

D. Transmission of the Nerve Impulses

1. The Italian Luigi Galvani discovered in 1786 that a nerve is stimulated by an electric current.
2. An impulse is too slow to be due to simply an electric current in an axon.
3. Julius Bernstein proposed that the impulse is the movement of unequally distributed ions on either side of an axomembrane, the plasma membrane of the axon.
4. The 1963 Nobel Prize went to the British researchers A. L. Hodgkin and A. F. Huxley who confirmed this theory.
   a. They and other researchers inserted a tiny electrode into giant axon of a squid.
   b. The electrode was attached to a voltmeter and oscilloscope to trace a change in voltage over time.
   c. The voltage measured the difference in the electrical potential between the inside and outside of the membrane.
   d. An oscilloscope indicated any changes in polarity.

E. Resting Potential
   1. When an axon is not conducting an impulse, an oscilloscope records a membrane potential equal to -65 mV indicating that the inside of the neuron is more negative than the outside.
   2. This is **resting membrane potential** because the axon is not conducting an impulse.
   3. This polarity is due to the difference in electrical charge on either side of the axomembrane.
      a. The inside of the plasma membrane is more negatively charged than the outside.
      b. Although there is a higher concentration of K^+ ions inside the axon, there is a much higher concentration of Na^+ ions outside the axon.
      c. The plasma membrane is more permeable to K^+ ions so this gradient is less and the K^+ ion potential is less.
      d. The sodium-potassium pump maintains this unequal distribution of Na^+ and K^+ ions.
   4. The **sodium-potassium (**Na^+**-**K^+**) pump** is an active transport system that moves Na^+ ions out and K^+ ions into axon.
   5. The pump is always working because the membrane is permeable to these ions and they tend to diffuse toward the lesser concentration.
   6. Since the plasma membrane is more permeable to potassium ions than to sodium ions, there are always more positive ions outside; this accounts for some polarity.
   7. The large negatively charged proteins in the cytoplasm of the axon also contribute to the resting potential of – 65 mV.

F. Action Potential
   1. When an axon conducts a nerve impulse, the rapid change in the membrane potential is the **action potential**.
   2. Protein-lined channels in axomembrane open to allow either sodium or potassium ions to pass; these are sodium and potassium **gates**.
   3. The action potential is generated only after the occurrence of a threshold value.
   4. The oscilloscope goes from -65 mV to +40 mV in a **depolarization phase** indicating the cytoplasm is now more positive than the tissue fluid.
   5. The trace returns to -65 mV again in the **repolarization phase** indicating the inside of the axon is negative again.
   6. At completion, there are more potassium ions outside and more sodium ions inside.

G. Propagation of Action Potentials
   1. If an axon is unmyelinated, an action potential stimulates an adjacent axomembrane to produce an action potential.
   2. In myelinated fibers, the action potential at one neurofibril node causes action potential at next node.
      a. The myelinated sheath has **neurofibril nodes,** gaps where one neurolemmocyte ends and next begins.
      b. The action potential "leaps" from one neurofibril node to another during **saltatory conduction**.
      c. Saltatory conduction may reach rates of over 100 meters/second, compared to 1 meter/second without it.
   3. As each impulse passes, the membrane undergoes a short refractory period before it can open the sodium gates again.
   4. The conduction of a nerve impulse is an all-or-nothing event.
   5. This ensures a one-way direction to the impulse.

H. Transmission Across a Synapse
   1. The minute space between the axon bulb and the cell body of the next neuron is the **synapse**.
   2. A synapse consists of a **presynaptic membrane**, a **synaptic cleft**, and the **postsynaptic membrane**.
      a. Synaptic vesicles store neurotransmitters that diffuse across the synapse.
      b. When the action potential arrives at the presynaptic axon bulb, synaptic vesicles merge with the presynaptic membrane.
      c. When **vesicles** merge with the membrane, **neurotransmitters** are discharged into the synaptic cleft.
      d. Neurotransmitter molecules diffuse across the synaptic cleft to the postsynaptic membrane where they bind with specific receptors.
      e. The type of neurotransmitter and/or receptor determines if the response is excitation or inhibition.
      f. Excitatory neurotransmitters use gated ion channels and are fast acting.
      g. Other neurotransmitters affect the metabolism of the postsynaptic cells and are slower.

I. Neurotransmitter Molecules
   1. At least 25 different neurotransmitters have been identified.
   2. **Acetylcholine** (**Ach**) and **norepinephrine** (**NE**) are two well-known neurotransmitters.
   3. Once a neurotransmitter is released into a synaptic cleft, it initiates a response and is then removed from the cleft.
   4. In some synapses, the postsynaptic membrane contains enzymes that rapidly inactivate the neurotransmitter.
   5. Acetylcholinesterase breaks down acetylcholine.
   6. In other synapses, the presynaptic membrane reabsorbs neurotransmitter for repackaging in synaptic vesicles or for molecular breakdown.
   7. The short existence of neurotransmitters in a synapse prevents continuous stimulation (or inhibition) of postsynaptic membranes.
   8. Many drugs that affect the nervous system act by interfering with or potentiating the action of neurotransmitters.

J. Synaptic Integration
   1. A neuron has many dendrites and may have one to ten thousand synapses with other neurons.
   2. A neuron receives many excitatory and inhibitory signals.
   3. Excitatory signals have a depolarizing effect; inhibitory signals have a hyperpolarizing effect.
   4. Integration is the summing up of excitatory and inhibitory signals.
   5. If a neuron receives many excitatory signals, or at a rapid rate from one synapse, the axon will probably transmit a nerve impulse.
   6. If both positive and inhibitory signals are received, the summing may prohibit the axon from firing.

39.3 Central Nervous System: Brain and Spinal Cord

A. Introduction to the CNS
   1. The central nervous system (**spinal cord** and **brain**) is where sensory impulses are received and motor control is initiated.
   2. Both the brain and the spinal cord are protected by bone.
   3. Both are wrapped in three connective tissue coverings called **meninges**.
   4. The spaces between the meninges are filled with **cerebrospinal fluid** to cushion and protect the CNS.
   5. The cerebrospinal fluid is contained in the central canal of the spinal cord and within the **ventricles** of the brain.
   6. The ventricles are interconnecting spaces that produce and serve as reservoirs for the cerebrospinal fluid.

B. The Spinal Cord
   1. The spinal cord has two main functions.
      a. It is the center for many reflex actions.
      b. It provides the means of communication between the brain and the spinal nerves.
   2. The spinal cord is composed of white and gray matter.
      a. Gray Matter
         1) The unmyelinated cell bodies and short fibers give **gray matter** its color.
         2) In a cross section, the gray area looks like a butterfly or the letter H.
         3) It contains portions of sensory neurons and motor neurons; short interneurons connect them.
      b. White Matter
         1) Myelinated long fibers of interneurons run together in tracts and give the white matter its color.
         2) Tracts conduct impulses between the brain and the spinal nerves; ascending tracts are dorsal and descending tracts from the brain are ventral.
         3) Tracts cross over near the brain; therefore the left side of the brain controls the right side of the body.

C. The Brain
   1. Brain has four ventricles: two lateral ventricles and a third and fourth ventricle.
   2. The cerebrum is associated with the two lateral ventricles, the diencephalon with the third, and the brain stem and cerebellum with the fourth.

D. The Cerebrum
   1. The **cerebrum**, also called the telencephalon, is the largest part of the brain in humans.
   2. It is the last center receiving sensory input and carrying out integration to command motor responses.
   3. The cerebrum carries out higher thought processes for learning and memory, language and speech.

E. The Cerebral Hemispheres
   1. The right and left **cerebral hemispheres** are connected by a bridge of nerve fibers, the **corpus callosum**.
   2. The outer portion is a highly convoluted **cerebral cortex** consisting of gray matter containing cell bodies and short unmyelinated fibers.
   3. The cerebral cortex in each hemisphere contains four surface lobes: the frontal, parietal, occipital, and temporal lobes.
   4. Different functions are associated with each lobe
   5. The cerebral cortex contains motor, sensory, and association areas.
      a. The human hand takes up a large proportion of the primary motor area.
      b. Ventral to the primary motor area is a premotor area that organizes motor functions before the primary area sends signals to the cerebellum.
      c. The left frontal lobe has Broca's area for our ability to speak.
      d. Sensory information from the skin and skeletal muscles arrives at a primary somatosensory area.
      e. The primary visual area in the occipital lobe receives information from the eyes; a visual association area associates new visual information with old information.
      f. The primary auditory area in the temporal lobe receives information from our ears.
      g. The primary taste area is in the parietal lobe.
      h. Our somatosensory association area processes and analyzes sensory information from skin and muscles.
      i. A general interpretation area receives information from all of the sensory association areas and allows us to quickly integrate signals and send them to the prefrontal area for immediate response.
      j. The prefrontal area in the frontal lobe receives input from other association areas and reasons and plans.
      k. White Matter
         1) White matter in the CNS consists of long myelinated axons organized into tracts.
         2) Descending tracts from the primary motor area communicate with lower brain centers.
         3) Ascending tracts from lower brain centers send sensory information up to the primary somatosensory area.
         4) These tracts cross over near the brain; therefore the left side of the brain controls the right side of the body.
      l. Basal Nuclei
         1) Aside from the tracts, there are masses of gray matter located deep within the white matter.
         2) These basal nuclei integrate motor commands; malfunctions cause Huntingdon and Parkinson disease.

F. The Diencephalon
   1. The **hypothalamus** and **thalamus** are in a portion of the brain known as the **diencephalon**, where the third ventricle is located.
   2. The hypothalamus forms the floor of the third ventricle.
   3. The hypothalamus maintains homeostasis.
      a. It is an integrating centers that regulates hunger, sleep, thirst, body temperature, water balance, and blood pressure.
      b. It controls the pituitary gland and thereby serves as a link between the nervous and endocrine systems.
   4. The thalamus consists of two masses of gray matter in the sides and roof of the third ventricle.
      a. It is the last portion of the brain for sensory input before the cerebrum.
      b. It is a central relay station for sensory impulses traveling up from the body or from the brain to cerebrum.
      c. Except for smell, it channels sensory impulses to specific regions of cerebrum for interpretation.
   5. The pineal gland, which secretes melatonin hormone, is in the diencephalon.

F. The Cerebellum
   1. The **cerebellum** is separated from the brain stem by the fourth ventricle.
   2. The cerebellum is in two portions joined by a narrow median portion.
   3. The cerebellum integrates impulses from higher centers to coordinate muscle actions, maintain equilibrium and muscle tone, and sustain normal posture.
   4. It receives information from the eyes, inner ear, muscles, etc. indicating body position, integrates the information and sends impulses to muscles maintaining balance.
   5. The cerebellum assists in the learning of new motor skills, as in sports or playing the piano.

G. The Brain Stem
   1. The **medulla oblongata**, **pons**, and **midbrain** all form the brain stem.
   2. Besides acting as a relay station for tracts passing between the cerebrum and spinal cord or cerebellum, the **midbrain** has reflex centers for visual, auditory, and tactile responses.
   3. The **pons** contains bundles of axons traveling between the cerebellum and rest of CNS.
      a. The pons functions with the medulla to regulate the breathing rate.
      b. It has reflex centers concerned with head movements in response to visual or auditory stimuli.
   4. The **medulla oblongata** lies between the spinal cord and the pons, anterior to the cerebellum.
      a. It contains **vital centers** for regulating heartbeat, breathing, and vasoconstriction.
      b. It contains reflex centers for vomiting, coughing, sneezing, hiccuping, and swallowing.
      c. It contains nerve tracts that ascend or descend between the spinal cord and the brain's higher centers.

H. The Limbic System
   1. The limbic system is a complex network of tracts and nuclei that incorporate medial portions of cerebral lobes, subcortical nuclei, and diencephalon.
   2. It blends higher mental functions and primitive emotions.
   3. Its two major structures are the **hippocampus** and **amygdala** for learning and memory.
      a. The hippocampus makes prefrontal area aware of past experiences stored in association areas.
      b. The amygdala causes experiences to have emotional overtones.
      c. Inclusion of the frontal lobe in the limbic system allows reasoning to keep us from acting out strong feelings.
   4. Learning and Memory
      a. Memory is the ability to hold thoughts in the mind and to recall past events.
      b. Learning takes place when we retain and utilize past memories.
      c. The prefrontal area in the frontal lobe is active in short-term memory (e.g., telephone numbers).
      d. Long-term memory is a mix of semantic memory (numbers, words) and episodic memory (persons, events).
      e. Skill memory is the ability to perform motor activities.
      f. The hippocampus serves as a go-between to bring memories to mind.
      g. The amygdala is responsible for fear conditioning and associates danger with sensory stimuli.
      h. Long-term potentiation (LTP) is an enhanced response at synapses within hippocampus.
      i. LTP is essential to memory storage; excited postsynaptic cells may die due to a glutamate neurotransmitter.
      j. Extinction of too many cells in the hippocampus is the underlying cause of Alzheimer disease.

39.4 Peripheral Nervous System

A. Introduction to the PNS
   1. The peripheral nervous system lies outside the CNS.
      a. **Cranial nerves** connect to the brain.
      b. **Spinal nerves** lie on either side of the spinal cord.
   2. Axons in nerves are called nerve fibers.
   3. The cell bodies of neurons are found in the CNS or in ganglia.
   4. Ganglia are collections of cell bodies in the PNS.
   5. Humans have 12 pairs of **cranial nerves** attached to the brain.
      a. Sensory nerves only contain sensory nerve fibers.
      b. Motor nerves only contain motor nerve fibers.
      c. Mixed nerves contain both sensory and motor nerve fibers.
      d. Cranial nerves mostly connect to the head, neck, and facial regions.
      e. The vagus nerve also branches to the pharynx, larynx, and some internal organs.

6. Humans have 31 pairs of **spinal nerves** emerging from the **spinal cord**.
    a. The paired spinal nerves leave the spinal cord by two short branches (**spinal roots**).
    b. The dorsal or sensory root contains fibers of sensory neurons conducting nerve impulses to the spinal cord.
    c. The **ventral root** contains the axons of motor neurons that conduct nerve impulses away from the spinal cord.
    d. All spinal nerves are mixed nerves that conduct impulses to and from the spinal cord.
    e. Spinal nerves are mixed nerves with sensory and motor fibers; each serves its own region.

B. Somatic System
1. The **somatic system** has nerves to carry sensory information to the CNS and motor commands away from the CNS to **skeletal** muscles.
2. Any voluntary control of muscles involves the brain; reflexes involve the brain or spinal cord.
3. Outside stimuli can initiate reflex actions, some of which involve the brain.

C. The Reflex Arc
1. **Reflexes** are automatic, involuntary responses.
2. A reflex arc involves the following pathway.
    a. **Sensory receptors** generate an impulse in a **sensory neuron** that moves along sensory axons toward the spinal cord.
    b. Sensory neurons enter the cord dorsally and pass signals to interneurons.
    c. Impulses travel along motor axons to an effector, which brings about a response to the stimulus.
    d. The immediate response is that muscles contract to withdraw from source of pain.
3. Reflex response occurs because the sensory neuron stimulates several interneurons.
4. Some impulses extend to the cerebrum, which makes a person conscious of the stimulus and the reaction.

D. Autonomic System
1. The **autonomic system** is a part of the PNS and regulates cardiac and smooth muscle and glands.
2. There are two divisions: the sympathetic and parasympathetic systems.
    a. Both function automatically and usually in an involuntary manner.
    b. Both innervate all internal organs.
    c. Both utilize two neurons and one ganglion for each impulse.
        1) The first neuron has a cell body within the CNS and a **preganglionic fiber**.
        2) The second neuron has a cell body within the ganglion and a **postganglionic fiber**.
    d. Breathing rate and blood pressure are regulated by reflex actions to maintain homeostasis.

E. Sympathetic Division
1. Most preganglionic fibers of the **sympathetic system** arise from the middle (**thoracic-lumbar**) portion of the spinal cord and almost immediately terminate in ganglia that lie near the cord (thoracic-lumbar portion).
2. Therefore the preganglionic fiber is short, but the postganglionic fiber that contacts an organ is long.
3. The sympathetic system is especially important during emergency situations (the "fight or flight" response).
4. To defend or flee, muscles need a supply of glucose and oxygen; the sympathetic system accelerates heartbeat, and dilates bronchi.
5. To divert energy from less necessary digestive functions, the sympathetic system inhibits digestion.
6. The neurotransmitter released by the postganglionic axon is mainly norepinephrine, similar to epinephrine (adrenaline) used as a heart stimulant.

F. Parasympathetic Division
1. The **parasympathetic system** consists of a few cranial nerves, including the vagus nerve, and fibers that arise from the bottom craniosacral portion of the spinal cord.
2. In this case, the preganglionic fibers are long and the postganglionic fibers are short.
3. This system is a "housekeeper system"; it promotes internal responses resulting in a relaxed state.
4. The parasympathetic system causes the eye pupil to constrict, promotes digestion, and retards heartbeat.
5. The neurotransmitter released is acetylcholine.