Chapter 12 Outline

I. INTRODUCTION

A. The *nervous system*, along with the endocrine system, helps to keep controlled conditions within limits that maintain health and helps to maintain homeostasis.

B. The nervous system is responsible for all our behaviors, memories, and movements.

C. The branch of medical science that deals with the normal functioning and disorders of the nervous system is called *neurology*.

II. OVERVIEW OF THE NERVOUS SYSTEM

A. Structures of the Nervous System

1. The *nervous system* is made up of the brain, cranial nerves, spinal cord, spinal nerves, ganglia, enteric plexus, and sensory receptors.
2. The *brain* is housed within the skull.
3. Twelve pairs of *cranial nerves* emerge from the base of the brain through foramina of the skull.
4. A *nerve* is a bundle of hundreds or thousands of neuron fibers outside of the central nervous system. The *spinal cord* connects to the brain through the foramen magnum of the skull and is encircled by the bones of the vertebral column.
5. Thirty-one pairs of *spinal nerves* emerge from the spinal cord, each serving a specific region of the body.
6. Ganglia, located outside the brain and spinal cord, are small masses of nervous tissue, containing primarily cell bodies of neurons.
7. Enteric *plexuses* help regulate the digestive system.
8. Sensory *receptors* are either parts of neurons or specialized cells that monitor changes in the internal or external environment.
9. Be sure you know the differences between nerves and tracts, nuclei and ganglia.

B. Functions of the Nervous Systems

1. The sensory *function* of the nervous system is to sense changes in the internal and external environment through sensory receptors. *Sensory neurons* serve this function.
2. The integrative *function* is to analyze the sensory information, store some aspects, and make decisions regarding appropriate behaviors. *Association* or *interneurons* serve this function.
3. The motor *function* is to respond to stimuli by initiating action. *Motor neurons* serve this function.

C. Organization of the Nervous System

1. The *central nervous system* (CNS) consists of the brain and spinal cord.
2. The *peripheral nervous system* (PNS) consists of cranial and spinal nerves with sensory (efferent) and motor (afferent) components, ganglia, and sensory receptors.
    a. The sensory component consists of a variety of different receptors as well as sensory neurons.
    b. The motor component consists of motor neurons which conduct nerve impulses from the CNS to muscles and glands.
3. The PNS is also subdivided into somatic (voluntary), autonomic (involuntary), and enteric nervous systems.
    a. 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.
    b. 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.
        1) The motor part of the ANS consists of the *sympathetic division* and the *parasympathetic division*.

2) Usually, the two divisions have opposing actions.

c. The *enteric nervous system* (ENS) consists of neurons in enteric plexuses that extend the length of the GI tract.

1) Many neurons of the enteric plexuses function independently of the ANS and CNS.

2) Sensory neurons of the ENS monitor chemical changes within the GI tract and stretching of its walls, whereas enteric motor neurons govern contraction of GI tract organs, and activity of the GI tract endocrine cells.

III. HISTOLOGY OF THE NERVOUS SYSTEM

A. Neurons

1. Neurons have the property of electrical excitability.

2. Most *neurons*, or nerve cells, consist of a cell body (soma), many dendrites, and usually a single axon.

a. The *cell body* contains a nucleus, lysosomes, mitochondria, a Golgi complex, and cytoplasmic inclusions.

1) Chromatophilic substances (Nissl bodies) are an orderly arrangement of rough ER.

2) Neurofibrils form the cytoskeleton.

b. The *dendrites* are the receiving or input portions of a neuron.

c. 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).

d. The site of functional contact between two neurons or between a neuron and an effector cell is called a *synapse*.

3. *Axonal transport*, a natural mechanism of intracellular transport in neurons, is exploited by certain microorganisms to reach other parts of the nervous system.

4. *Fast axonal transport* is the route by which some toxins (such as toxins produced by *Clostridium tetani* bacteria) and disease causing viruses make their way from axon terminals near skin cuts to cell bodies, where they cause damage.
5. Diversity in Neurons
    a. Both structural and functional features are used to classify the various neurons in the body.
    b. On the basis of the number of processes extending from the cell body, neurons are classified structurally as *multipolar*, *bipolar*, and *unipolar*.
    c. Functionally, neurons are classified as sensory, motor, or association (interneurons) and sensory and motor neurons can be further subdivided into somatic or visceral.

B. Neuroglia

1. *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.
2. *Schwann cells* and *oligodendrocytes* are examples of neuroglial cells.

C. Myelination

1. A multilayered lipid and protein covering called the *myelin sheath* and produced by Schwann cells and oligodendrocytes surrounds the axons of most neurons.
2. The sheath electrically insulates the axon and increases the speed of nerve impulse conduction.
3. Schwann cells produce the myelin sheath in the PNS.
    a. The outer nucleated cytoplasmic layer of the Schwann cell, which encloses the myelin sheath, is called the *neurolemma* and is found only around axons in the PNS.
    b. The neurolemma aids in regeneration in an injured axon by forming a regeneration tube that guides and stimulates regrowth of the axon (Figure

        c. The myelin sheath has gaps called *nodes of Ranvier* along the axon.

    4. Oligodendrocytes form myelin sheaths for CNS axons.
        a. No neurolemma is formed as the oligodendrocyte does not remain around the axon once the myelin sheath is formed.
        b. No regrowth after injury occurs.

D. Gray and White Matter

    1. *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.
    2. 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.
    3. A nucleus is a mass of nerve cell bodies and dendrites inside the CNS.

IV. ELECTRICAL SIGNALS IN NEURONS

A. Excitable cells communicate with each other by *action potentials* or *graded potentials*.

    1. *Action potentials* allow communication over short and long distances whereas *graded potentials* allow communication over short distances only.
    2. Production of both types of potentials depend upon the existence of a resting membrane potential and the presence of certain types of ion channels.
        a. The *membrane potential* is an electrical voltage across the membrane.
        b. Graded and action potentials occur because of ion channels in the membrane that allow ion movement across the membrane that can change the membrane potential.

B. Ion Channels

    1. The two basic types of ion channels are *leakage* (*nongated*) and *gated*.
    2. *Leakage* (*nongated*) *channels* are always open.

3. *Gated channels* open and close in response to some sort of stimulus.
    a. *Gated ion channels* respond to voltage changes, ligands (chemicals), mechanical pressure and light.
    b. *Voltage-gated channels* respond to a direct change in the membrane potential.
    c. *Ligand-gated channels* respond to a specific chemical stimulus.
    d. *Mechanically gated ion channels* respond to mechanical vibration or pressure.

C. Resting Membrane Potential

1. 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^+.
2. A typical value for the resting membrane potential is -70mV, and the membrane is said to be polarized.
3. The *resting membrane potential* is determined by the unequal distribution of ions across the plasma membrane and the selective permeability of the membrane to Na^+ and K^+. More K+ leaks out than Na+ leaks in.
4. The sodium-potassium pumps compensate for slow leakage of Na^+ into the cell by pumping it back out and K+ out of the cell by pumping it back in. For every three Na+ pumped out, only two K+ are pumped in.

D. Graded Potentials

1. A *graded potential* is a small deviation from the resting membrane potential that makes the membrane either more polarized (*hyperpolarization*) or less polarized (*depolarization*).
2. Graded potentials occur most often in the dendrites and cell body of a neuron.
3. The signals are *graded*, meaning they vary in amplitude (size), depending on the strength of the stimulus and *localized*.

E. Generation of an Action Potential

1. An *action potential* (AP) or *impulse* is a sequence of rapidly occurring events that decrease and eventually reverse the membrane potential (*depolarization*) and then restore it to the resting state (*repolarization*).
2. During an action potential, voltage-gated Na^+ and K^+ channels open in sequence.
3. Rapid opening of voltage-gated Na^+ channels causes depolarization. If the depolarization is to threshold, the membrane potential reverses. Depolarization occurs due to the interaction of the two voltage-gated Na^+ channel gates: an activation gate and an inactivation gate.
4. The slower opening of voltage-gated K^+ channels and closing of previously open Na^+ channels leads to repolarization, the recovery of the resting membrane potential.
5. 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 large impulse.
6. 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*).
7. An action potential *conducts* or *propagates* (travels) from point to point along the membrane; the traveling action potential is a nerve impulse.
8. Local anesthetics and certain neurotoxins prevent opening of voltage-gated Na^+ channels so nerve impulses cannot pass the obstructed region.
9. The step-by-step depolarization of each adjacent area of the plasma membrane is called *continuous conduction*. Nerve impulse conduction in which the impulse jumps from node to node (of Ranvier) is called *saltatory conduction*.
10. The propagation speed of a nerve impulse is not related to stimulus strength.

a. Larger-diameter fibers conduct impulses faster than those with smaller diameters.

b. Myelinated fibers conduct impulses faster than unmyelinated fibers.

c. Nerve fibers conduct impulses faster when warmed and slower when cooled.

11. The intensity of a stimulus is coded in the rate of impulse production, i.e., the frequency of action potentials.

12. Nerve and muscle action potentials differ in size of the resting membrane potential, duration of the impulses, and velocity of conduction of the impulse.

VI. Graded and action potentials differ in amplitude, duration, types of channels used, location, polarity, propagation, and refractory period.

VII. SIGNAL TRANSMISSION AT SYNAPSES

A. A *synapse* is the functional junction between one neuron and another or between a neuron and an effector such as a muscle or gland.

B. Electrical Synapses

1. At an *electrical synapse*, ionic current spreads directly from one cell to another through gap junctions (see Chap. 4).

2. Electrical synapses allow faster communication, can synchronize the activity of a group of neurons or muscle fibers.

C. Chemical Synapses

1. At a *chemical synapse*, there is only one-way information transfer from a presynaptic neuron to a postsynaptic neuron.

2. Neurotransmitters at chemical synapses cause either an excitatory or inhibitory graded potential.

a. An *excitatory neurotransmitter* is one that can depolarize or make less negative the postsynaptic neuron's membrane, bringing the membrane potential closer to threshold.

1) A depolarizing postsynaptic potential (PSP) is called an *excitatory postsynaptic potential* (*EPSP*).

2) 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.

b. 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*).

3. Neurotransmitter is removed from the synaptic cleft in three ways: *diffusion, enzymatic degradation*, and *uptake into cells* (neurons and glia).

4. If several presynaptic end bulbs release their neurotransmitter at about the same time, the combined effect may generate a nerve impulse in the postsynaptic neuron due to spatial *summation*; if one presynaptic end bulb releases neurotransmitter multiple times in rapid succession, a nerve impulse in the postsynaptic neuron may be generated due to *temporal summation.*

5. The postsynaptic neuron is an integrator, receiving and integrating signals, then responding.

   a. If the excitatory effect is greater than the inhibitory effect but less that the threshold level of stimulation, the result is a subthreshold EPSP, making it easier to generate a nerve impulse.

   b. If the excitatory effect is greater than the inhibitory effect and reaches or surpasses the threshold level of stimulation, the result is a threshold or suprathreshold EPSP and a nerve impulse.

   c. If the inhibitory effect is greater than the excitatory effect, the membrane hyperpolarizes (IPSP) with failure to produce a nerve impulse.

C. Neurotransmitters

1. 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.
2. Examples of neurotransmitters include *acetylcholine, glutamate, aspartate, gamma aminobutyric acid (GABA), glycine, norepinephrine, epinephrine, dopamine and serotonin.*
3. Neurotransmitters can be modified by stimulating or inhibiting neurotransmitter synthesis, blocking or enhancing neurotransmitter release, stimulating or inhibiting neurotransmitter removal, and/or blocking or activating the receptor site.
4. Neurotransmitters can be divided into two classes: *small-molecule neurotransmitters* and *neuropeptides.*
   a. Small-molecule neurotransmitters include acetylcholine, amino acids, biogenic amines, ATP and other purines, and gases.
   b. Neurotransmitters consisting of 3-40 amino acids linked by peptide bonds are called neuropeptides.
5. Enkephalins, endorphins, and dynorphins are examples of neuropeptides which have opiate-like effects. Substance P is released by neurons carrying pain signals and its release is suppressed by enkephalins.
6. Substances naturally present in the body, drugs, and toxins can modify the effects of neurotransmitters by: stimulating or inhibiting neurotransmitter synthesis, enhancing or blocking neutotransmitter release. activating or blocking neurotransmitter receptors, or stimulating or inhibiting neurotransmitter removal.

VI. NEURONAL CIRCUITS

A. Neurons in the CNS 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.

B. Neuronal pools are organized into circuits. These include simple series, diverging, converging, reverberating, and parallel after-discharge circuits.

VII. REGENERATION AND REPAIR OF NERVOUS TISSUE

A. Throughout life, the nervous system exhibits *plasticity*, the capability for change with learning.

   1. Despite plasticity, neurons have a limited capacity to repair or replicate themselves.
   2. In the PNS, damage to dendrites and myelinated axons may be repaired if the cell body remains intact and if Schwann cells are active.
   3. In the CNS, there is little or no repair of damage to neurons.

B. Current research is going on to find ways to promote *neurogenesis* and to find ways to encourage and promote regrowth in the CNS.