Chapter 20 Adapted from Tortora 10th ed.

LECTURE OUTLINE

A. Introduction (p. 632)
   1. The autonomic nervous system (ANS) regulates the activity of smooth muscle, cardiac muscle, and certain glands.
   2. The ANS includes:
      i. autonomic sensory neurons
      ii. integrating centers in the CNS
      iii. autonomic motor neurons
   3. The ANS is regulated by centers in the brain, primarily the hypothalamus and brain stem.

B. Comparison of Somatic and Autonomic Nervous Systems (p. 633)
   1. In the somatic nervous system:
      i. sensory neurons transmit information from receptors for the special senses and somatic senses
      ii. these sensations are (normally) consciously perceived
      iii. somatic motor neurons innervate skeletal muscle to:
         a. produce voluntary movement
         b. cause excitation, i.e., contraction
      iv. each somatic motor pathway consists of a single somatic motor neuron that extends from the CNS to skeletal muscle
      v. somatic motor neurons release acetylcholine (ACh)
   2. In the autonomic nervous system:
      i. autonomic sensory (afferent) neurons transmit information from interoceptors, such as chemoreceptors
      ii. sensations are usually not consciously perceived
      iii. autonomic motor (efferent) neurons innervate smooth muscle, cardiac muscle, and glands to:
         a. produce activities that are usually not under conscious control
         b. cause excitation or inhibition of effector tissue activity
      iv. autonomic motor pathways consist of sets of two motor neurons in series:
         a. the first neuron has its cell body in the CNS and its myelinated axon extends from the CNS to an autonomic ganglion
         b. the second neuron has its cell body in the autonomic ganglion and its unmyelinated axon extends directly to the autonomic effector
      v. autonomic motor neurons release either acetylcholine or norepinephrine (NE)
      vi. the output (motor) part of the ANS has two divisions:
         a. sympathetic division
         b. parasympathetic division
           - most autonomic effectors have dual innervation
   3. Table 20.1 provides an excellent summary of the similarities and differences between the somatic and autonomic nervous systems.

C. Anatomy of Autonomic Motor Pathways (p. 634)
   1. Anatomical components:
i. The first of the two autonomic motor neurons is called a **preganglionic neuron**:
   a. its cell body is in the brain or spinal cord
   b. its myelinated axon exits the CNS as part of a cranial or spinal nerve, separates from the nerve, and extends to an autonomic ganglion where it synapses with a postganglionic neuron

ii. The **postganglionic neuron** is the second of the two autonomic motor neurons and is located entirely outside the CNS:
   a. its cell body and dendrites are located in the autonomic ganglion, where it synapses with one or more preganglionic fibers
   b. its unmyelinated axon extends to a visceral effector

2. **Preganglionic neurons**:
   i. In the sympathetic division:
      a. preganglionic neurons have their cell bodies in the lateral gray horns of the 12 thoracic segments and the first two lumbar segments of the spinal cord
      b. therefore, the sympathetic division is also called the **thoracolumbar division** and the axons of the sympathetic preganglionic neurons are known as the **thoracolumbar outflow**
   ii. In the parasympathetic division:
      a. preganglionic neurons have their cell bodies located in the brain stem nuclei of four cranial nerves (III, VII, IX, and X) and in the lateral gray horns of the second through fourth sacral segments of the spinal cord
      b. therefore, the parasympathetic division is also called the **craniosacral division** and the axons of the parasympathetic preganglionic neurons are known as the **craniosacral outflow**

3. **Autonomic ganglia**:
   i. **Sympathetic ganglia** include:
      a. **sympathetic trunk ganglia** that are a series of ganglia that lie in a vertical row on either side of the vertebral column, extending from the base of the skull to the coccyx
         - they are also called **vertebral chain ganglia** or **paravertebral ganglia**
         - due to the close proximity of these ganglia to the spinal cord, most sympathetic preganglionic axons are relatively short
         - postganglionic axons, in general, innervate organs above the diaphragm
         - examples include the **superior**, **middle**, and **inferior cervical ganglia**
      b. **prevertebral (collateral) ganglia** that are located anterior to the spine and close to the large abdominal arteries
         - postganglionic axons, in general, innervate organs below the diaphragm
         - examples include the **celiac ganglion**, **superior** and **inferior mesenteric ganglia**
   ii. **Parasympathetic ganglia**:
      a. parasympathetic preganglionic fibers extend to **terminal (intramural) ganglia** which are located very close to or within the wall of a visceral organ
- therefore, parasympathetic preganglionic axons tend to be relatively long axons
- examples include the ciliary ganglion and otic ganglion

iii. In the thorax, abdomen, and pelvis, axons of both sympathetic and parasympathetic neurons form tangled networks called autonomic plexuses, many of which lie along major arteries that they are named after; examples include the cardiac plexus, pulmonary plexus, celiac (solar) plexus, superior and inferior mesenteric plexuses, hypogastric plexus, and the renal plexuses.

4. Postganglionic neurons:
   i. Axons of sympathetic preganglionic neurons extend to sympathetic trunk ganglia:
      a. some axons synapse with postganglionic neurons in these ganglia
      b. some axons ascend or descend to a higher or lower ganglion before synapsing with postganglionic neurons
      c. other axons continue, without synapsing, through the sympathetic trunk ganglion to end at a prevertebral ganglion where they synapse with postganglionic neurons
      d. some axons extend to and terminate in the adrenal medulla
      e. in most cases, a single sympathetic preganglionic fiber may synapse with 20 or more postganglionic neurons, i.e., there is divergence and therefore sympathetic responses tend to be widespread throughout the body; postganglionic fibers typically innervate several visceral effectors
   ii. Axons of parasympathetic preganglionic neurons extend to terminal ganglia where they synapse with 4 or 5 postganglionic neurons, all of which innervate a single visceral effector; therefore, parasympathetic effects tend to be localized.

5. Structure of the Sympathetic Division: (p. 639)
   i. The myelinated sympathetic preganglionic axons leave the lateral gray horns of all thoracic and the first two lumbar segments of the spinal cord; they leave along with somatic motor fibers via the anterior root of a spinal nerve.
   ii. After exiting through the intervertebral foramina, the preganglionic axons enter a short pathway called a white ramus before extending to the nearest sympathetic trunk ganglion on the same side; collectively, the white rami are called white rami communicantes.
   iii. The paired sympathetic trunk ganglia are located anterior and lateral to the spine, one on either side; typically, they include:
      a. 3 cervical sympathetic trunk ganglia
      b. 11 or 12 thoracic sympathetic trunk ganglia
      c. 4 or 5 lumbar sympathetic trunk ganglia
      d. 4 or 5 sacral sympathetic trunk ganglia
      e. 1 coccygeal ganglion
   iv. Although the sympathetic trunk ganglia extend downward along the entire length of the spine, the ganglia receive preganglionic fibers only from the thoracic and lumbar segments of the spinal cord.
   v. The cervical portion of each sympathetic trunk is subdivided into:
      a. superior cervical ganglion whose postganglionic fibers serve the head and heart
b. **middle cervical ganglion** whose postganglionic fibers innervate the heart

c. **inferior cervical ganglion** whose postganglionic fibers also innervate the heart

vi. The thoracic portions of the sympathetic trunk ganglia receive most of the sympathetic preganglionic fibers; the postganglionic fibers from these ganglia innervate thoracic viscera and skin structures.

vii. Unmyelinated postganglionic fibers from the lumbar and sacral sympathetic trunk ganglia enter a short pathway called a **gray ramus** and then merge with a spinal nerve or join the hypogastric plexus in the pelvis via direct visceral branches; the **gray ramus communicans** is the structure containing the postganglionic fibers that connect the ganglion to the spinal nerve.

viii. As preganglionic fibers extend from a white ramus communicans into the sympathetic trunk, they give off several axon collaterals that terminate and synapse in several ways; among these are some which pass up or down the sympathetic trunk for a variable distance to form the **sympathetic chains** along which the ganglia are strung.

ix. Some preganglionic fibers pass through the sympathetic trunks without terminating; beyond the trunks, they form nerves called **splanchnic nerves** which extend to and terminate in prevertebral ganglia.

x. Splanchnic nerves from the thoracic area terminate in the **celiac ganglion** or, in other instances, pass through this ganglion to terminate in other nearby ganglia; postganglionic fibers from all of these ganglia innervate abdominal viscera.

xi. Similarly, postganglionic fibers serviced by the **lumbar splanchnic nerve** innervate abdominal and pelvic visceral effectors.

xii. Sympathetic preganglionic fibers also extend to the adrenal medullae which are modified sympathetic ganglia, and their cells are similar to sympathetic postganglionic neurons; these cells secrete the hormones **norepinephrine** (about 20%) and **epinephrine** (about 80%) plus a trace amount of **dopamine** into the blood (this is one exception to the usual pattern of two efferent neurons in an autonomic motor pathway).

6. **Structure of the Parasympathetic Division:** (p. 641)

i. Cell bodies of parasympathetic preganglionic neurons are located in brain stem nuclei and the lateral gray horns of the second through fourth sacral segments of the spinal cord.

ii. The **cranial parasympathetic outflow** consists of preganglionic axons that emerge from the brain stem in four cranial nerves; these preganglionic fibers end in terminal ganglia where they synapse with postganglionic neurons.

iii. The **sacral parasympathetic outflow** consists of preganglionic axons that emerge in anterior roots of the second through fourth sacral nerves; these preganglionic fibers also end in terminal ganglia where they synapse with postganglionic neurons.

iv. The cranial outflow has 5 components:

   a. **ciliary ganglia**
   b. **pterygopalatine ganglia**
   c. **submandibular ganglia**
   d. **otic ganglia**
- postganglionic axons from these four pairs of ganglia innervate structures in the head

e. preganglionic fibers that leave the brain as part of the vagus (X) nerves

- the vagus nerves carry preganglionic fibers that comprise nearly 80% of the total craniosacral outflow
- these preganglionic fibers extend to many terminal ganglia in the thorax and abdomen
- postganglionic fibers from these terminal ganglia travel relatively short distances to innervate many organs in the thoracic and abdominal cavities

v. The sacral parasympathetic outflow consists of preganglionic axons from the anterior roots of the second through fourth sacral nerves and collectively form the pelvic splanchnic nerves; these nerves extend to terminal ganglia where they synapse with postganglionic neurons that innervate smooth muscle and glands in the walls of abdominal and pelvic organs.

D. ANS Neurotransmitters and Receptors (p. 641)

1. Based on the neurotransmitter they release, autonomic neurons are classified as either cholinergic or adrenergic; the neurotransmitter receptors are integral membrane proteins in the plasma membrane of the postsynaptic neuron or effector cell.

2. Cholinergic Neurons and Receptors:

i. Cholinergic neurons release acetylcholine (ACh) and include:

   a. all sympathetic and parasympathetic preganglionic neurons
   b. all parasympathetic postganglionic neurons
   c. sympathetic postganglionic neurons that innervate most sweat glands

   - ACh binds to cholinergic receptors on the postsynaptic cell to cause excitation or inhibition; there are two types of cholinergic receptors, nicotinic receptors and muscarinic receptors.
   - ACh is quickly inactivated by acetylcholinesterase (AChE) and therefore its effects on postsynaptic cells are brief.

ii. Adrenergic neurons release norepinephrine (NE) or noradrenalin; most sympathetic postganglionic neurons are adrenergic and secrete norepinephrine whose effect on postsynaptic cells is to cause excitation or inhibition

   - adrenergic receptors bind both norepinephrine and epinephrine
   - there are two main types of adrenergic receptors, alpha (α) receptors and beta (β) receptors
   - the effects of norepinephrine are terminated when the NE is taken up by the axon that released it or when the NE is enzymatically inactivated by catechol-O-methyltransferase (COMT) or monoamine oxidase (MAO)
- since NE lingers in the synaptic cleft longer than ACh, the effects triggered by adrenergic neurons are longer lasting than those triggered by cholinergic neurons

E. Functions of the ANS (p. 643)

1. Most autonomic effectors have dual innervation; the two divisions generally have opposing effects with one division causing excitation and the other division causing inhibition.
2. The hypothalamus regulates the balance of sympathetic versus parasympathetic activity.
3. The two divisions have opposing effects because their postganglionic neurons release different neurotransmitters and the effectors have different neurotransmitter receptors.
4. Some autonomic effectors receive only sympathetic innervation; they include:
   i. sweat glands
   ii. arrector pili muscles
   iii. kidneys
   iv. spleen
   v. most blood vessels
   vi. adrenal medullae
5. Sympathetic and Parasympathetic Responses:
   i. The sympathetic division:
      a. is dominant over the parasympathetic division during times of physical or emotional stress
      b. high sympathetic activity favors body functions that can support vigorous physical activity and rapid ATP production
      c. elicits, along with adrenal medullary hormones, a series of physiological responses collectively called the fight-or-flight response
      d. these effects are longer lasting and more widespread than the effects of parasympathetic stimulation
   ii. The parasympathetic division:
      a. enhances “rest-and-digest” activities that support body functions that conserve and restore body energy during times of rest or recovery
      b. is normally dominant over the sympathetic division in affecting the organs of the digestive system
      c. elicits “SLUDD” responses:
          - salivation
          - lacrimation
          - urination
          - digestion
          - defecation
      d. also decreases heart rate, decreases bronchiole diameter, and decreases pupil diameter
   iii. Table 20.2 compares the structural and functional features of the sympathetic and parasympathetic divisions of the ANS.
   iv. Table 20.3 summarizes the responses of glands, smooth muscle, and cardiac muscle to stimulation by the sympathetic and parasympathetic divisions of the ANS.
F. Integration and Control of Autonomic Functions (p. 646)
   1. Autonomic reflexes adjust the activities of visceral effectors (e.g., heart, blood vessels, bronchioles, GI tract, etc.) and therefore play a key role in activities involved in homeostasis.
   2. An autonomic reflex arc has 5 components:
      i. receptor
      ii. sensory neuron
      iii. integrating center in the CNS
      iv. motor neurons:
         a. preganglionic neuron
         b. postganglionic neuron
      v. effector, i.e., smooth muscle, cardiac muscle, or gland

G. Autonomic Control by Higher Centers (p. 646)
   1. The hypothalamus is the major control and integration center of the ANS.
   2. The hypothalamus receives sensory input related to visceral functions, olfaction, gustation, body temperature, osmolarity, and levels of various substances in the blood; it also receives input relating to emotions from the limbic system.
   3. Output from the hypothalamus influences autonomic centers:
      i. Axons from hypothalamic nuclei form tracts that lead to sympathetic and parasympathetic nuclei in the brain stem and spinal cord through relays in the reticular formation.
      ii. The posterior and lateral portions of the hypothalamus control the sympathetic division.
      iii. The anterior and medial portions of the hypothalamus control the parasympathetic division.

H. Key Medical Terms Associated with the Autonomic Nervous System (p. 647)
   1. Students should familiarize themselves with the glossary of key medical terms.