

# Autonomic Nervous System

## Chapter 16

### INTRODUCTION

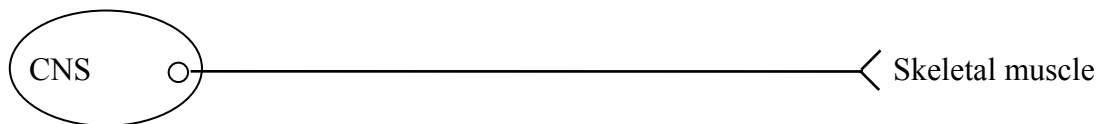
The ANS regulates many important functions.

1. Circulation
2. Respiration
3. Digestion
4. Temperature regulation
5. Sexual reactions
6. Water balance
7. Fight or flight response
8. Response to stress

### CONTRASTING THE SOMATIC MOTOR AND AUTONOMIC NERVOUS SYSTEMS

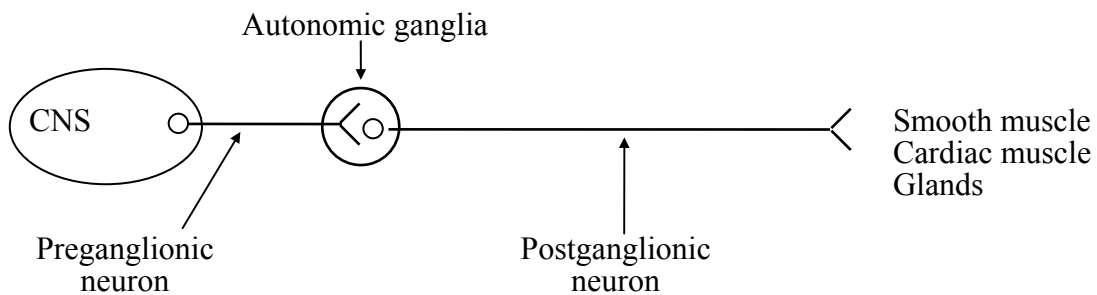
FIGURE 16.1

1. Somatic motor nervous system.



- A. There is one neuron extending from the central nervous system to the skeletal muscle.
- B. Stimulation of the neuron results in muscle contraction.
- C. The somatic nervous system is responsible for conscious and unconscious (e.g., reflexes) control of skeletal muscle.

2. Autonomic nervous system.



- A. There are two neurons between the central nervous system and the effector organs (smooth muscle, cardiac muscle, and glands).
  - 1) The **preganglionic neuron** has its cell body in the central nervous system.
  - 2) The preganglionic neuron synapses with the postganglionic neuron in an **autonomic ganglion**.
  - 3) The **postganglionic neuron** has its cell body in the autonomic ganglion and extends to the effector organ where it synapses.
- B. Stimulation of the effector organ results in excitation or inhibition.
- C. The autonomic nervous system is responsible for unconscious control of its effector organs. However it can be influenced by conscious functions (e.g., biofeedback, emotions).

### **ANATOMY OF THE AUTONOMIC NERVOUS SYSTEM**

- 1. The ANS can be divided into sympathetic and parasympathetic divisions and the enteric nervous system (ENS).
- 2. These divisions differ from each other structurally and functionally.

#### **Sympathetic Division**

FIGURE 16.2

- 1. The preganglionic neuron cell bodies are located in the lateral horns of the spinal cord gray matter from T1 to L2.
- 2. The axons of the preganglionic neurons extend to autonomic ganglia where they synapse with postganglionic neurons.
  - A. Sympathetic chain ganglia are located close to the spinal cord and are connected to each other to form a chain of ganglia on the right and left sides of the body.
  - B. Collateral ganglia are located farther from the spinal cord than sympathetic chain ganglia. They are in the abdominopelvic cavity.

FIGURE 16.3

- 3. All sympathetic axons extend to the sympathetic chain ganglia in the same way.
  - A. The axon of the preganglionic neuron exits through the ventral root into a spinal nerve. The axon leaves the spinal nerve and pass through a **white ramus communicans** into a **sympathetic chain ganglion**.
  - B. The white ramus communicans is white because the preganglionic axons are myelinated.
  - C. Only spinal nerves T1 to L2 have white rami communicantes.

3. Sympathetic axons exit the sympathetic chain ganglia by four different routes.
- A. **Spinal nerves.**
- 1) The preganglionic neuron synapses with a postganglionic neuron within a sympathetic chain ganglion. The ganglion can be at the same or at a different level from that at which the preganglionic axon entered the sympathetic chain.
  - 2) The postganglionic axon rejoins the spinal nerve through the **gray ramus communicans**, which are gray because the postganglionic axons are unmyelinated. All spinal nerves have gray rami communicantes.
  - 3) Sympathetic fibers passing through the spinal nerves go to structures supplied by the spinal nerves, such as skeletal muscles and the skin.
    - a) Smooth muscle in blood vessels and in arrector pili.
    - b) Sweat glands.
- B. **Sympathetic nerves.**
- 1) The preganglionic neuron synapses with a postganglionic neuron within a sympathetic chain ganglion. The ganglion can be at the same or at a different level from that at which the preganglionic axon entered the sympathetic chain.
  - 2) The postganglionic axon leaves the sympathetic chain ganglion in a sympathetic nerve.
  - 3) Sympathetic fibers in the sympathetic nerves supply structures **not** reached by spinal nerves in the head. This includes structures innervated by the cranial nerves in the anterior head and the face.
    - a) Smooth muscle in blood vessels, arrector pili, and the intrinsic eye muscles (dilator pupillae = radial muscles of the iris)
    - b) Sweat glands and salivary glands.
  - 4) Sympathetic fibers in the sympathetic nerves supply structures **not** reached by spinal nerves in the thorax.
    - a) Smooth muscle in the air passageways of the lungs and in blood vessels.
    - b) Cardiac muscle.
- C. **Splanchnic nerves.** The preganglionic axons (from T5 to T12) form splanchnic (L. viscera) nerves.
- 1) The preganglionic axon leaves the sympathetic chain ganglion, without synapsing, through a splanchnic nerve.
  - 2) The preganglionic axon can exit at the level of entry or ascend or descend to a different level before exiting.
  - 3) The preganglionic axon synapses with a postganglionic neuron in a collateral ganglion. A **collateral ganglion** is a collection of sympathetic postganglionic neuron cell bodies within a splanchnic nerve.
  - 4) Splanchnic nerves supply the abdominopelvic organs.
    - a) Smooth muscle in blood vessels and the walls of organs such as the stomach.
    - b) Glands such as the liver, pancreas, and glands of the digestive tract.

D. **Innervation to the adrenal gland.** The distribution of sympathetic axons to the adrenal gland is different from other structures supplied by the sympathetic division because it consists of only preganglionic neurons.

- 1) The preganglionic axon passes through the collateral ganglion and goes to the adrenal medulla, which is the center part of the adrenal gland.
- 2) The preganglionic axons synapse with specialized cells in the adrenal medulla. These specialized cells are derived during development from the cells that give rise to the postganglionic neurons.
- 3) The adrenal medulla, when stimulated, releases epinephrine (adrenaline) and norepinephrine (noradrenalin) into the blood. These hormones prepare the body for physical activity.

Phenylalanine → Tyrosine → Dopa → Dopamine → Norepinephrine → Epinephrine

## Parasympathetic Division

FIGURE 16.4

1. General comments.
  - A. In the brainstem the preganglionic neuron cell bodies are in the nuclei of cranial nerves: oculomotor (III), facial (VII), glossopharyngeal (IX), and vagus (X) nerves.
  - B. In the spinal cord the preganglionic neuron cell bodies are in the lateral spinal cord gray matter from S2 to S4.
2. Details of the course of parasympathetic axons.
  - A. **Cranial nerves.**
    - 1) Preganglionic axons extend through cranial nerves to terminal ganglia. A **terminal ganglion** is a collection of parasympathetic postganglionic neuron cell bodies near or embedded within the wall of the organ innervated.
    - 2) The preganglionic axons synapse with postganglionic neurons located in the terminal ganglia.
    - 3) The postganglionic axons extend from the terminal ganglia to effector organs. The cranial nerves supply the head, thorax, and abdominal cavity.
      - a) Oculomotor nerve (III) supplies the intrinsic eye muscles (smooth muscle), i.e., the sphincter pupillae (circular muscles) of the iris and the ciliary muscle of the lens.
      - b) Facial nerve (VII) supplies lacrimal (tear) glands, salivary glands (submaxillary and sublingual), and glands in the oral cavity.
      - c) Glossopharyngeal nerve (IX) supplies salivary glands (parotid) and glands in the oral cavity.

- d) The vagus nerve (X). Approximately 75% of parasympathetic fibers are found in the vagus nerves.
  - 1] Smooth muscle within the walls of thoracic organs such as the lungs and inferior esophagus. Smooth muscle in abdominal organs such as the stomach to the transverse colon, gallbladder, etc.).
  - 2] Cardiac muscle.
  - 3] Glands (e.g., within the digestive tract from the esophagus to the transverse colon; the liver, pancreas, etc.).

**B. Pelvic nerves.**

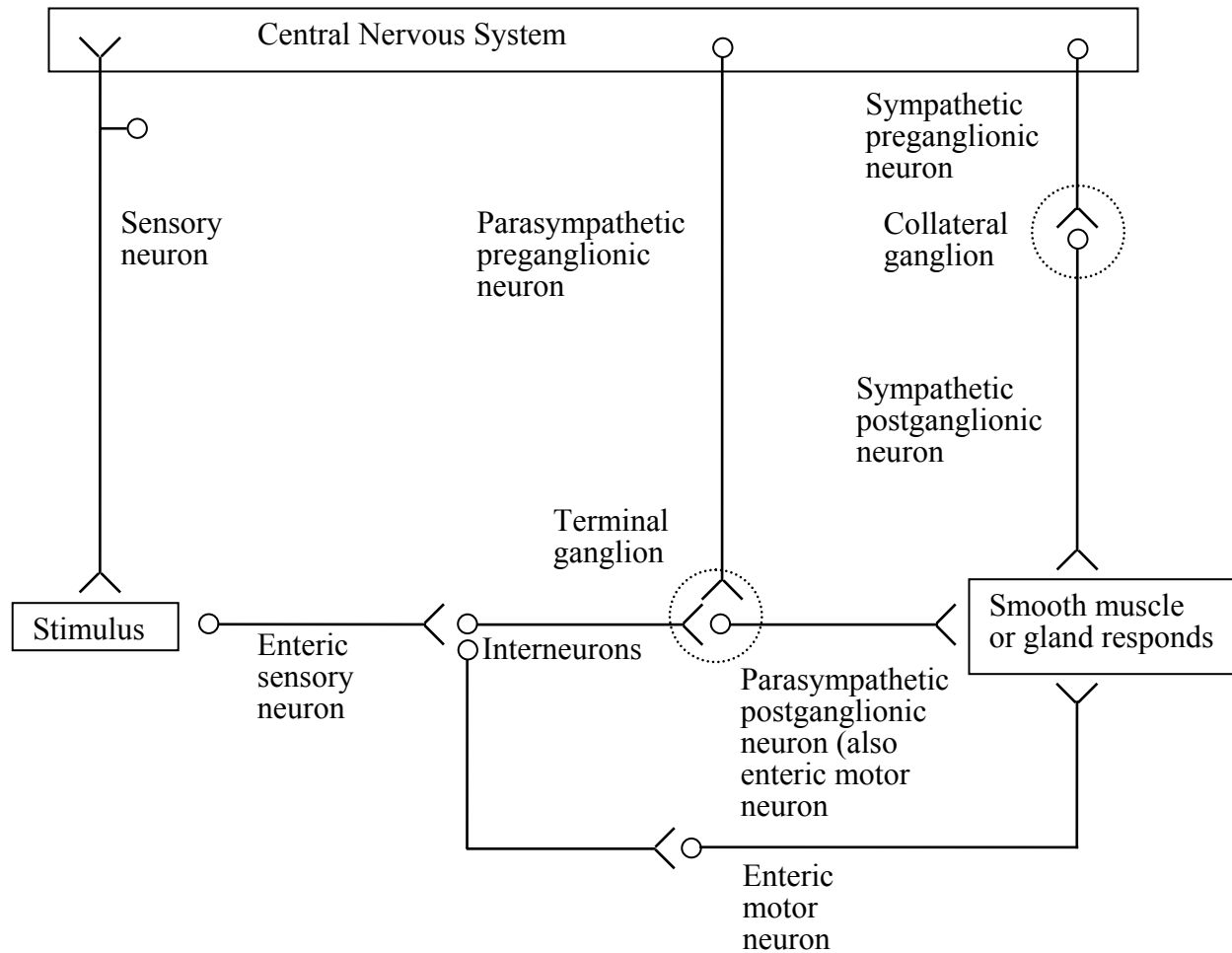
- 1) Preganglionic axons extend through ventral roots S2 - S4 into pelvic nerves to terminal ganglia.
- 2) The preganglionic axons synapse with postganglionic neurons located in the terminal ganglia.
- 3) The postganglionic axons extend from the terminal ganglia to effector organs. Pelvic nerves supply the pelvic cavity.
  - a) Smooth muscle within the walls of the transverse colon, urinary bladder, uterus, vagina, and reproductive ducts.
  - b) Glands within the pelvic organs and accessory sex organs (prostate and seminal vesicles).

**Enteric Nervous System**

- 1. The enteric nervous system (ENS) consist of nerve plexuses within the wall of the digestive tract.

FIGURE 24.4

- 2. **Enteric neurons** are confined to just the ENS. There are three types of enteric neurons.
  - A. Sensory neurons that detect changes in the chemical composition of the digestive tract contents or changes in the stretch of the digestive tract wall.
  - B. Enteric motor neurons that can stimulate or inhibit smooth muscle contraction and gland secretion.
  - C. Enteric interneurons that connect sensory and motor neurons to form **local reflexes** that allow the ENS to operate independently of the CNS.



3. In addition to enteric neurons, two other types of neurons contribute to the ENS.
  - A. Sensory neurons that connect the ENS to the CNS.
  - B. ANS motor neurons that connect the CNS to the digestive tract.
    1. Sympathetic postganglionic neurons synapse with smooth muscle and glands.
    2. Parasympathetic preganglionic neurons synapse with parasympathetic postganglionic neurons in the terminal ganglia. Thus, the parasympathetic postganglionic neurons are part of the parasympathetic division and are part of the ENS (i.e., enteric neurons confined to the digestive tract).
  - C. The sensory and motor neurons are part of **autonomic reflexes** that influence the activities of smooth muscle and glands in the digestive tract. The sensory neurons carry action potentials to ANS reflex centers in the CNS and the motor neurons carry action potentials from the CNS to the digestive tract.

## The Distribution of Autonomic Nerve Fibers

FIGURE 16.5

### Sympathetic Division

1. Sympathetic axons from the sympathetic chain ganglia pass through spinal, sympathetic, and splanchnic nerves.
2. Sympathetic and splanchnic nerves can join **autonomic nerve plexuses**, which are complex, interconnected neural networks formed by the neurons of the sympathetic and parasympathetic divisions.
3. Collateral ganglia are located in the autonomic nerve plexuses. There are three major collateral ganglia: celiac, superior mesenteric, and inferior mesenteric.

### Parasympathetic Division

1. Parasympathetic outflow is through cranial nerves and pelvic nerves.
2. The oculomotor (III), facial (VII), and glossopharyngeal (IX) nerves supply the head and neck. There are four major terminal ganglia associated with the cranial nerves of the head: ciliary, pterygopalatine, submandibular, and otic ganglia.
3. The vagus (X) and pelvic nerves contribute to the autonomic plexuses of the thorax, abdomen, and pelvis.

### Sensory Neurons in Autonomic Nerve Plexuses

1. Sensory neurons in the organs supplied by the ANS run through the autonomic nerve plexuses to the CNS.
2. The sensory neurons are part of reflex arcs regulating the organs or convey pain and pressure sensations from the organs to the CNS.

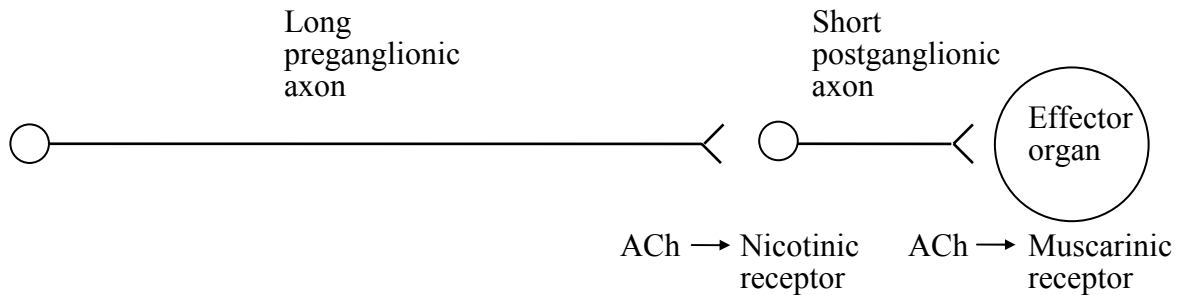
## PHYSIOLOGY OF THE AUTONOMIC NERVOUS SYSTEM

FIGURE 16.6

1. A **neurotransmitter (NT)** is a molecule released by a neuron that moves to a target cell (another neuron, gland, or muscle) where it binds to a receptor.
2. A **receptor** is a molecule in the target cell that combines with the NT. The receptor-NT binding is the first step in the response of the target cell, such as the production of an action potential. If the NT does not combine with the receptor, no effect is produced.
3. Remember the lock and key model of enzymes. Only a specific NT, or a very similar NT, can combine with the receptor.

## Parasympathetic Division

### 1. Arrangement of parasympathetic neurons.



☞ Why are parasympathetic preganglionic axons longer than parasympathetic postganglionic axons?

### 2. Neurotransmitter.

A. Both preganglionic and postganglionic neurons secrete acetylcholine (ACh).

B. Neurons that secrete ACh are called **cholinergic**.

### 3. Receptors.

A. Receptors that bind to ACh are called **cholinergic receptors**, of which there are two types.

1) The postganglionic neurons have **nicotinic receptors** (as do skeletal muscle). Nicotinic receptors combine with ACh and nicotine.

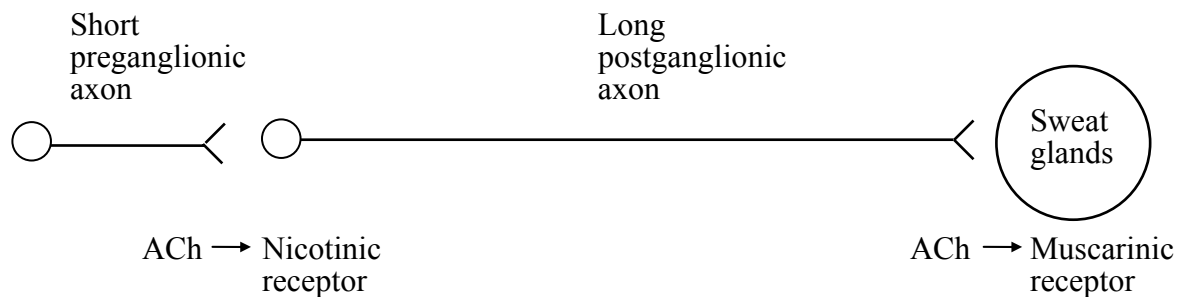
2) Effector organs of the parasympathetic division have **muscarinic receptors**. Muscarinic receptors combine with ACh and muscarine (a poison from mushrooms).

B. Note that nicotinic and muscarinic receptors are very similar because they both bind with ACh. However, they are different because nicotine combines with nicotinic receptors but not muscarinic receptors, whereas muscarine combines with muscarinic receptors but not nicotinic receptors.

C. Analogy: Imagine two different locks, each with a different key. Key A (nicotine) opens lock A (nicotinic receptors), but does not open lock B (muscarinic receptors). Key B (muscarine) opens lock B (muscarinic receptors), but does not open lock A (nicotinic receptors). A master key (ACh), however, can open both locks (nicotinic and muscarinic receptors).

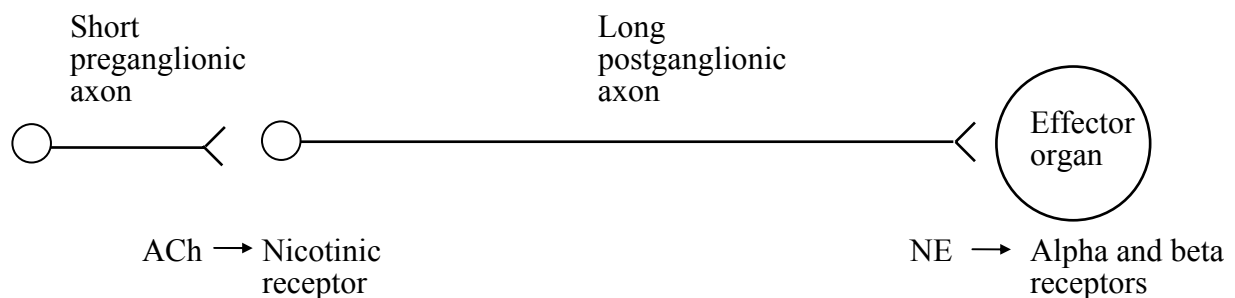
## Sympathetic Division

1. SOME sympathetic neurons have the same neurotransmitter and receptors as the parasympathetic division, i.e., the sympathetic supply to sweat glands.



- ☞ Why are most sympathetic preganglionic axons shorter than sympathetic postganglionic axons? Where are there exceptions to this generalization?

2. The effector organs that are innervated by ACh secreting sympathetic postganglionic neurons are sweat glands.
3. MOST sympathetic fibers have a different neurotransmitter and receptors at the effector organ than the parasympathetic division.



- A. Norepinephrine (NE) is secreted by MOST sympathetic postganglionic neurons. Neurons that secrete NE are called **adrenergic**.

- B. **Adrenergic receptors** are receptors that bind to NE (or epinephrine). There are two major types of adrenergic receptors. **Alpha and beta receptors** are found in MOST sympathetic effector organs.
- 1) The main adrenergic subtypes are  $\alpha_1$ ,  $\alpha_2$ ,  $\beta_1$  and  $\beta_2$ .
  - 2)  $\alpha_1$  and  $\beta_1$  receptors are mostly stimulated by the release of NE in synapses. Thus, they respond to nervous system stimulation.
  - 3)  $\alpha_2$  and  $\beta_2$  receptors are mostly stimulated by epinephrine (also NE) released from the adrenal medulla. Thus they respond to endocrine system stimulation.
  - 4) Some alpha receptors excite, others inhibit the effector organ. Some beta receptors excite, others inhibit the effector organ. For example, beta receptors excite cardiac muscle but inhibit intestinal smooth muscle.
4. ALL sympathetic and parasympathetic preganglionic neurons secrete ACh within autonomic ganglia, and ALL sympathetic and parasympathetic postganglionic neurons have nicotinic receptors within the autonomic ganglia.

### REGULATION OF THE ANS

1. Much of the regulation of ANS function occurs through autonomic reflexes.
  - A. Autonomic reflexes have the same components as other reflexes, i.e., sensory receptor; sensory neuron, interneuron, motor neuron, and effector organ.
  - B. Autonomic reflexes have the same characteristics as other reflexes, i.e., they help to maintain homeostasis, produce the same response when stimulated, and do not require conscious thought.
  - C. An example of an ANS reflex is the maintenance of blood pressure.

FIGURE 16.7

- 1) Baroreceptors detect an increase in blood pressure. Through the parasympathetic division heart rate is decreased, which cause blood pressure to decrease.
  - 2) Baroreceptors detect a decrease in blood pressure. Through the sympathetic division heart is increased, which causes blood pressure to increase. In addition, sympathetic reflexes cause blood vessels to vasoconstrict, which also increases blood pressure.
2. Other areas of the CNS can affect the activity of ANS.

FIGURE 16.8

- A. The hypothalamus is in overall control of the ANS. The hypothalamus can stimulate ANS centers in the brainstem and the spinal cord.
- B. The hypothalamus has connections with the cerebrum and is an important part of the limbic system.

- 1) Thoughts initiated in the cerebrum can change ANS activity, e.g., thinking of a lemon can cause the salivary glands to secrete.
- 2) Emotions mediated through the limbic system can change ANS activity, e.g., anger can increase heart rate and blood pressure.
3. The enteric nervous system is regulated by autonomic reflexes mediated through the CNS and by local reflexes, which operate independently of the CNS.

## **FUNCTIONAL GENERALIZATIONS ABOUT THE ANS**

### **Stimulatory vs. Inhibitory Effects**

Each division can excite or inhibit effector organs. For example:

	Sympathetic division	Parasympathetic division
Wall of GI tract	Relax	Constrict
Sphincter of GI tract	Constrict	Relax

### **Dual Innervation**

FIGURE 16.9

1. Most organs supplied by the ANS are innervated by both divisions.
2. Sweat glands, arrector pili, and blood vessels are innervated almost exclusively by the sympathetic division.
3. When both divisions innervate the same organ, one division usually has a bigger effect. For example, the parasympathetic division is most important for regulating the digestive tract.

### **Opposite Effects**

1. As a general rule, each division opposes the actions of the other division when they innervate the same organ. Thus the ANS can increase or decrease the activity of the structure.
2. In a few cases both divisions produce the same response in the same organ, e.g., both divisions cause an increase in salivary gland secretion.

### **Cooperative Effects**

1. One division can coordinate the activities of several organs. For example, the parasympathetic division stimulates the pancreas to release digestive enzymes into the small intestine, and stimulates the small intestine to contract and mix the enzymes with food.
2. Both divisions can act together to produce a response. For example, the parasympathetic division stimulates erection of the penis and the sympathetic division stimulates ejaculation.

**General vs. Localized Effects**

1. Activation of the sympathetic division often results in the release of epinephrine and norepinephrine from the adrenal medulla. These hormones circulate in the blood and produce generalized effects.
2. Sympathetic stimulation often affects many organs at the same time, for example, during exercise. However, the sympathetic division can selectively affect one structure at a time. For example, vasoconstriction of blood vessels in a cold hand can occur independently of other sympathetic changes.
3. In the sympathetic division there are many (up to 17) postganglionic neurons for each preganglionic neuron, whereas in the parasympathetic division there are few postganglionic neurons for each preganglionic neuron. Therefore, activation of the sympathetic division produces a more intense response.

**Functions at Rest Versus Activity**

1. In general, the parasympathetic division has the greatest influence under resting conditions and regulates such activities as digestion, defecation, and urination.
2. The sympathetic division has the greatest influence under conditions of activity (the "fight or flight" syndrome). An exception is the regulation of blood pressure by the sympathetic division under resting conditions.

The generalizations about the ANS can be used to remember the actions of the ANS.

Increased Sympathetic  
Stimulation

Increased Parasympathetic  
Stimulation

**Shutdown of nonessentials**

GI tract

Peristalsis (moves food)

Sphincter constriction (prevents  
movement of food)

Secretions (e.g., digestive enzymes)

Pancreatic secretions (insulin)

Urinary bladder constriction (empties bladder)

Constriction of blood vessels in visceral organs  
(results in decreased blood flow)

Constriction of blood vessels in the skin

**Increase of essentials**

Bronchial (airway passages in lungs) dilation

Heart rate

Release of glucose from the liver increases

Release of fatty acids from fat cells

Secretions (mostly epinephrine)  
from the adrenal gland increase

**Miscellaneous**

Pupil of eye

Arrector pili constriction  
(hair stands on end)

Sweat glands (increased sweating)

Salivary glands

Sexual response

☞ When people have a heart attack, why does their skin become clammy (moist and cold)?

☞ Why doesn't injury to the spinal cord at level C8 result in complete dysfunction of thoracic and abdominopelvic organs?

### **THE INFLUENCE OF DRUGS ON THE ANS - See Clinical Focus p. 572.**

#### **Importance**

1. Drugs can either stimulate or inhibit the ANS.
  - A. **Stimulating agents** bind to receptors and activate them. Receptors can also be activated by drugs that increase the release or prevent the breakdown or uptake of neurotransmitters by the presynaptic terminal.
  - B. **Blocking agents** bind to receptors and prevent them from being activated. Receptor activation can also be prevented by drugs that prevent neurotransmitter production or release.
2. Drug effects.
  - A. Some drugs have therapeutic value and can be used to increase or decrease ANS functions, e.g., slow a rapid heart rate.
  - B. Some drugs are used for research purposes to determine how the ANS operates.
  - C. Some drugs are harmful, e.g., nicotine in tobacco.

### **Drugs that Affect Nicotinic Receptors**

1. **Nicotinic agents** are drugs that bind to nicotinic receptors and activate them.

- ☞ Would you expect nicotine to increase or decrease heart rate? To answer this question you must know the following information: where are nicotinic receptors located in the ANS, and what happens when they are stimulated.

2. **Ganglionic blocking agents** are drugs that bind to and block nicotinic receptors.

- ☞ Ganglionic blocking agents are used primarily to lower blood pressure. Explain how they can cause a decrease in blood pressure. How could they cause undesirable side effects?

### **Drugs that Affect Muscarinic Receptors**

1. **Muscarinic agents** or **parasympathomimetic agents** (mimics the effect of parasympathetic division stimulation) are drugs that bind to and activate muscarinic receptors.

- ☞ Why does activation of muscarinic receptors produce primarily a parasympathetic effect?

☞ What effect would a muscarinic agent have on the following:

Heart rate	Increase or decrease
GI tract motility	Increase or decrease
Sweat production	Increase or decrease

2. **Muscarinic blocking agents** or **parasympathetic blocking agents** are drugs that bind to and block muscarinic receptors.

☞ Atropine is a muscarinic blocking agent used during eye examinations. Its effects allow the examiner to better see inside the eye. Explain how atropine accomplishes this effect.

☞ During surgery an anesthetized patient can produce excess saliva and choke. Would atropine be a good drug to use to prevent this from happening? Explain.

### **Drugs that Affect Adrenergic Receptors**

1. **Adrenergic agents** or **sympathomimetic agents** (mimic the effects of sympathetic division stimulation) are drugs that bind to and activate adrenergic receptors (alpha or beta).
2. **Adrenergic blocking agents** or **sympathetic blocking agents** are drugs that bind to and block adrenergic receptors (alpha or beta).

Given the following drugs:

1. alpha-adrenergic agent
2. alpha-adrenergic blocking agent
3. beta-adrenergic agent
4. beta-adrenergic blocking agent

Explain which drug you would recommend for treatment of the following disorders:

- ☞ Raynaud's disease results in severe vasoconstriction of blood vessels in the periphery, e.g., the skin of the hands, when exposed to the cold. At first the lack of blood supply causes pain but after many years the blood vessels can become continuously constricted and produce gangrene.
  
  
  
  
  
  
  
  
  
  
- ☞ A patient is having an asthma attack because of an allergic reaction that causes the smooth muscle in the airway system to constrict and reduce air delivery.
  
  
  
  
  
  
  
  
  
  
- ☞ A patient is recovering from a heart attack. It is important that the heart rest in order not to produce further damage to the heart.