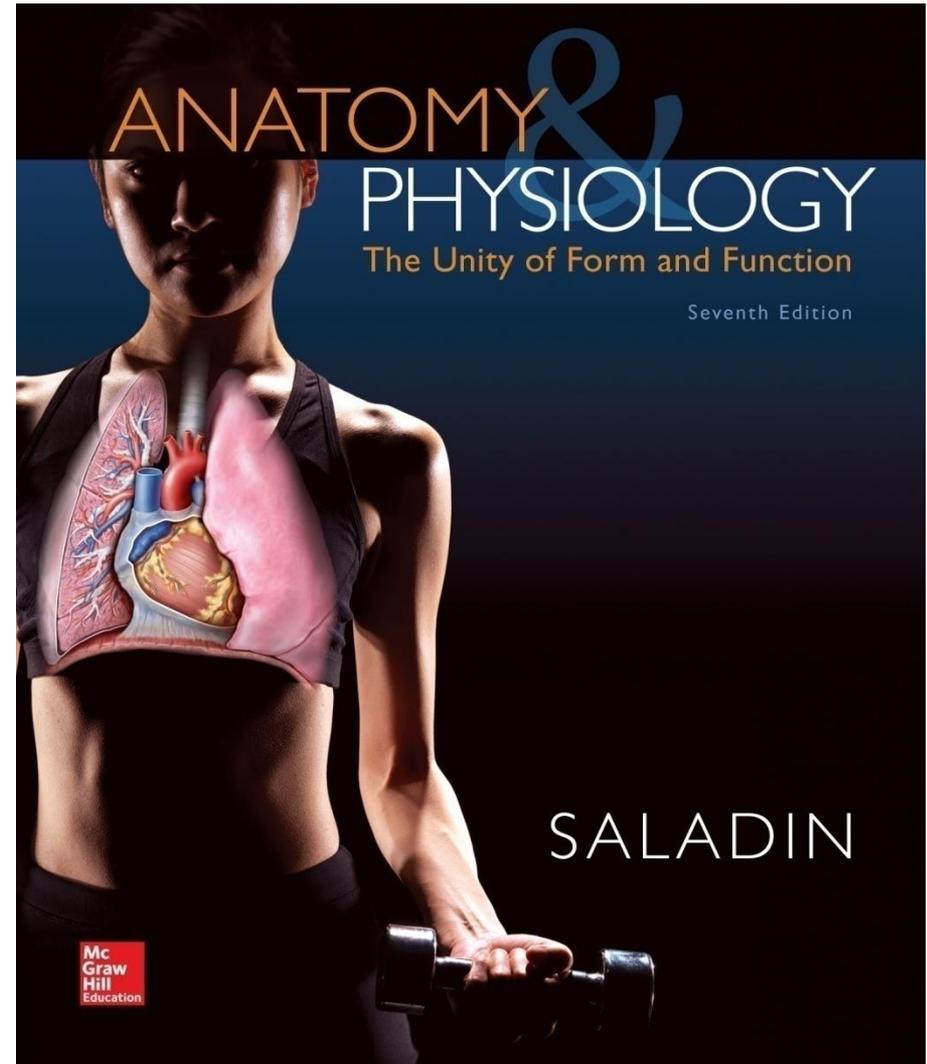


# Chapter 15

## Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.



# Introduction

- Autonomic means “self-governed”; the **autonomic nervous system (ANS)** is independent of our will
- It regulates fundamental states and life processes such as heart rate, BP, and body temperature
- **Walter Cannon coined the terms “*homeostasis*” and the “*flight-or-fight*”**
  - He dedicated his career to the study of the ANS
  - Found that animals without ANS cannot survive on their own (must be kept warm and stress-free)

# General Properties of the Autonomic Nervous System

- **Expected Learning Outcomes**
  - Explain how the autonomic and somatic nervous systems differ in form and function.
  - Explain how the two divisions of the autonomic nervous system differ in general function.

# General Properties of the Autonomic Nervous System

- **Autonomic nervous system (ANS)**—a motor nervous system that controls glands, cardiac muscle, and smooth muscle
  - Also called **visceral motor system**
  - **Primary organs of the ANS**
    - Viscera of thoracic and abdominal cavities
    - Some structures of the body wall
      - Cutaneous blood vessels
      - Sweat glands
      - Piloerector muscles

# General Properties of the Autonomic Nervous System

(continued)

- **Autonomic nervous system (ANS)**
  - Carries out actions **involuntarily**: without our conscious intent or awareness
    - Visceral effectors do not depend on the ANS to function; only to adjust their activity to the body's changing needs
    - **Denervation hypersensitivity**—exaggerated responses of cardiac and smooth muscle if autonomic nerves are severed

# Visceral Reflexes

- **Visceral reflexes**—unconscious, automatic, stereotyped responses to stimulation involving visceral receptors and effectors
- **Visceral reflex arc**
  - **Receptors:** nerve endings that detect stretch, tissue damage, blood chemicals, body temperature, and other internal stimuli
  - **Afferent neurons:** lead to CNS
  - **Integrating center:** interneurons in the CNS
  - **Efferent neurons:** carry motor signals away from the CNS
  - **Effectors:** carry out end response
- **ANS considered the efferent pathway**

# Visceral Reflexes

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- **Baroreflex:** (1) high blood pressure detected by arterial stretch receptors; (2) afferent neuron carries signal to CNS; (3) efferent signals on vagus nerve of ANS travel to the heart; (4) heart then slows, reducing blood pressure
- **Example of homeostatic negative feedback loop**

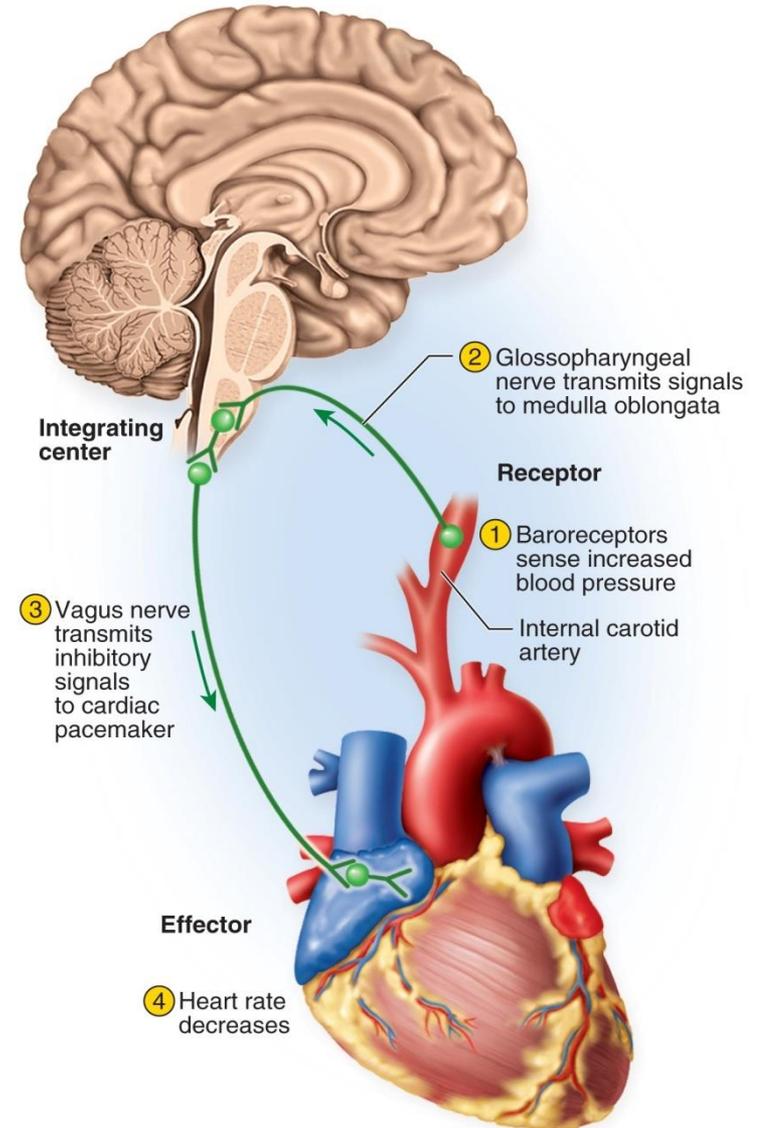


Figure 15.1

# Divisions of the ANS

- **Two divisions often innervate same target organ**
  - May have cooperative or contrasting effects
- **Sympathetic division**
  - Prepares body for physical activity: exercise, trauma, arousal, competition, anger, or fear
    - Increases heart rate, BP, airflow, blood glucose levels, etc.
    - Reduces blood flow to the skin and digestive tract
    - “Fight-or-flight”
- **Parasympathetic division**
  - Calms many body functions reducing energy expenditure and assists in bodily maintenance
    - Digestion and waste elimination
    - “Resting and digesting” state

# Divisions of the ANS

- **Autonomic tone**—normal background rate of activity that represents the balance of the two systems according to the body's needs
  - **Parasympathetic tone**
    - Maintains smooth muscle tone in intestines
    - Holds resting heart rate down to about 70 to 80 beats per minute
  - **Sympathetic tone**
    - Keeps most blood vessels partially constricted and maintains blood pressure
- **Sympathetic division excites the heart but inhibits digestive and urinary function, while parasympathetic has the opposite effect**

# Autonomic Output Pathways

- **ANS has components in both the central and peripheral nervous systems**
  - Control nuclei in the **hypothalamus** and other brainstem regions
  - Motor neurons in the spinal cord and peripheral ganglia
  - Nerve fibers that travel through the cranial and spinal nerves

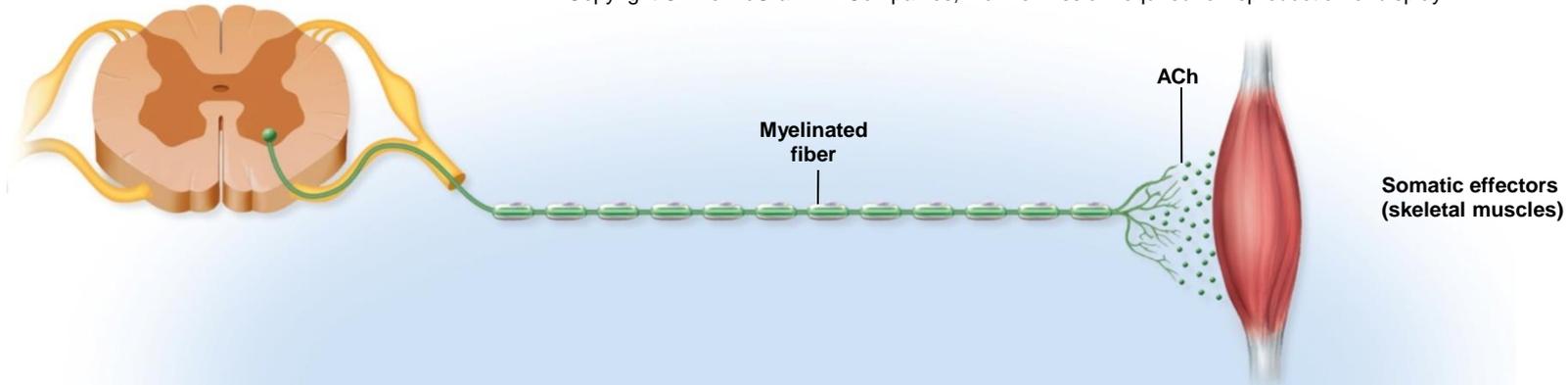
# Autonomic Output Pathways

- **ANS contrasts to somatic motor pathway**
  - In **somatic pathway**
    - A motor neuron from brainstem or spinal cord issues a myelinated axon that reaches all the way to skeletal muscle
  - In **autonomic pathway**
    - Signal must travel across **two neurons** to get to the target organ
    - Must cross a synapse where these two neurons meet in an autonomic ganglion
    - **Presynaptic neuron:** the first neuron has a soma in the brainstem or spinal cord
    - Synapses with a **postganglionic neuron** whose axon extends the rest of the way to the target cell

# Autonomic Output Pathways

## Somatic efferent innervation

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## Autonomic efferent innervation

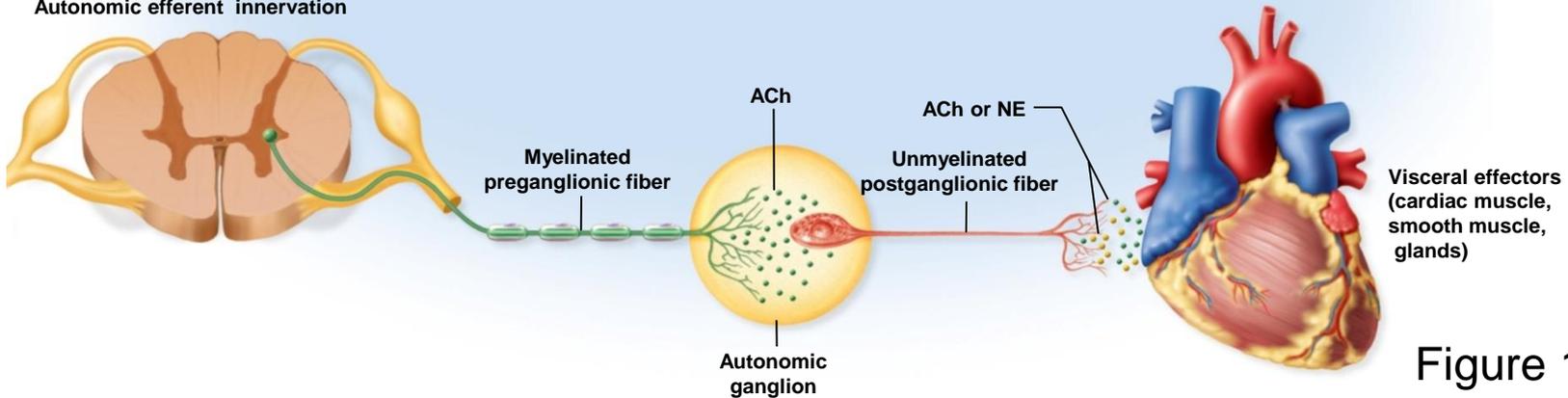


Figure 15.2

## ANS—two neurons from CNS to effector

- Presynaptic neuron cell body is in CNS
- Postsynaptic neuron cell body is in peripheral ganglion

# Autonomic Output Pathways

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<b>TABLE 15.1</b>	<b>Comparison of the Somatic and Autonomic Nervous Systems</b>	
<b>Feature</b>	<b>Somatic</b>	<b>Autonomic</b>
Effectors	Skeletal muscle	Glands, smooth muscle, cardiac muscle
Control	Usually voluntary	Usually involuntary
Distal nerve endings	Neuromuscular junctions	Varicosities
Efferent pathways	One nerve fiber from CNS to effector; no ganglia	Two nerve fibers from CNS to effector; synapse at a ganglion
Neurotransmitters	Acetylcholine (ACh)	ACh and norepinephrine (NE)
Effect on target cells	Always excitatory	Excitatory or inhibitory
Effect of denervation	Flaccid paralysis	Denervation hypersensitivity

Table 15.1

# Anatomy of the Autonomic Nervous System

- **Expected Learning Outcomes**

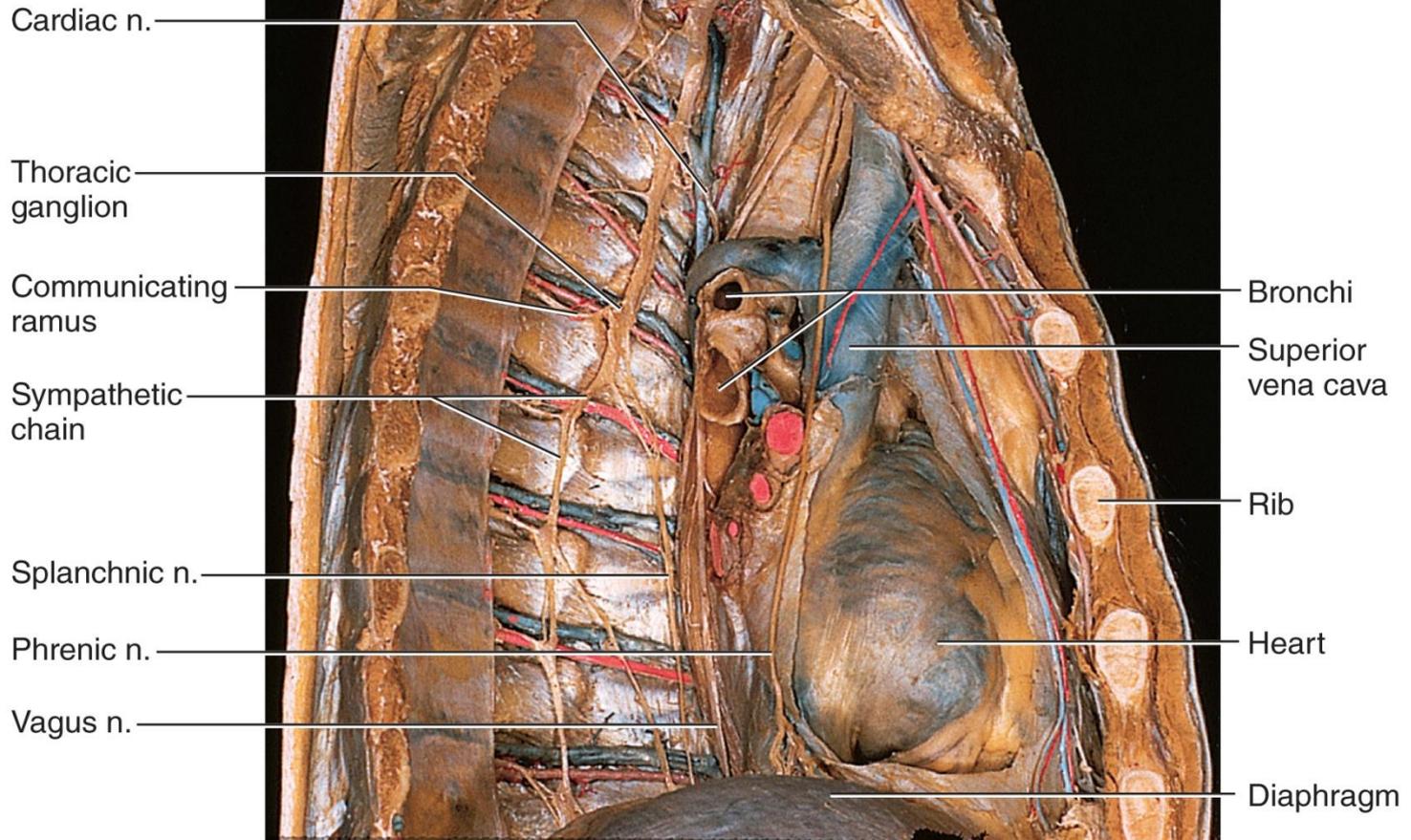
- Identify the anatomical components and nerve pathways of the sympathetic and parasympathetic divisions.
- Discuss the relationship of the adrenal glands to the sympathetic nervous system.
- Describe the enteric nervous system of the digestive tract and explain its significance.

# The Sympathetic Division

- Also called the **thoracolumbar division** because it arises from the thoracic and lumbar regions of the spinal cord
- Relatively **short preganglionic** and **long postganglionic** fibers
- **Preganglionic neurosomas** in lateral horns and nearby regions of spinal cord gray matter
  - Fibers exit spinal cord by way of spinal nerves T1 to L2
  - Lead to nearby **sympathetic chain of ganglia (paravertebral ganglia)**
    - Series of longitudinal ganglia adjacent to both sides of the vertebral column from cervical to coccygeal levels
    - Usually 3 cervical, 11 thoracic, 4 lumbar, 4 sacral, and 1 coccygeal ganglion
    - Sympathetic nerve fibers are distributed to every level of the body

# The Sympathetic Chain Ganglia

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Figure 15.3

# The Sympathetic Division

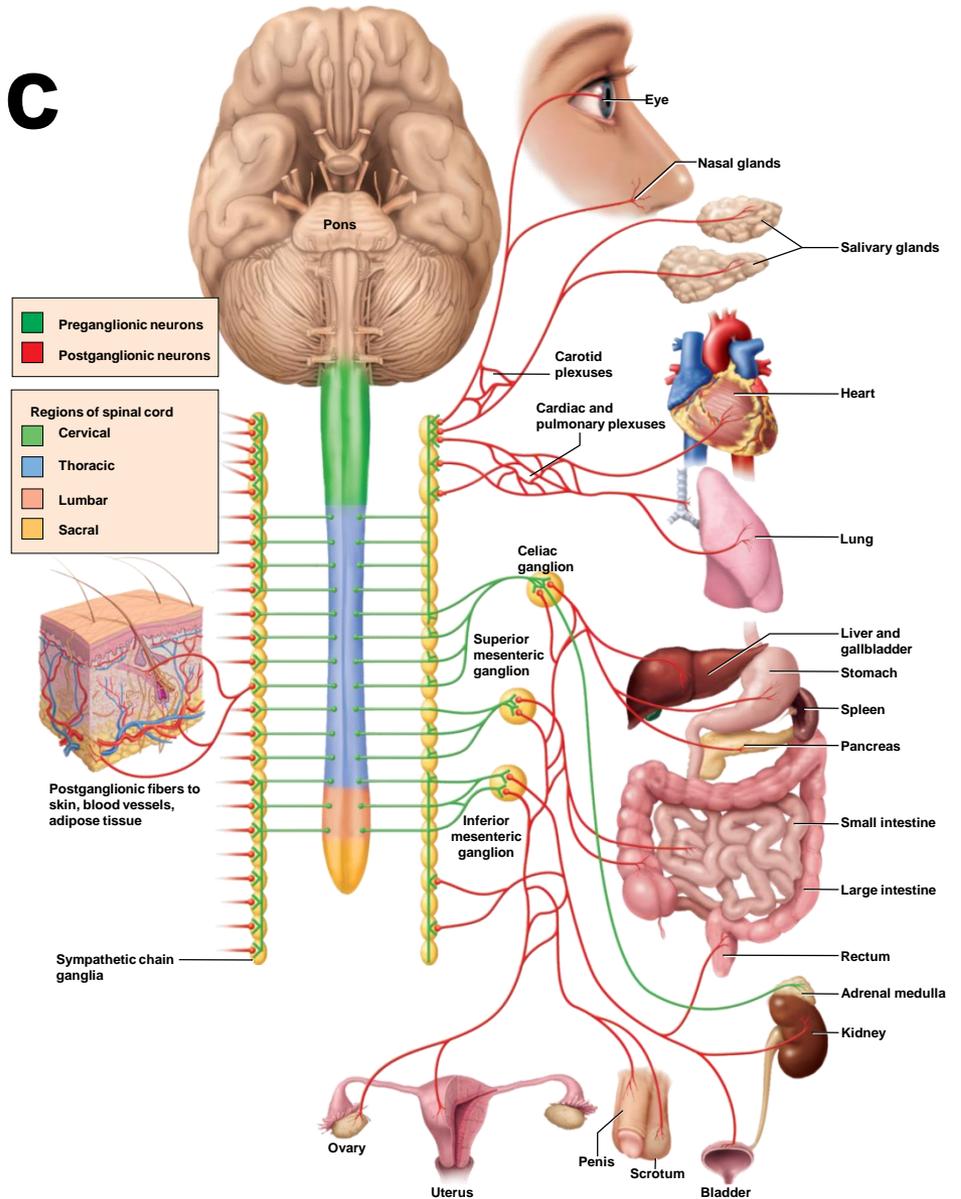


Figure 15.4

# The Sympathetic Division

- Each paravertebral ganglion is connected to a spinal nerve by two branches: **communicating rami**
  - **Preganglionic fibers** are **small myelinated fibers** that travel from spinal nerve to the ganglion by way of the **white communicating ramus (myelinated)**
  - **Postganglionic fibers** leave the ganglion by way of **the gray communicating ramus (unmyelinated)**
    - Forms a bridge back to the spinal nerve
  - **Postganglionic fibers** extend the rest of the way to the target organ

# The Sympathetic Division

- **After entering the sympathetic chain, the postganglionic fibers may follow any of three courses**
  - **Some end in ganglia** which they enter and synapse immediately with a postganglionic neuron
  - **Some travel up or down the chain** and synapse in ganglia at other levels
    - These fibers link the paravertebral ganglia into a chain
    - Only route by which ganglia at the cervical, sacral, and coccygeal levels receive input
  - **Some pass through the chain without synapsing** and continue as **splanchnic nerves**

# Sympathetic Chain Ganglia

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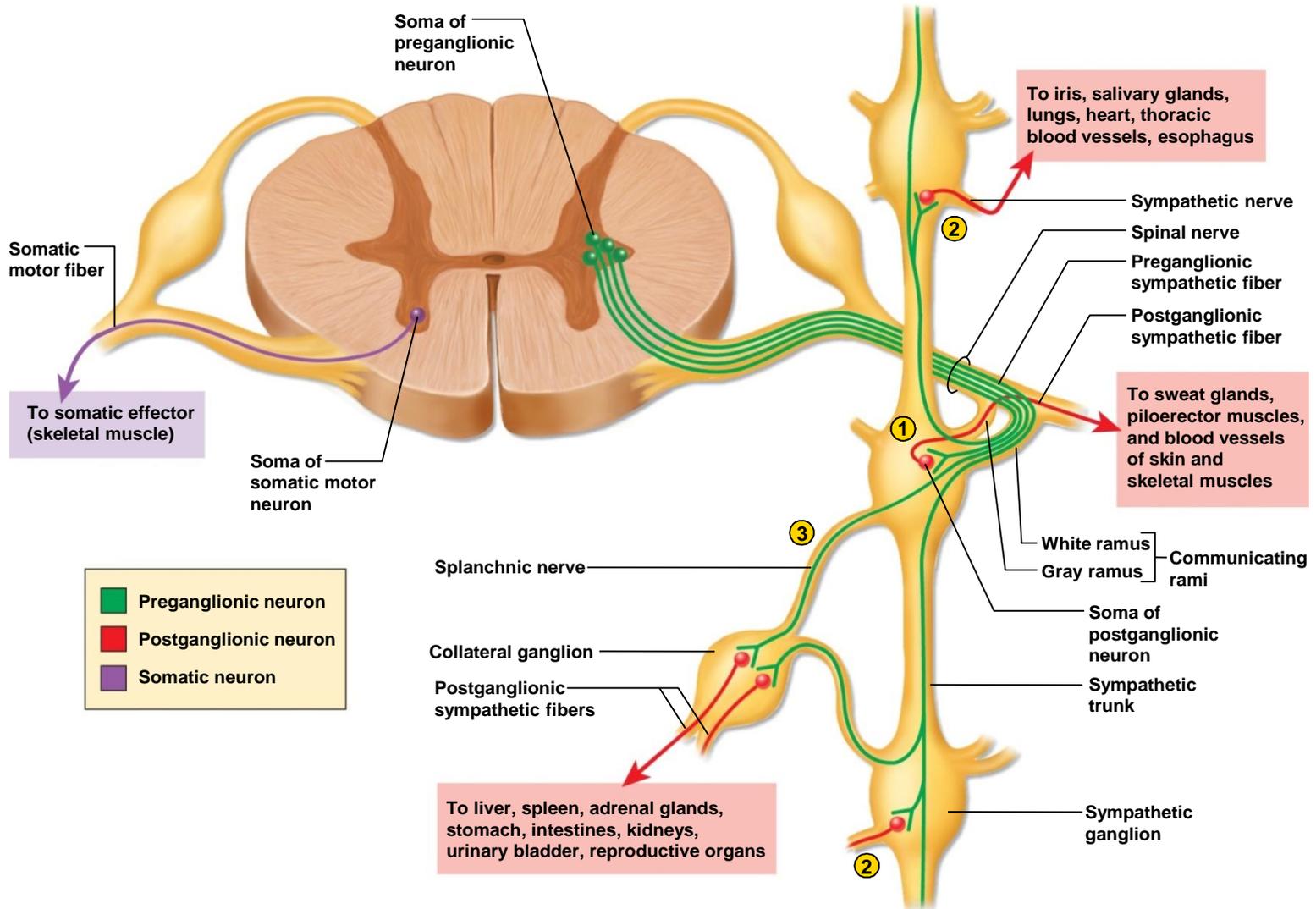


Figure 15.5

# The Sympathetic Division

- Nerve fibers leave the sympathetic chain by three routes: **spinal, sympathetic, and splanchnic nerves**
  - **Spinal nerve route**
    - Some postganglionic fibers exit a ganglion by way of the gray ramus
    - Return to the spinal nerve and travel the rest of the way to the target organ
    - Most sweat glands, piloerector muscles, and blood vessels of the skin and skeletal muscles

# The Sympathetic Division

- **Routes (continued)**
  - **Sympathetic nerve route**
    - Other nerves leave by way of sympathetic nerves that extend to the heart, lungs, esophagus, and thoracic blood vessels
    - These nerves form carotid plexus around each carotid artery of the neck
    - Issue fibers from there to the effectors in the head
      - Sweat, salivary, nasal glands; piloerector muscles; blood vessels; dilators of iris
    - Some fibers of superior and middle cervical ganglia form **cardiac nerves** to the heart

# The Sympathetic Division

- **Routes (continued)**
  - **Splanchnic nerve route**
    - Some fibers that arise from spinal nerves T5 to T12 pass through the sympathetic ganglia without synapsing
      - Continue on as the splanchnic nerves
      - Lead to second set of ganglia: **collateral (prevertebral) ganglia** and synapse there

# The Sympathetic Division

- Collateral ganglia contribute to a network called the **abdominal aortic plexus**
  - Wraps around abdominal aorta
  - Three major collateral ganglia in this plexus
    - **Celiac, superior mesenteric, and inferior mesenteric**
    - Postganglionic fibers accompany arteries of the same names and their branches to their target organs
  - **Solar plexus:** collective name for the celiac and superior mesenteric ganglia
    - Nerves radiate from ganglia like rays of the sun

# The Sympathetic Division

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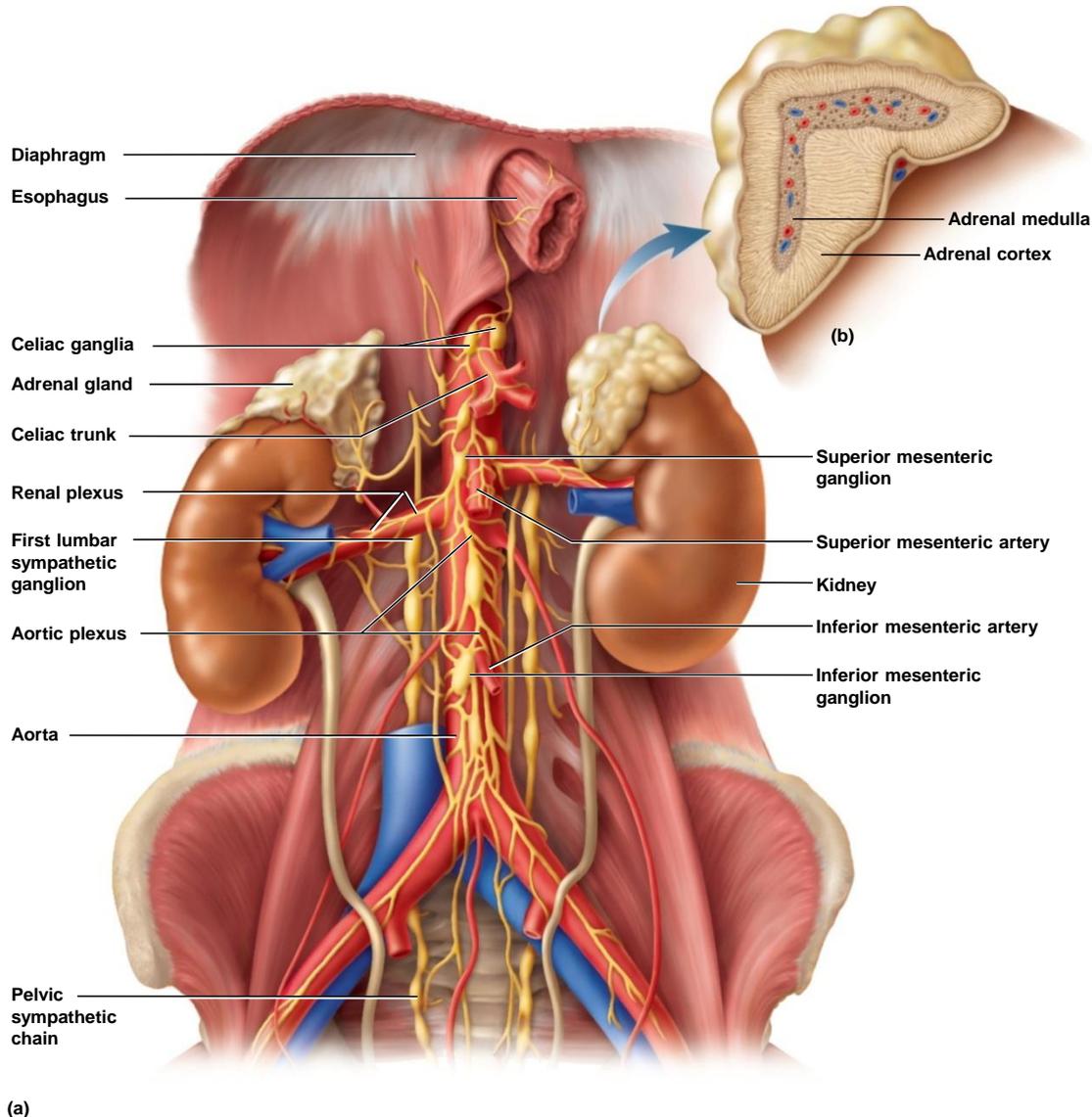


Figure 15.6

# The Sympathetic Division

- **Neuronal divergence** predominates in the sympathetic division
  - Each preganglionic cell branches and synapses on 10 to 20 postganglionic cells
  - One preganglionic neuron can excite multiple postganglionic fibers leading to different target organs
  - Has relatively widespread effects

# The Adrenal Glands

- Paired **adrenal (suprarenal) glands** located on superior poles of kidneys
- **Each is two glands** with different functions
  - **Adrenal cortex (outer layer)**
    - Secretes steroid hormones
  - **Adrenal medulla (inner core)**
    - Essentially a sympathetic ganglion consisting of modified postganglionic neurons (without fibers)
    - Stimulated by preganglionic sympathetic neurons
    - **Sympathoadrenal system** is the name for the **adrenal medulla** and **sympathetic nervous system**
    - Secretes a mixture of **hormones** into bloodstream
    - **Catecholamines**—85% **epinephrine (adrenaline)** and 15% **norepinephrine (noradrenaline)**

# The Parasympathetic Division

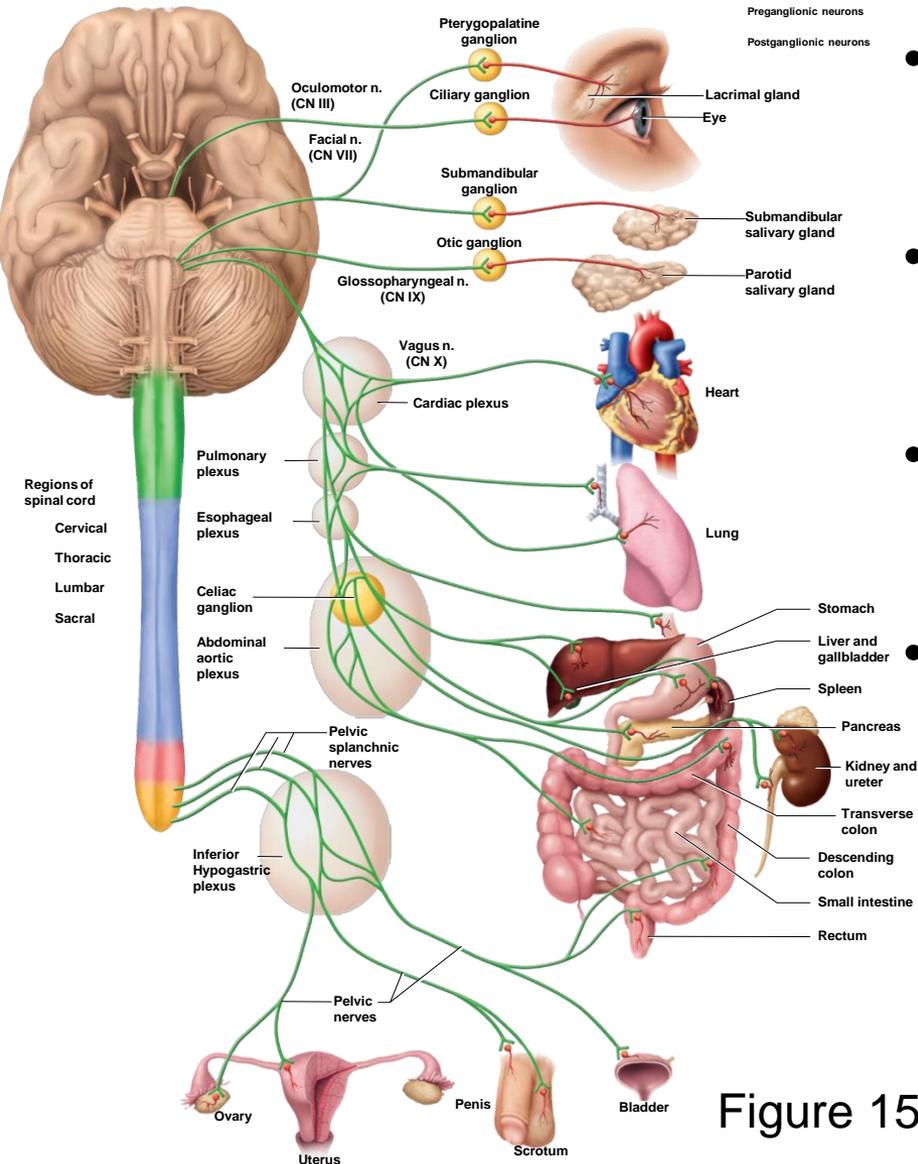
- **Parasympathetic division** is also called the **craniosacral division**
  - Arises from the brain and sacral regions of the spinal cord
  - Fibers travel in certain cranial and sacral nerves
- **Origins of long preganglionic neurons:**
  - Midbrain, pons, and medulla
  - Sacral spinal cord segments S2 to S4
- Preganglionic fiber end in **terminal ganglia** in or near target organs
  - Long preganglionic, short postganglionic fibers

# The Parasympathetic Division

- **Parasympathetic division is relatively selective in stimulation of target organ**
  - There is only a little **neural divergence** (less than divergence exhibited by sympathetic division)

# Parasympathetic Cranial Nerves

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- **Oculomotor nerve (III)**
  - Narrows pupil and focuses lens
- **Facial nerve (VII)**
  - Tear, nasal, and salivary glands
- **Glossopharyngeal nerve (IX)**
  - Parotid salivary gland
- **Vagus nerve (X)**
  - Viscera as far as proximal half of colon
  - Cardiac, pulmonary, and esophageal plexuses that give off anterior and posterior vagal trunks

Figure 15.7

# The Parasympathetic Division

- Remaining parasympathetic fibers arise from levels S2 to S4 of the spinal cord
- Form **pelvic splanchnic nerves** that lead to the **inferior hypogastric plexus**
- Most form **pelvic nerves** to their terminal ganglion on the target organs
  - Distal half of colon, rectum, urinary bladder, and reproductive organs

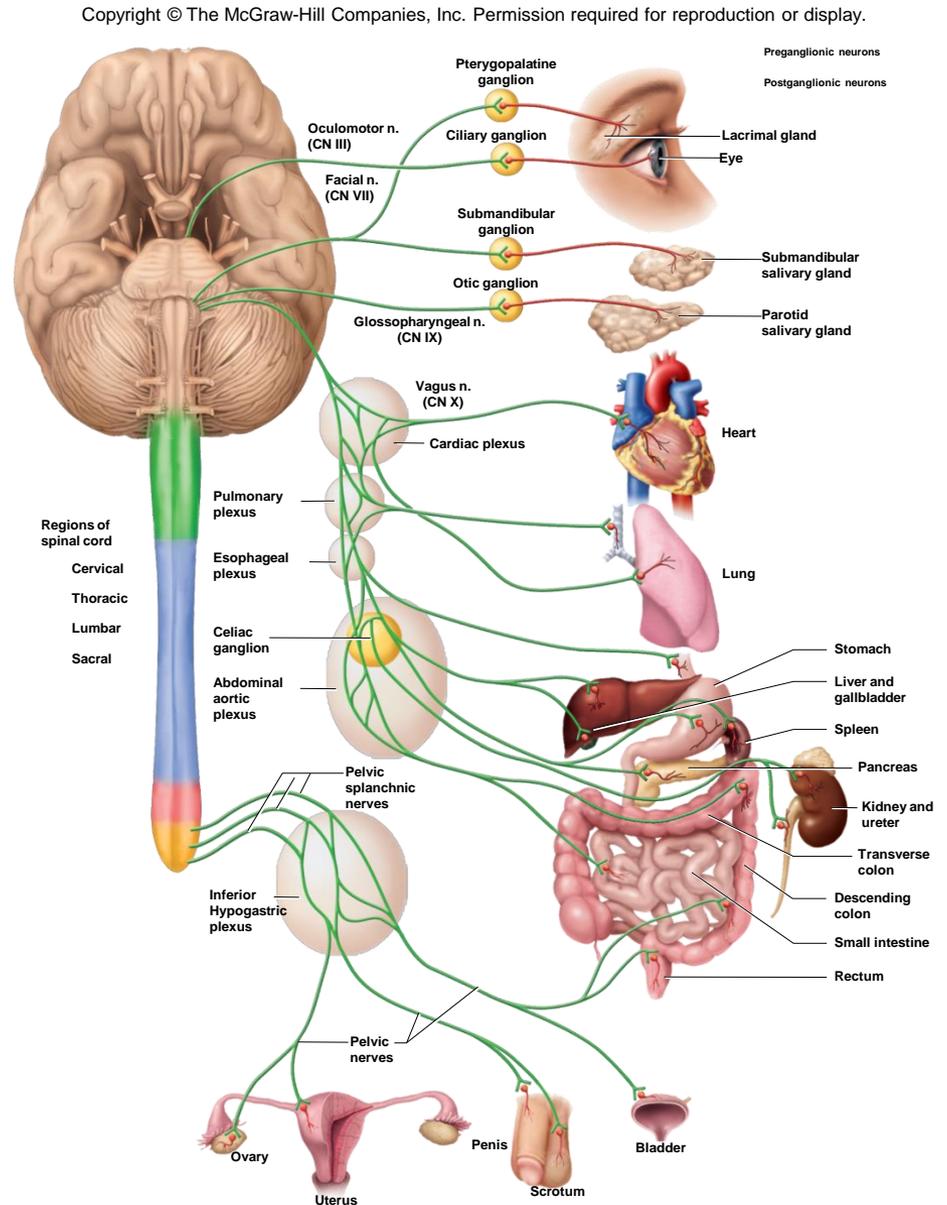


Figure 15.7

# Comparison of Autonomic Divisions

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<b>TABLE 15.3</b>	<b>Comparison of the Sympathetic and Parasympathetic Divisions</b>	
<b>Feature</b>	<b>Sympathetic</b>	<b>Parasympathetic</b>
Origin in CNS	Thoracolumbar	Craniosacral
Location of ganglia	Paravertebral ganglia adjacent to spinal column and prevertebral ganglia anterior to it	Terminal ganglia near or within target organs
Fiber lengths	Short preganglionic Long postganglionic	Long preganglionic Short postganglionic
Neural divergence	Extensive	Minimal
Effects of system	Often widespread and general	More specific and local

Table 15.3

# The Enteric Nervous System

- **Enteric nervous system**—the nervous system of the digestive tract
  - Does not arise from the brainstem or spinal cord (no CNS components)
  - Innervates smooth muscle and glands
- **Composed of 100 million neurons found in the walls of the digestive tract**
- **Has its own reflex arcs**
- **Regulates motility** of esophagus, stomach, and intestines and secretion of digestive enzymes and acid
- **Normal digestive function also requires regulation by sympathetic and parasympathetic systems**

# Megacolon

- **Hirschsprung disease**—hereditary defect causing absence of enteric nervous system
  - No innervation in sigmoid colon and rectum
  - Constricts permanently and will not allow passage of feces
  - Feces becomes impacted above constriction
  - **Megacolon:** massive dilation of bowel accompanied by abdominal distension and chronic constipation
  - May be colonic gangrene, perforation of bowel, and **peritonitis**
  - Usually evident in newborns who fail to have their first bowel movement

# Autonomic Effects on Target Organs

- **Expected Learning Outcomes**

- Name the neurotransmitters employed at different synapses of the ANS.
- Name the receptors for these neurotransmitters and explain how they relate to autonomic effects.
- Explain how the ANS controls many target organs through dual innervation.
- Explain how control is exerted in the absence of dual innervation.

# Neurotransmitters and Their Receptors

- **How do autonomic neurons have contrasting effects on organs?**
- **Two fundamental reasons:**
  - Sympathetic and parasympathetic fibers secrete different neurotransmitters (norepinephrine and acetylcholine)
  - The receptors on target cells vary
    - Target cells respond to the same neurotransmitter differently depending on the type of receptor they have for it
    - There are two different classes of receptors for acetylcholine and two classes of receptors for norepinephrine

# Neurotransmitters and Their Receptors

- **Acetylcholine (ACh) is secreted by all preganglionic neurons in both divisions and by postganglionic parasympathetic neurons**
  - Axons that secrete ACh are called **cholinergic fibers**
  - Any receptor that binds ACh is called a **cholinergic receptor**

# Neurotransmitters and Their Receptors

- **Two types of cholinergic receptors**
  - **Muscarinic receptors**
    - All cardiac muscle, smooth muscle, and gland cells have muscarinic receptors
    - Excitatory or inhibitory due to subclasses of muscarinic receptors
  - **Nicotinic receptors**
    - On all ANS postganglionic neurons, in the adrenal medulla, and at neuromuscular junctions of skeletal muscle
    - Excitatory when ACh binding occurs

# Neurotransmitters and Their Receptors

- Norepinephrine (NE) is secreted by nearly all **sympathetic postganglionic neurons**
  - Called **adrenergic fibers**
  - Receptors for NE are called **adrenergic receptors**
    - **Alpha-adrenergic receptors**
      - Usually **excitatory**
      - Two subclasses use different second messengers ( $\alpha_1$  and  $\alpha_2$ )
    - **Beta-adrenergic receptors**
      - Usually **inhibitory**
      - Two subclasses with different effects, but both act through cAMP as a second messenger ( $\beta_1$  and  $\beta_2$ )

# Neurotransmitters and Their Receptors

- **Autonomic effects on glandular secretion** are often an indirect result of their effect on blood vessels
  - **Vasodilation:** increased blood flow; increased secretion
  - **Vasoconstriction:** decreased blood flow; decreased secretion
- **Sympathetic effects tend to last longer** than parasympathetic effects
  - NE by sympathetics is reabsorbed by nerve, diffuses to adjacent tissues, and much passes into bloodstream
  - ACh released by parasympathetics is broken down quickly at synapse

# Neurotransmitters and Their Receptors

- Many substances released as neurotransmitters that **modulate ACh and NE function**
  - **Sympathetic fibers** may also secrete enkephalin, substance P, neuropeptide Y, somatostatin, neurotensin, or gonadotropin-releasing hormone
  - Some **parasympathetic fibers** stimulate endothelial cells to release the gas nitric oxide, which causes vasodilation by inhibiting smooth muscle tone
    - Function is crucial to penile erection

# Neurotransmitters and Their Receptors

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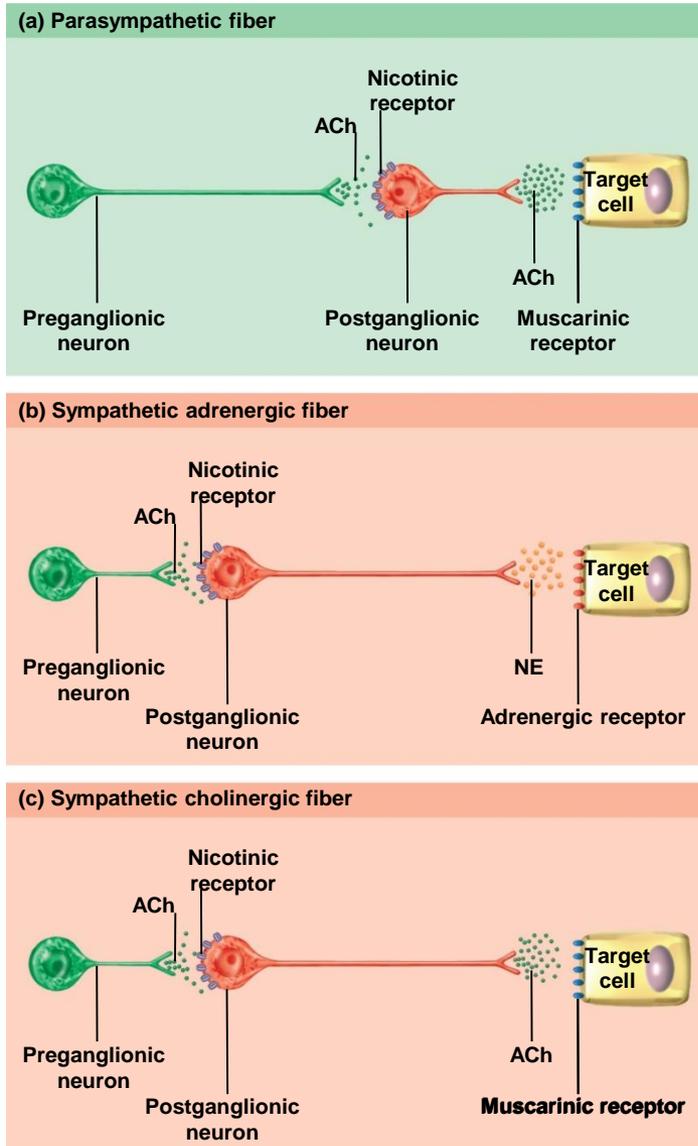


Figure 15.8

# Dual Innervation

- **Dual innervation**—most viscera receive nerve fibers from both parasympathetic and sympathetic divisions
  - **Antagonistic effect:** oppose each other
  - **Cooperative effects:** two divisions act on different effectors to produce a unified overall effect
- **Both divisions do not normally innervate an organ equally**
  - Parasympathetic exerts more influence on digestive organs
  - Sympathetic has greater effect on ventricular muscle of heart

# Dual Innervation

- **Antagonistic effects**—oppose each other
  - Exerted through dual innervation of same effector cells
    - Heart rate decreases (parasympathetic)
    - Heart rate increases (sympathetic)
  - Exerted because each division innervates different cells
    - Pupillary dilator muscle (sympathetic) dilates pupil
    - Constrictor pupillae (parasympathetic) constricts pupil

# Dual Innervation

- **Cooperative effects**—when two divisions act on different effectors to produce a unified effect
  - Parasympathetics increase salivary serous cell secretion
  - Sympathetics increase salivary mucous cell secretion

# Dual Innervation of the Iris

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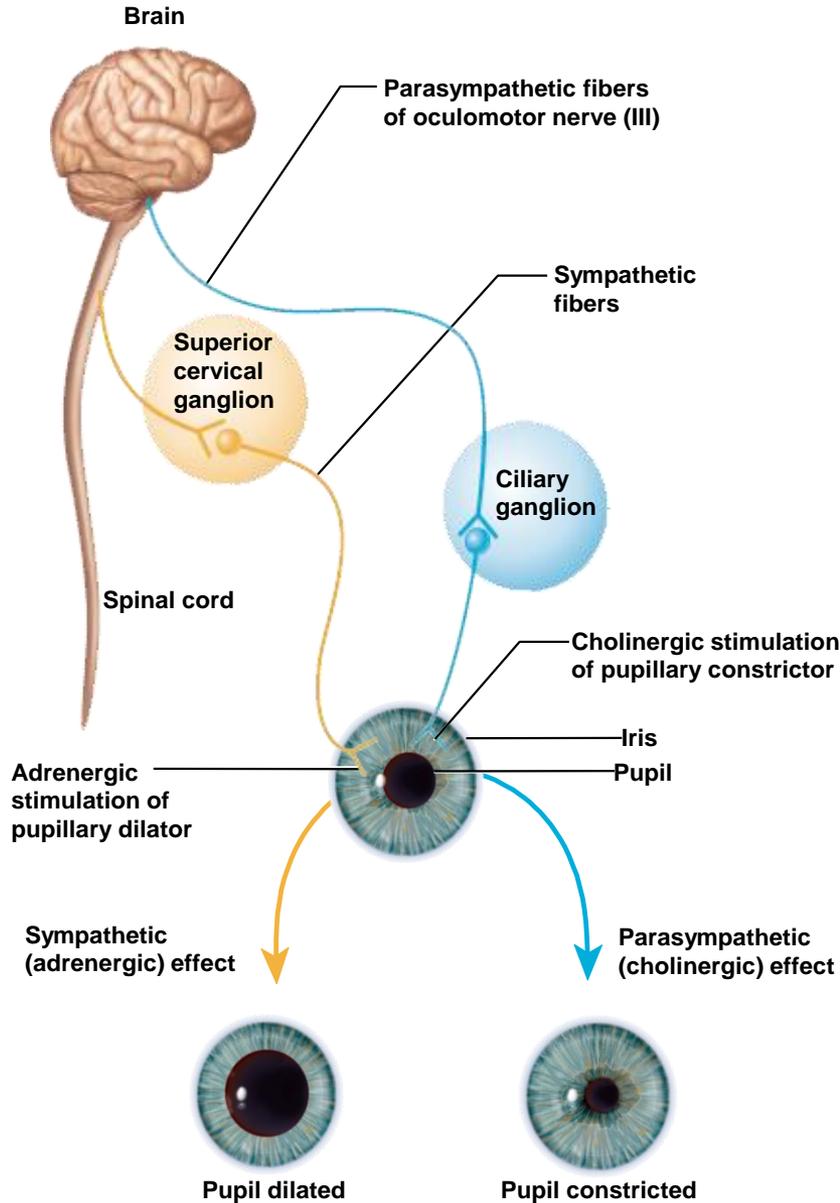


Figure 15.9

# Control Without Dual Innervation

- Some effectors receive **only sympathetic fibers**
  - Adrenal medulla, arrector pili muscles, sweat glands, and many blood vessels
- **Examples: regulation of blood pressure and routes of blood flow**

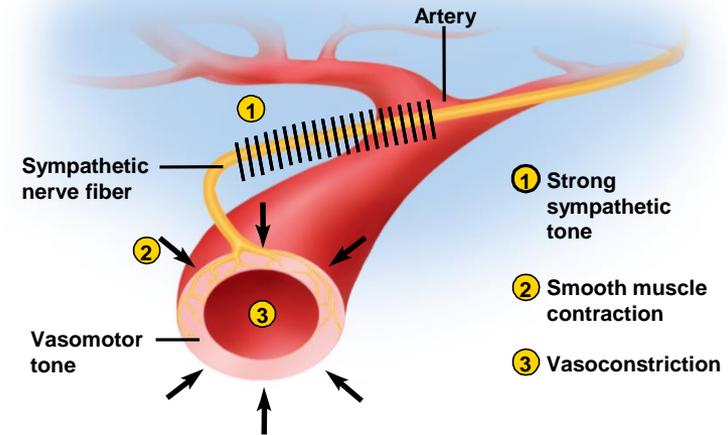
# Control Without Dual Innervation

- Sympathetic **vasomotor tone**—a baseline firing frequency of sympathetics
  - Keeps vessels in state of partial constriction
  - Sympathetic division acting alone can exert opposite effects on the target organ blood vessels
    - Increase in firing frequency—**vasoconstriction**
    - Decrease in firing frequency—**vasodilation**
  - Can shift blood flow from one organ to another as needed
    - During stress: blood vessels to muscles and heart dilate, while blood vessels to skin constrict

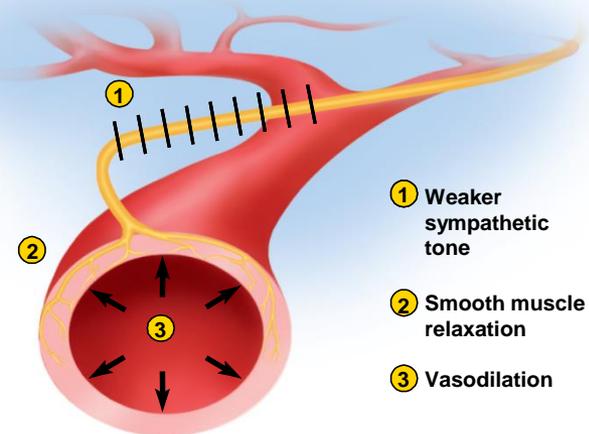
# Control Without Dual Innervation

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- Sympathetic division prioritizes blood vessels to skeletal muscles and heart in times of emergency
- Blood vessels to skin vasoconstrict to minimize bleeding if injury occurs during emergency



(a) Vasoconstriction



(b) Vasodilation

Figure 15.10

# Central Control of Autonomic Function

- **Expected Learning Outcome**
  - Describe how the autonomic nervous system is influenced by the central nervous system.

# Central Control of Autonomic Function

- ANS regulated by several levels of CNS
  - **Cerebral cortex** has an influence: anger, fear, anxiety
    - Powerful emotions influence the ANS because of the connections between our limbic system and the hypothalamus
  - **Hypothalamus**: major visceral motor control center
    - Nuclei for primitive functions—hunger, thirst, sex

# Central Control of Autonomic Function

(continued)

- **ANS regulated by several levels of CNS**
  - **Midbrain, pons, and medulla oblongata** contain:
    - Nuclei for cardiac and vasomotor control, salivation, swallowing, sweating, bladder control, and pupillary changes
  - **Spinal cord reflexes**
    - Defecation and micturition reflexes are integrated in spinal cord
    - We control these functions because of our control over skeletal muscle sphincters; if the spinal cord is damaged, the smooth muscle of bowel and bladder is controlled by autonomic reflexes built into the spinal cord

# Drugs and the Nervous System

- **Neuropharmacology**—study of effects of drugs on the nervous system
- **Sympathomimetics** enhance sympathetic activity
  - Stimulate receptors or increase norepinephrine release
    - Cold medicines that dilate the bronchioles or constrict nasal blood vessels
- **Sympatholytics** suppress sympathetic activity
  - Block receptors or inhibit norepinephrine release
    - Beta blockers reduce high BP interfering with effects of epinephrine/norepinephrine on heart and blood vessels

# Drugs and the Nervous System

- **Parasympathomimetics** enhance activity while **parasympatholytics** suppress activity
- **Many drugs also act on neurotransmitters in CNS**
  - Prozac blocks reuptake of serotonin to prolong its mood-elevating effect
- **Caffeine** competes with **adenosine** (the presence of which causes sleepiness) by binding to its receptors

# Drugs and the Nervous System

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Figure 15.11