Chapter 15

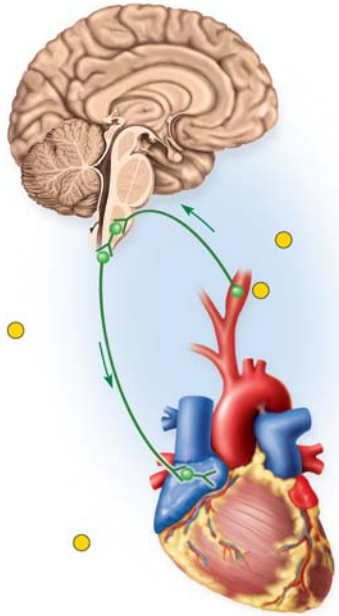
# Introduction to The Autonomic Nervous System

## Sympathetic N.S.

## Parasympathetic N.S.

## Adrenergic and Cholinergic Fibers

## Neurotransmitters



# Autonomic Nervous System

- Portion of the nervous system that operates in comparative secrecy (involuntary)
- ANS manages a multitude of unconscious processes responsible for the body's homeostasis
- Walter Cannon studied the ANS // coined the expressions *homeostasis* and *fight or flight response*
- <u>Homeostasis can not be maintained without the ANS</u>
- <u>An imbalance in homeostasis causes a disease state</u>

# General Properties of ANS

- a *motor nervous system* that controls glands, cardiac muscle, and smooth muscle
- also called the **visceral motor system**
- **primary organs of the ANS**
  - viscera of thoracic and abdominal cavities
  - also some structures in the body wall
    - cutaneous blood vessels
    - sweat glands
    - piloerector muscles

# General Properties of ANS

- carries out actions involuntarily // without our conscious intent or awareness

- <u>visceral effectors do not depend on the ANS for their function</u>

  - only to adjust their activity to the body's changing needs // e.g. the heart

- denervation hypersensitivity ***///*** exaggerated response of cardiac and smooth muscle if autonomic nerves are severed

# Visceral Reflexes

- unconscious, automatic, stereotyped responses to stimulation involving visceral receptors and effectors

- slower responses than somatic reflexes

# The Visceral Reflex Arc

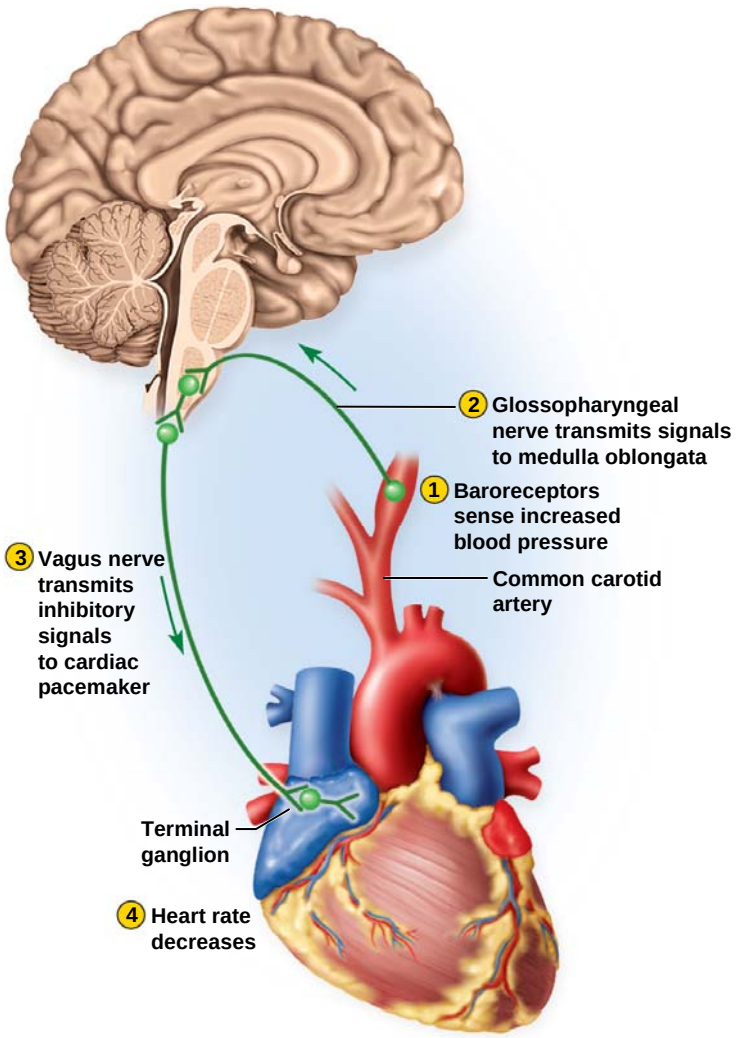
- receptors – nerve endings that detect stretch, tissue damage, blood chemicals, body temperature, and other internal stimuli
- afferent neurons – leading to the CNS
- interneurons – in the CNS
- efferent neurons – carry motor signals away from the CNS
- effectors – make adjustments to homeostasis *(not a skeletal muscle)*
  - ANS modify effector activity // effectors are not dependent upon ANS for their function!!!

# Visceral Reflex to High BP

- high blood pressure detected by arterial stretch receptors

- (1) afferent neuron
- (2) carries signal to CNS, efferent
- (3) signals travel to the heart
- (4), heart slows reducing blood pressure

- example of homeostatic negative feedback loop



# Divisions of ANS

- two divisions
- often innervate same target organs // may have cooperative or contrasting effects
- sympathetic division /// prepares body for physical activity – exercise, trauma, arousal, competition, anger, or fear
    - E.g. increases heart rate, BP, airflow, blood glucose levels, reduces blood flow to the skin and digestive tract
- parasympathetic division /// calms many body functions -reducing energy expenditure and assists in bodily maintenance
    - E.g. digestion and waste elimination // “resting and repair” / e.g. digesting state

# Divisions of ANS

- autonomic tone - normal background rate of activity that *represents the balance between the two systems*
  - parasympathetic tone
    - Example: maintains smooth muscle tone in intestines
    - Example: holds resting heart rate down to about 70 – 80 beats per minute
  - sympathetic tone
    - Example: keeps most blood vessels partially constricted and maintains blood pressure

# Divisions of ANS

- ANS division often provide a contrasting tone to same tissues:
  - **sympathetic division** excites the hearts but inhibits digestive system and urinary bladder activity
  - **parasympathetic** division inhibits the heart rate but excites the digestive and urinary bladder activity

# Neural Pathways

- ANS has components in both the central and peripheral nervous systems
  - controlling nuclei located in the hypothalamus and/or other brain stem regions
  - motor neurons in the spinal cord (lateral horns) and peripheral ganglia
  - nerve fibers reach effecter tissue by traveling through the cranial and spinal nerves

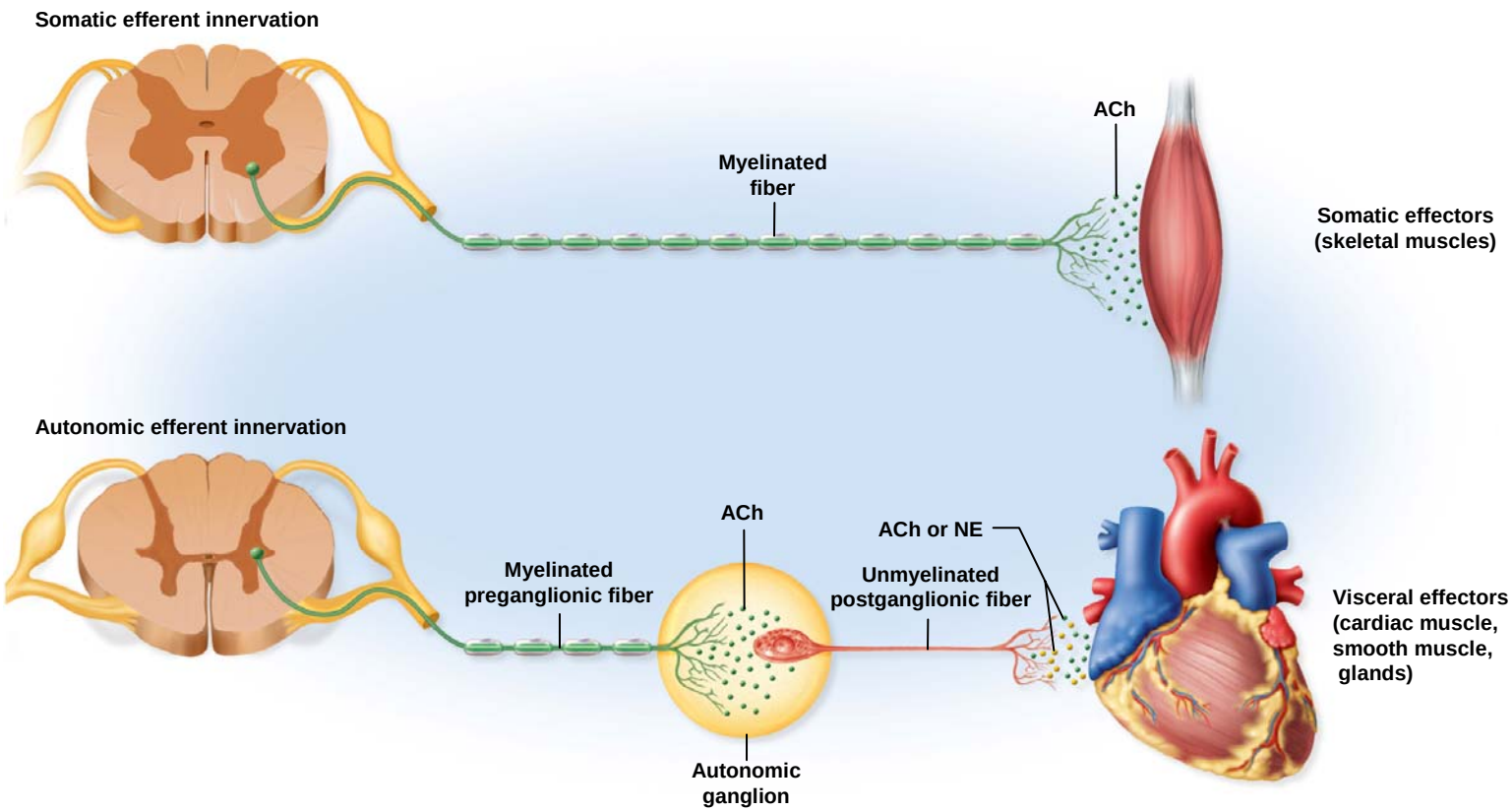
- In a somatic motor pathway
  - a motor neuron from the brainstem or spinal cord issues a myelinated axon that reaches all the way to the skeletal muscle *(not the case with ANS)*

# The ANS Neural 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
- **Pre-ganglionic neuron** – the first neuron has a soma in the brainstem or spinal cord (myelinated fiber)
- **Post-ganglionic neuron -** soma form the ganglion and its axon extends the rest of the way to the target cell (unmyelinated fiber)

• Note: *a ganglion is a collection of soma outside the CNS*

# Somatic versus ANS Pathways

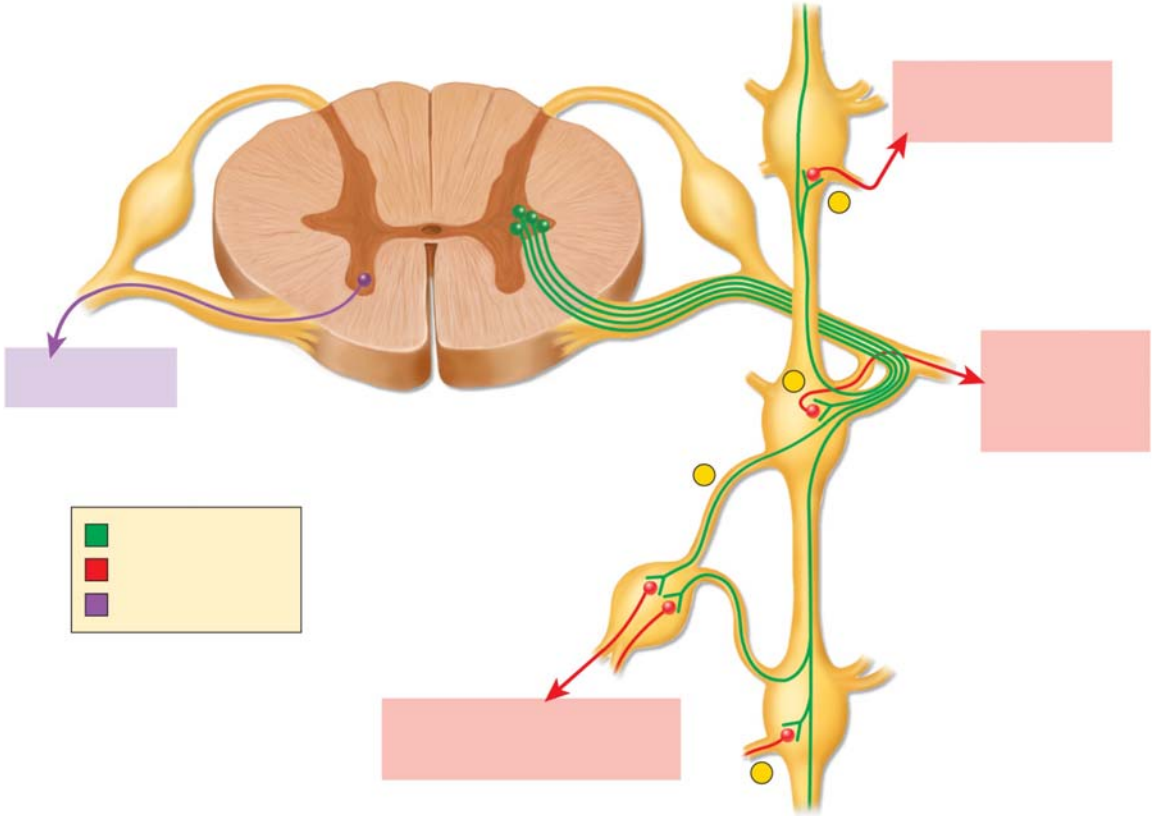



ANS – two neurons from CNS to effectors

- preganglionic neuron whose cell body is in CNS
- postganglionic neuron cell body in peripheral ganglion

# Chapter 15

# Sympathetic Nervous System



# Sympathetic Nervous System

- 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 the gray matter of spinal cord

# Sympathetic Nervous System

- These 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
  - May travel by various pathways

# Sympathetic Nervous System

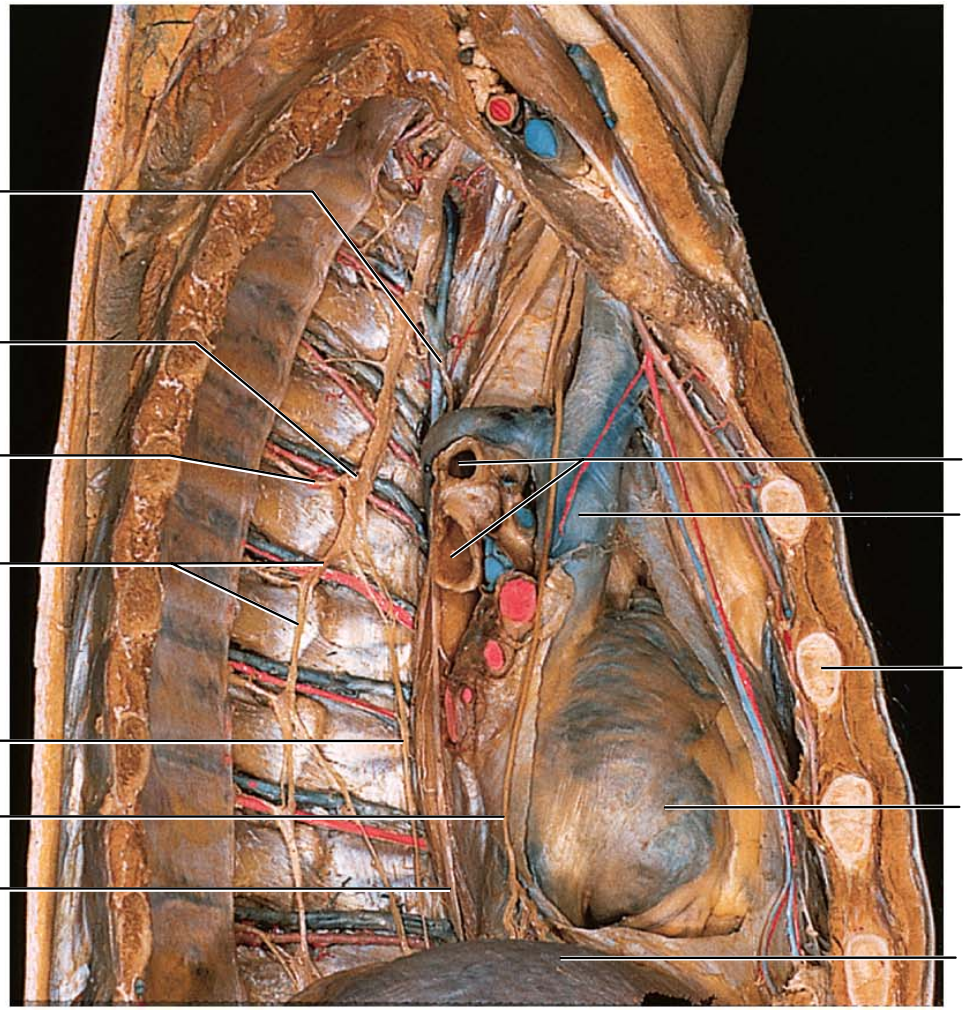
- each paravertebral ganglion is connected to a spinal nerve by two branches – communicating rami

- preganglionic fibers are small myelinated fibers that travel form 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

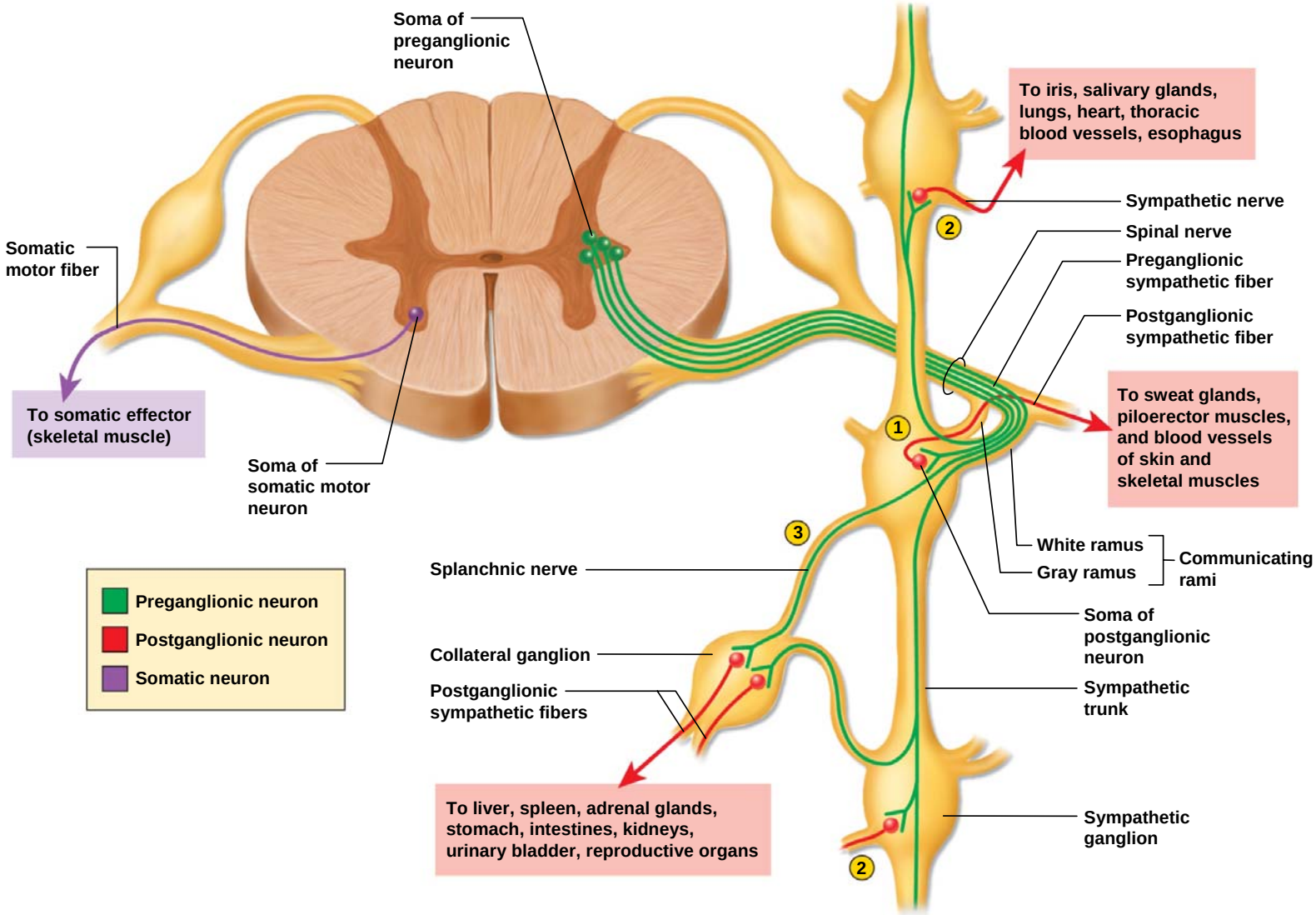
- *postganglionic fibers extend the rest of the way to the target organ*

# Sympathetic Chain Ganglia



# Preganglionic Pathways



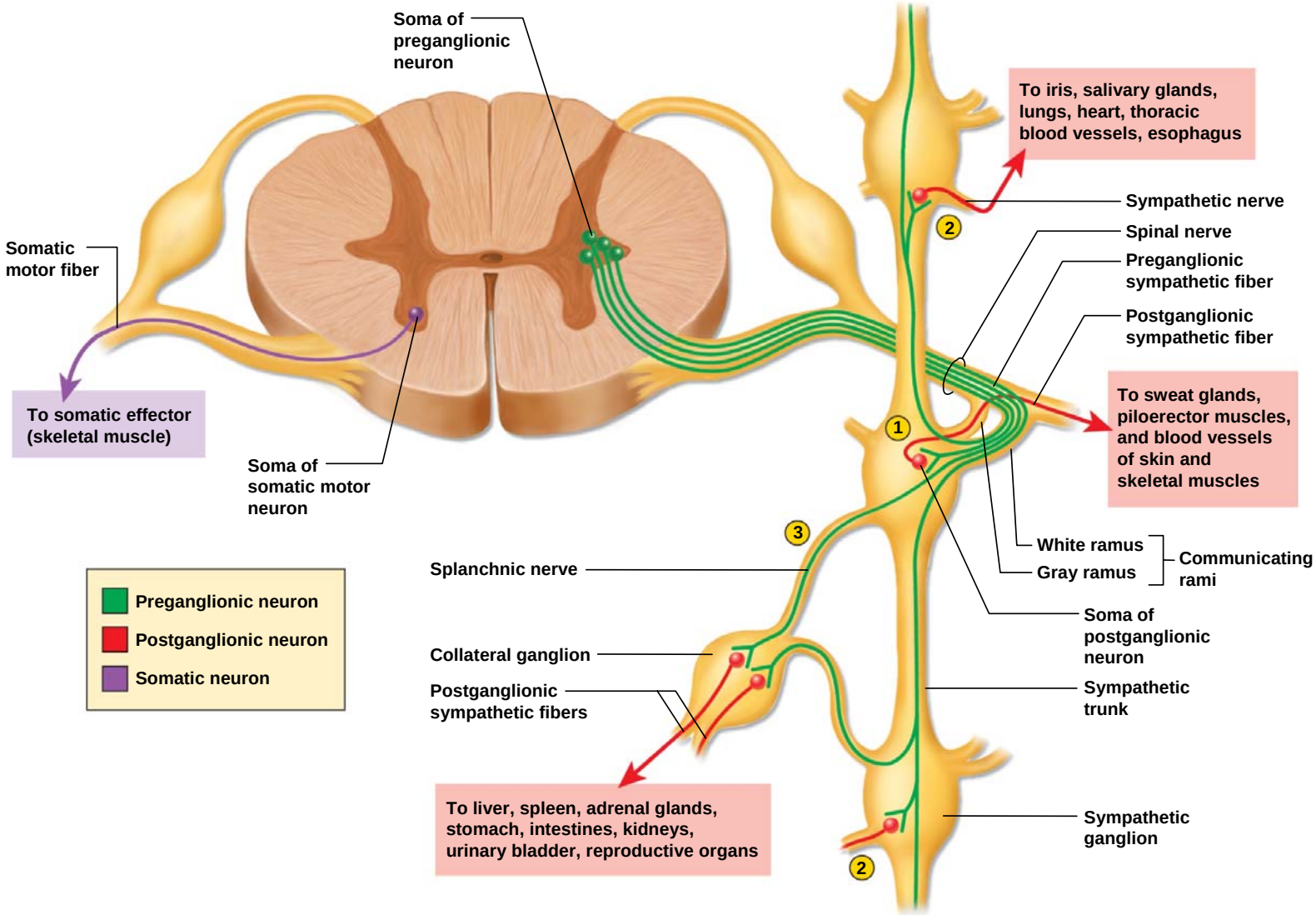


# Sympathetic Nervous System

- after entering the sympathetic chain /// the postganglionic fibers may follow any of three possible 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*

# Preganglionic Pathways





# Sympathetic Nervous System

- nerve fibers leave the sympathetic chain by spinal, sympathetic, and splanchnic nerves
  - spinal nerve route
    - some postganglionic fibers exit a ganglion by way of the gray ramus
    - returns to the spinal nerve and travels the rest of the way to the target organ
    - most sweat glands, piloerector muscles, and blood vessels of the skin and skeletal muscles

# Sympathetic Nervous System

– sympathetic nerve route

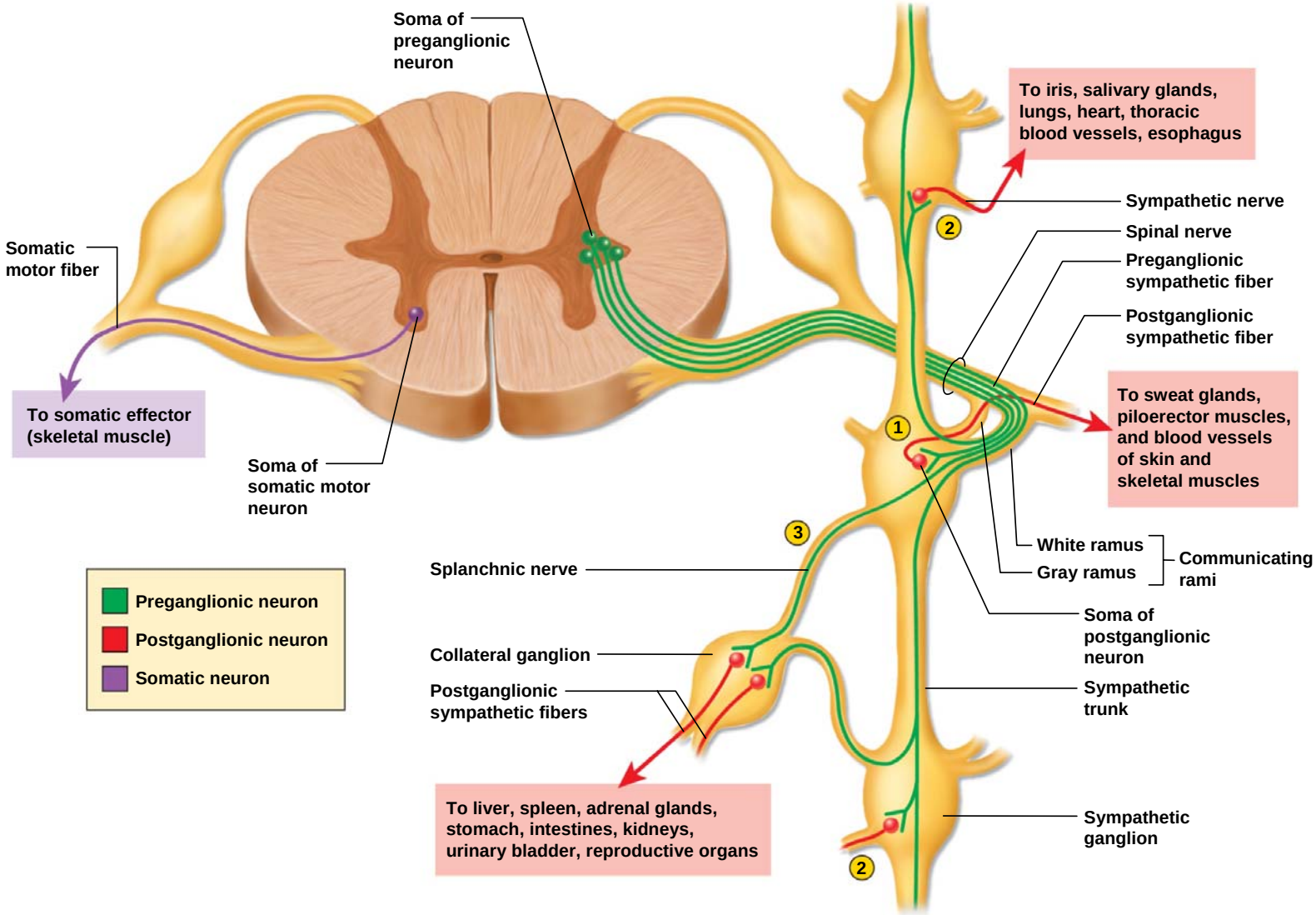
- other nerves leave by way of sympathetic nerves that extend to the heart, lungs, esophagus and thoracic blood vessels
- these nerves form carotid plexus around each carotid artery of the neck
- issue fibers from there to the effectors in the head // sweat, salivary, nasal glands, piloerector muscles, blood vessels, dilators of iris
- some fibers of superior and middle cervical ganglia form cardiac nerves to the heart

# Sympathetic Nervous System

- **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

# Preganglionic Pathways





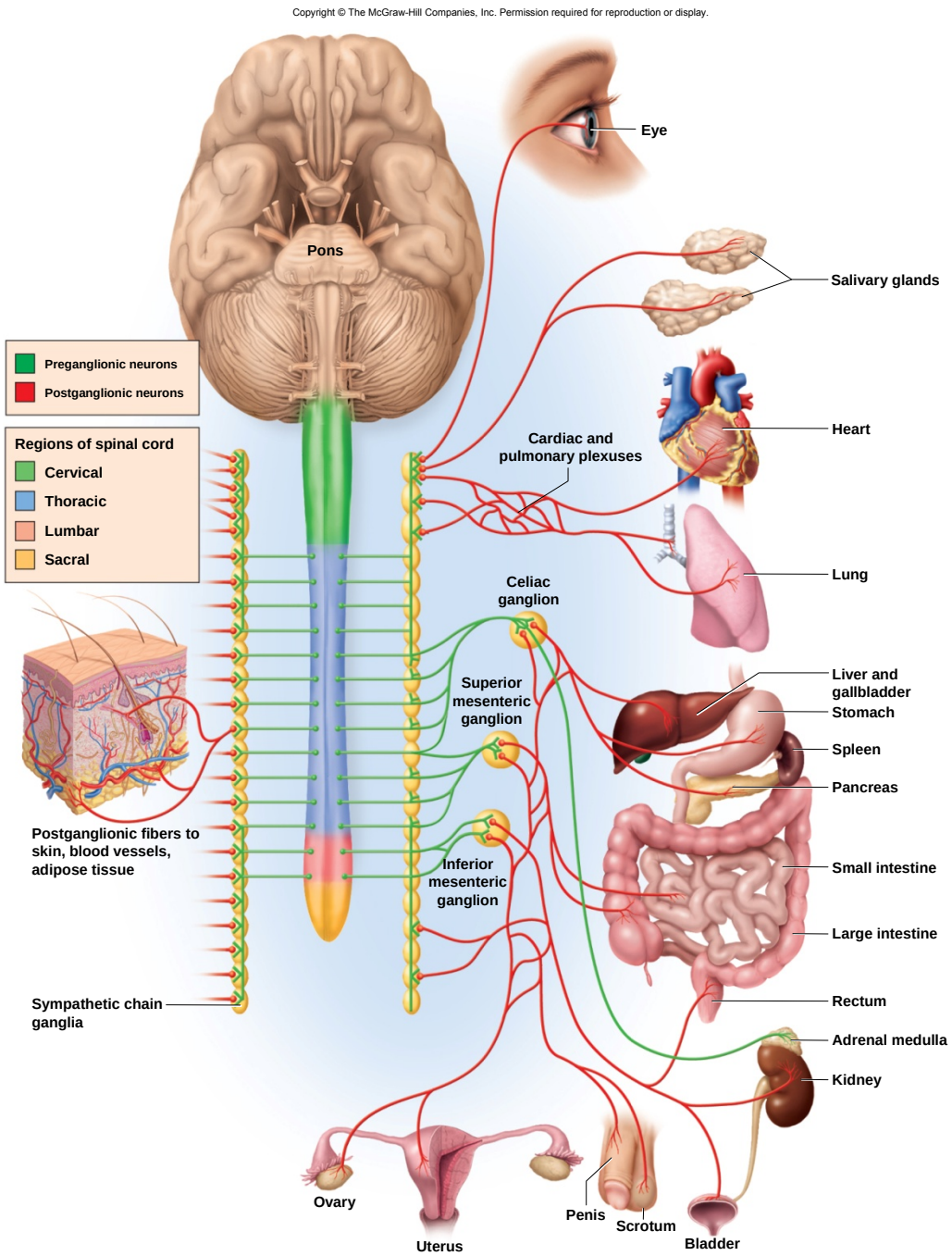
# Plexus of Sympathetic Nervous System

- collateral ganglia contribute to a network called the abdominal aortic plexus
  - The AAP wraps around abdominal aorta
  - Form three major collateral ganglia in this plexus (note: lab objectives)
    - celiac, superior mesenteric, and inferior mesenteric
    - These nerves of postganglionic fibers follow similar named arteries to their target organs

# Plexus of Sympathetic Nervous System

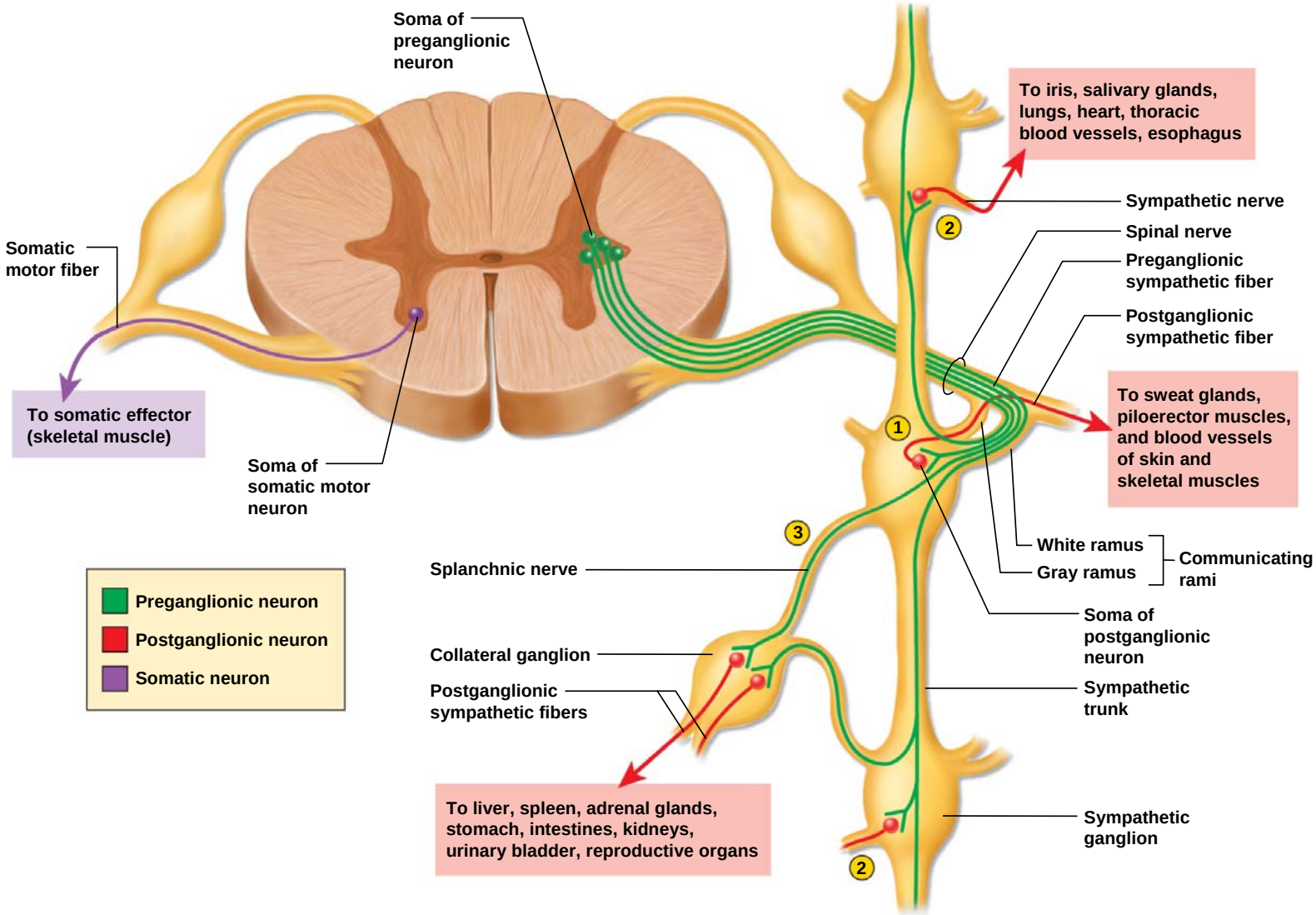
- **solar plexus**
  - collective name for the celiac and superior mesenteric ganglia
  - nerves radiate from ganglia like rays of the sun
- **neuronal divergence** predominates
  - each preganglionic cell branches and synapses on 10 to 20 postganglionic cells
  - one preganglionic neuron can excite multiple postganglionic fibers leading to different target organs
  - have relatively widespread effects

# Efferent Pathways



# Preganglionic Pathways

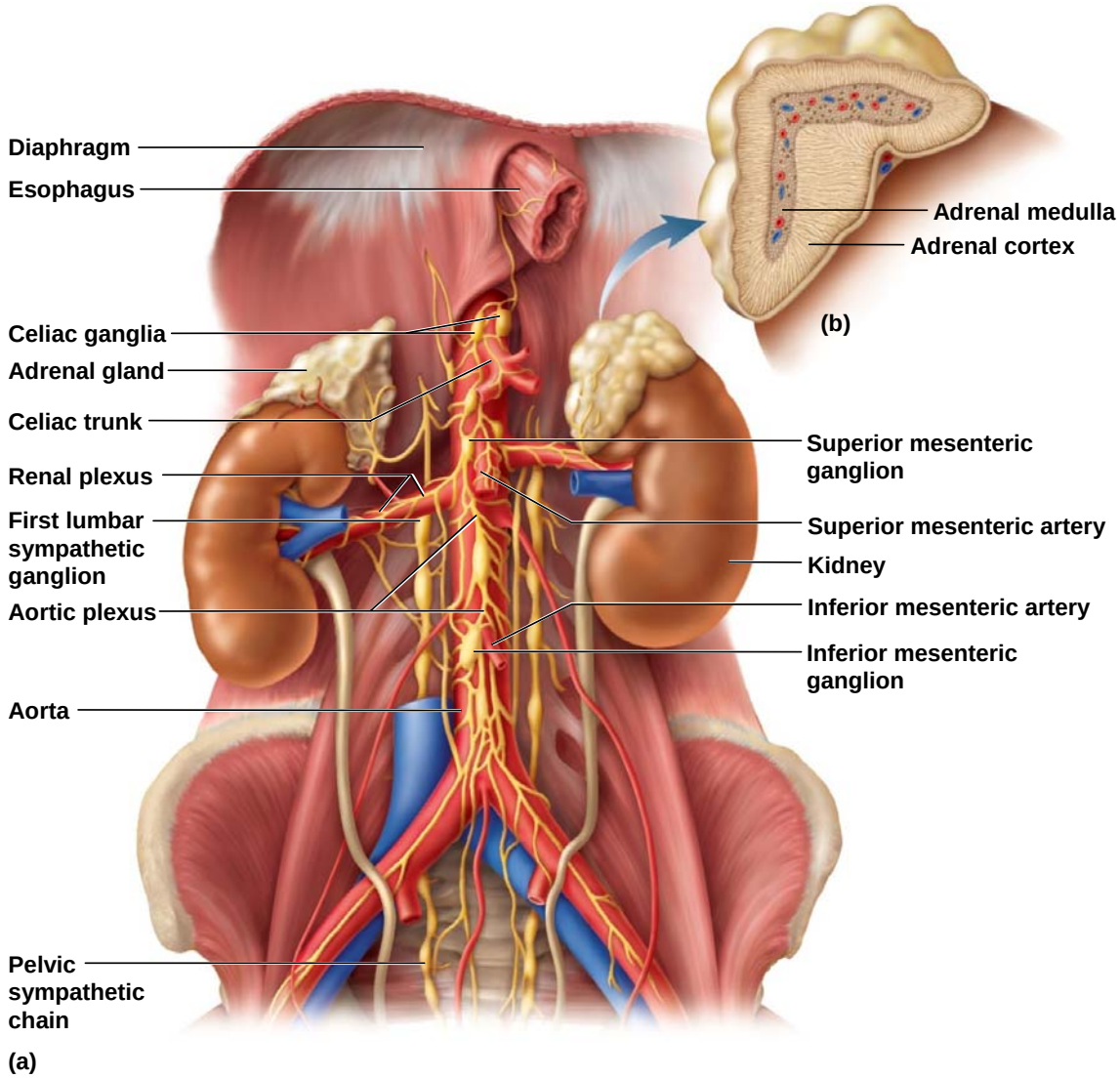




# Summary of Sympathetic Innervation

- effectors in body wall are innervated by sympathetic fibers in spinal nerves
- effectors in head and thoracic cavity are innervated by sympathetic fibers in sympathetic nerves
- effectors in abdominal cavity are innervated by sympathetic fibers in splanchnic nerves

# Ganglia and Abdominal Aortic Plexus



# Adrenal Glands

- paired adrenal (suprarenal) glands on superior poles of the kidneys

- Adrenal gland is actually two separate glands with different functions

  – adrenal cortex (outer layer) // secretes steroid hormones

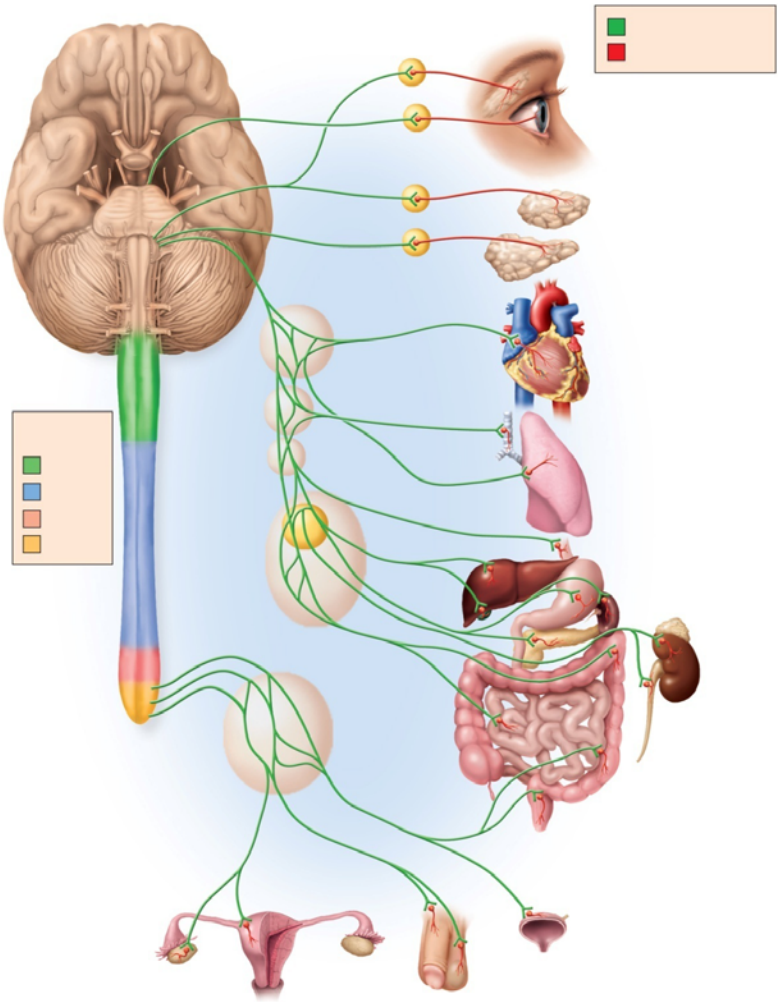
  – adrenal medulla (inner core) // *essentially a sympathetic ganglion*

# Adrenal Glands

- Adrenal medulla (inner core)
  - consists of modified postganglionic neurons without dendrites or axons
  - stimulated by preganglionic sympathetic neurons that terminate on these cells
  - Adrenal medulla secretes a mixture of hormones into bloodstream
    - catecholamines // 85% epinephrine (adrenaline) // 15% norepinephrine (noradrenaline) // norepinephrine also function as neurotransmitters
- sympathoadrenal system = the closely related functioning adrenal medulla and sympathetic nervous system

Chapter 15

# The Parasympathetic Nervous System



# Parasympathetic Division

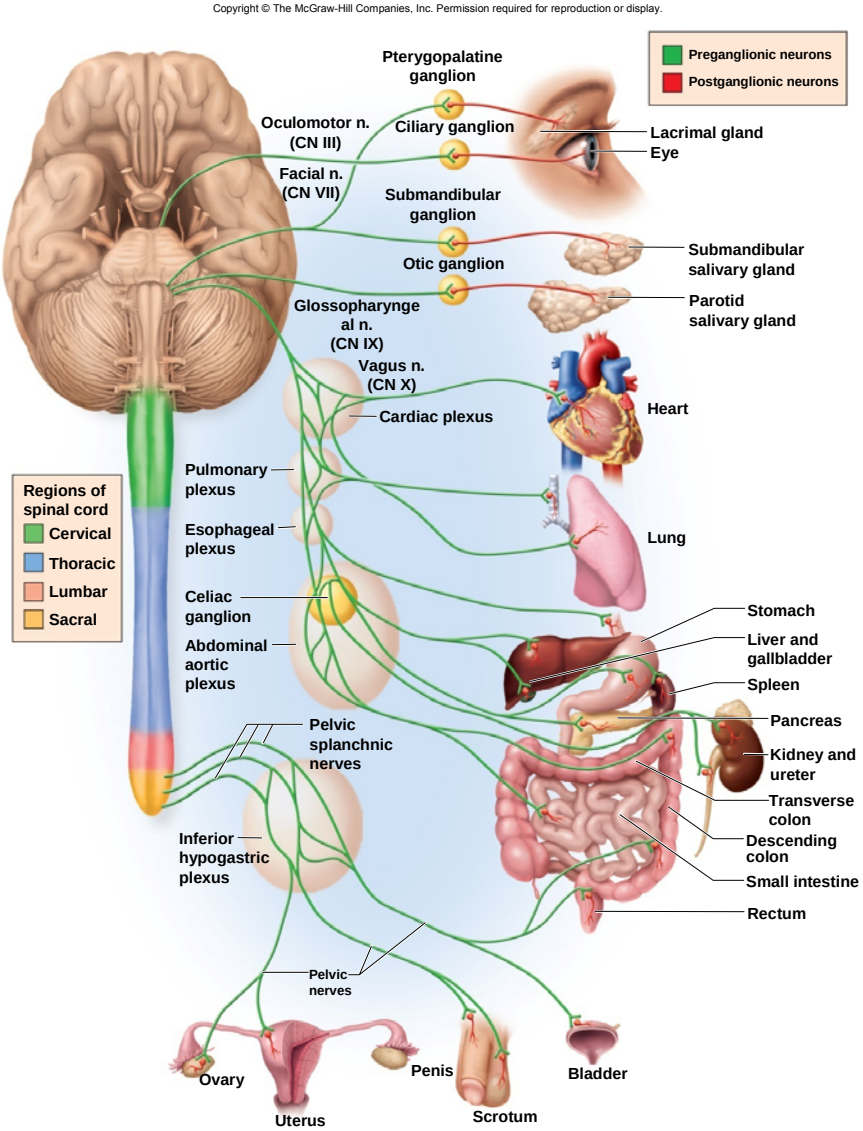
- **parasympathetic division** is also called the **craniosacral division**
  - arises from the brain and sacral regions of the spinal cord
  - fibers travel in certain cranial and sacral nerves

- origin of long preganglionic neurons
  - midbrain, pons, and medulla
  - sacral spinal cord segments S2-S4

# Parasympathetic Division

- pathways of long preganglionic fibers
  - fibers in cranial nerves III, VII, IX and X
  - fibers arising from sacral spinal cord
    - pelvic splanchnic nerves and inferior hypogastric plexus
- terminal ganglia in or near target organs
  - long preganglionic, short postganglionic fibers
- Less neuronal divergence than sympathetic division
  - one preganglionic fiber reaches the target organ and then stimulates fewer than 5 postganglionic cells

# Parasympathetic Cranial Nerves

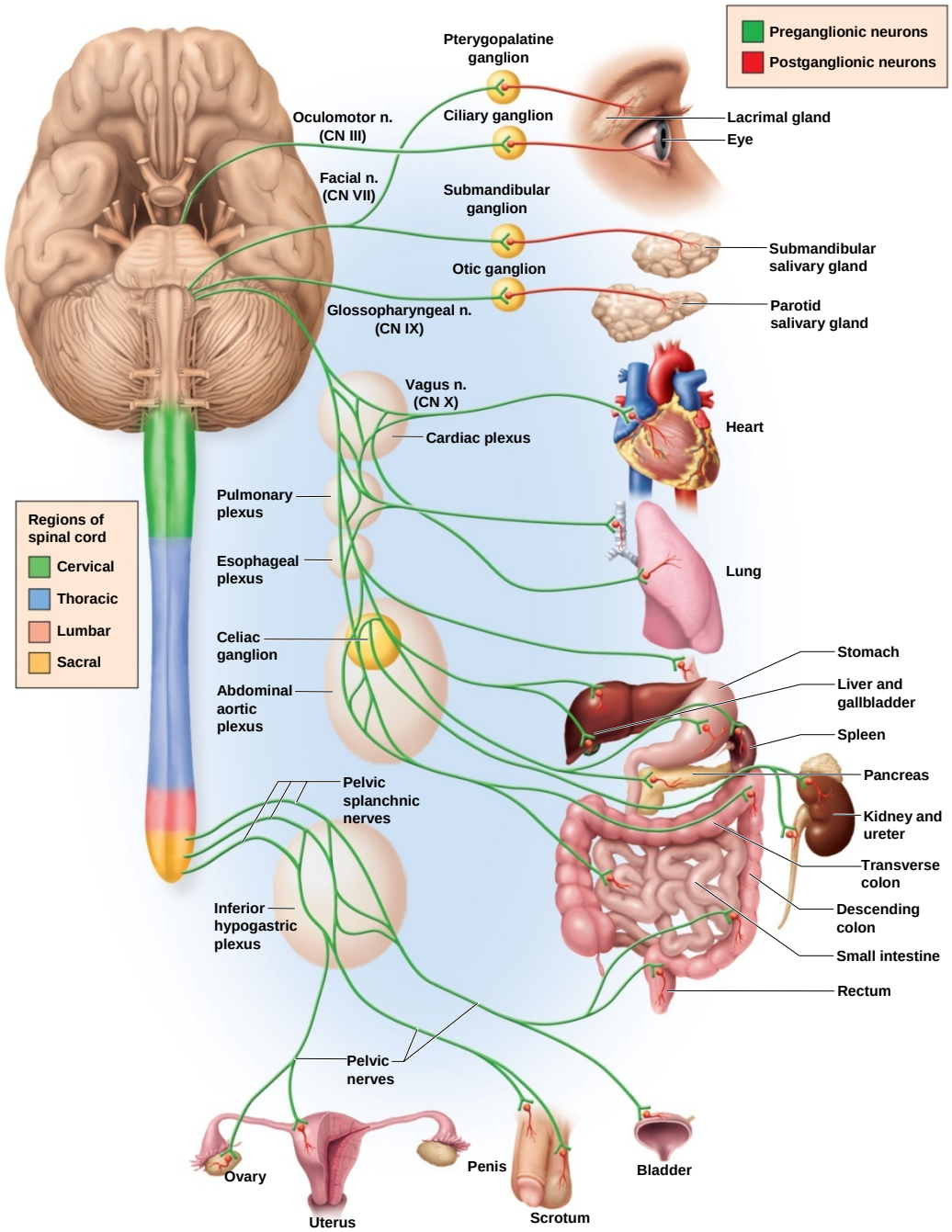



- **Oculomotor nerve (III)**
  - narrows pupil and focuses lens
- **Facial nerve (VII)**
  - tear, nasal and salivary glands
- **Glossopharyngeal nerve (IX)**
  - parotid salivary gland
- **Vagus nerve (X)**
  - viscera as far as proximal half of colon
  - cardiac, pulmonary, and esophageal plexus

# Efferent Pathways

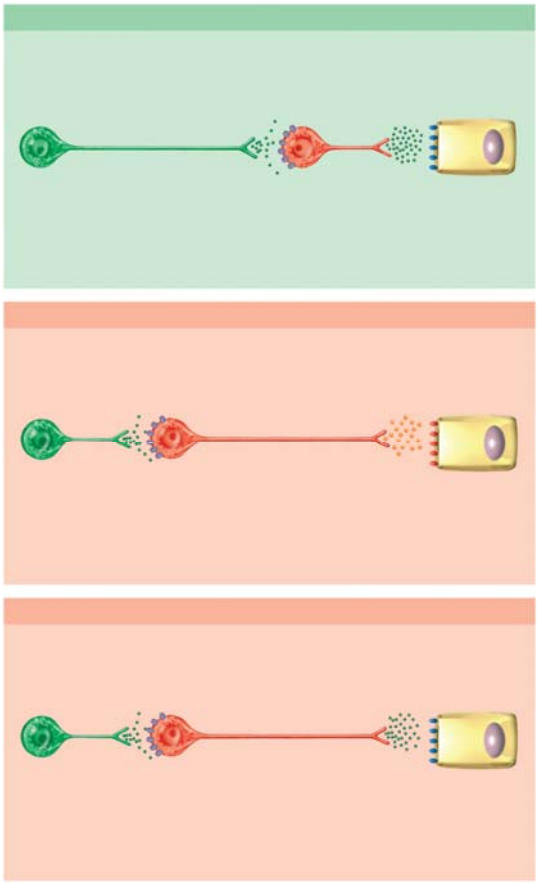
- remaining parasympathetic fibers arise from levels S2 to S4 of the spinal cord
- form pelvic splanchnic nerves that lead to the inferior hypogastric plexus
- most form pelvic nerves to their terminal ganglion on the target organs
  - distal half of colon, rectum, urinary bladder, and reproductive organs





# Chapter 15

# Neurotransmitters of the ANS



# Neurotransmitters and Receptors

- How can the same type of ANS neuron create different outcomes on different target tissue?

  1) variety of neurotransmitters

  2) different types of receptors for similar neurotransmitters

# Acetylcholine (ACh) – (1 of 3)

- ACh is secreted by all preganglionic neurons in both divisions of the ANS
- Ach is secreted by the postganglionic parasympathetic neurons
- Any fiber that secretes Ach is called a cholinergic fibers
- Any receptor that binds Ach is called a cholinergic receptor

# Acetylcholine (ACh) – (2 of 3)

- **2 types of cholinergic receptors**
  - **muscarinic receptors**
    - use the second messenger mode of action / not ion channel
    - all cardiac muscle
    - smooth muscle
    - gland cells have muscarinic receptors
    - Note: can be either excitatory or inhibitory due to sub-classes of muscarinic receptors

# Acetylcholine (ACh) – (3 of 3)

- **Second type of cholinergic receptors**
  - **nicotinic receptors**
    - Sodium ion channel mode of action
    - on all ANS postganglionic neuron's soma
    - adrenal medulla
    - neuromuscular junctions of skeletal muscle
    - Note: always excitatory when ACh binding occurs

# Norepinephrine (NE)

- NE is secreted by nearly all sympathetic postganglionic neurons
  - called adrenergic fibers
  - receptors for it called adrenergic receptors

# Norepinephrine (NE)

- alpha-adrenergic receptors
  - usually excitatory // 2 subclasses use different second messengers ($\alpha_1$ & $\alpha_2$)
- beta-adrenergic receptors
  - usually inhibitory // 2 subclasses with different effects
  - both act through cAMP as a second messenger ($\beta_1$ & $\beta_2$)

## TABLE 15.5 Effects of the Sympathetic and Parasympathetic Nervous Systems

| Target | Sympathetic Effect and Receptor Type | Parasympathetic Effect (All Muscarinic) |
|---|---|---|
| *Eye* | | |
| Iris | Pupillary dilation (α) | Pupillary constriction |
| Ciliary muscle and lens | Relaxation for far vision (β) | Contraction for near vision |
| Lacrimal (tear) gland | None | Secretion |
| *Integumentary system* | | |
| Merocrine sweat glands (cooling) | Secretion (muscarinic) | No effect |
| Apocrine sweat glands (scent) | Secretion (α) | No effect |
| Piloerector muscles | Hair erection (α) | No effect |
| *Adipose tissue* | Decreased fat breakdown (α)<br>Increased fat breakdown (α, β) | No effect |
| *Adrenal medulla* | Hormone secretion (nicotinic) | No effect |
| *Circulatory system* | | |
| Heart rate and force | Increased (β) | Decreased |
| Deep coronary arteries | Vasodilation (β)<br>Vasoconstriction (α) | Slight vasodilation |
| Blood vessels of most viscera | Vasoconstriction (α) | Vasodilation |
| Blood vessels of skeletal muscles | Vasodilation (β) | No effect |
| Blood vessels of skin | Vasoconstriction (α) | Vasodilation, blushing |
| Platelets (blood clotting) | Increased clotting (α) | No effect |
| *Respiratory system* | | |
| Bronchi and bronchioles | Bronchodilation (β) | Bronchoconstriction |
| Mucous glands | Decreased secretion (α)<br>Increased secretion (β) | No effect |
| *Urinary system* | | |
| Kidneys | Reduced urine output (α) | No effect |
| Bladder wall | No effect | Contraction |
| Internal urinary sphincter | Contraction, urine retention (α) | Relaxation, urine release |
| *Digestive system* | | |
| Salivary glands | Thick mucous secretion (α) | Thin serous secretion |
| Gastrointestinal motility | Decreased (α, β) | Increased |
| Gastrointestinal secretion | Decreased (α) | Increased |
| Liver | Glycogen breakdown (α, β) | Glycogen synthesis |
| Pancreatic enzyme secretion | Decreased (α) | Increased |
| Pancreatic insulin secretion | Decreased (α)<br>Increased (β) | No effect |
| *Reproductive system* | | |
| Penile or clitoral erection | No effect | Stimulation |
| Glandular secretion | No effect | Stimulation |
| Orgasm, smooth muscle roles | Stimulation (α) | No effect |
| Uterus | Relaxation (β)<br>Labor contractions (α) | No effect |

# Overview of ANS Function (1 of 3)

- Autonomic effects on glandular secretion are often an indirect result of their effect on blood vessels
  - vasodilation – increased blood flow results in an increased secretion
  - vasoconstriction – decreased blood flow results in a decreased secretion

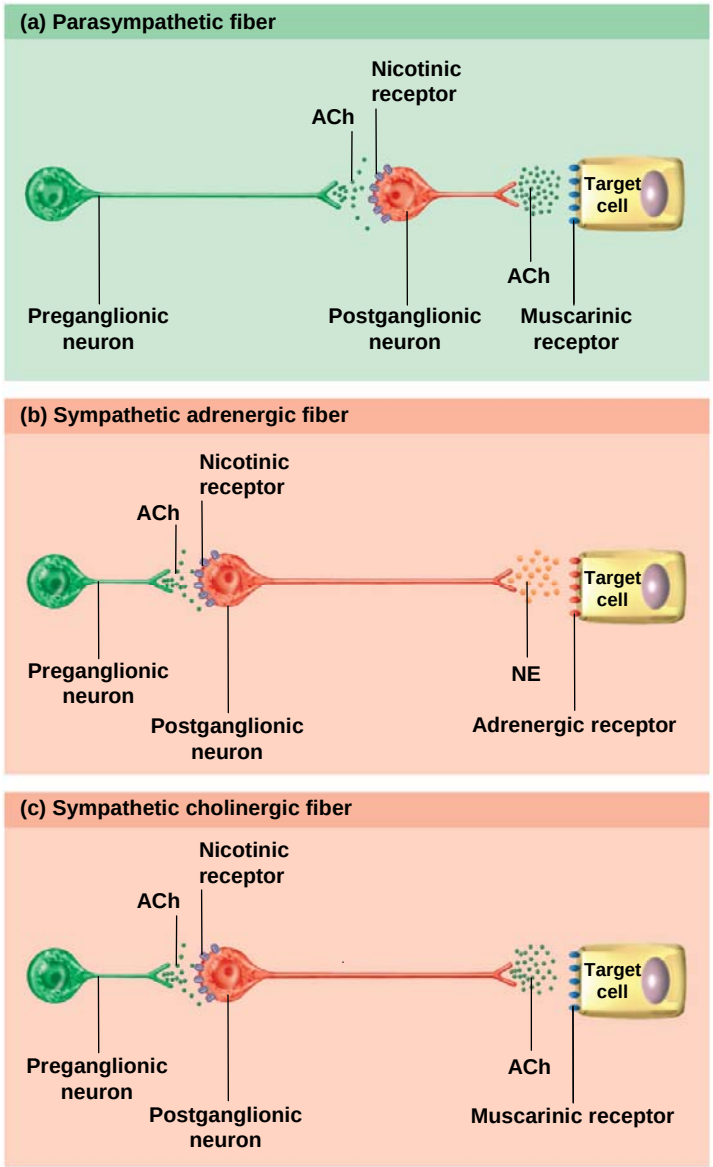
# Overview of ANS Function (2 of 3)

- Sympathetic effects tend to last longer than parasympathetic effects
  - ACh released by parasympathetics is broken down quickly at synapse
  - NE by sympathetics is reabsorbed by nerve
    - Slower process and some will diffuse to adjacent tissues
    - And much passes into bloodstream /// Circulate in blood and can “hit” other adrenergic receptors

# Overview of ANS Function (3 of 3)

- Many substances are released as neuromodulators that **modulate ACh and NE function**
  - **sympathetic fibers** also secrete enkephalin, substance P, neuropeptide Y, somatostatin, neurotensin, or gonadotropin-releasing hormone
  - **parasympathetic fibers** stimulate endothelial cells to release the gas, nitric oxide – causes vasodilation by inhibiting smooth muscle tone
    - function is crucial to penile erection - means of action of Viagra

# Neurotransmitters and Receptors




Merocrine sweat gland (cooling)

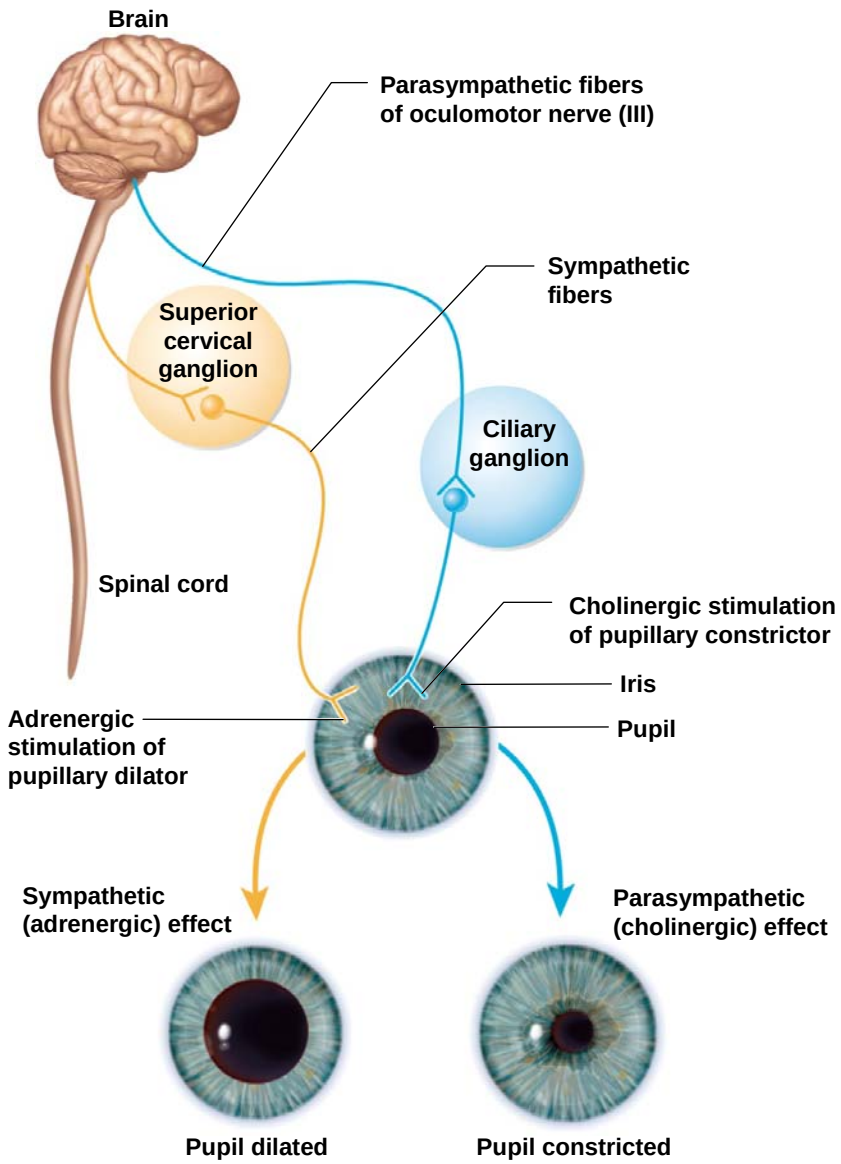
# Dual Innervation

- *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 the same organ equally

# Dual Innervation

- antagonistic effects (i.e. oppose each other)
  - 1st option // exerted through dual innervation of same group of cells
    - heart rate decreases (parasympathetic)
    - heart rate increases (sympathetic)
  - 2nd option // exerted because each division innervates different group of cells
    - pupillary dilator muscle (sympathetic) dilates pupil
    - constrictor pupillae (parasympathetic) constricts pupil

# Dual Innervation of the Iris



# Dual Innervation

- **cooperative effects** - when the two divisions act on different effectors to produce a unified effect

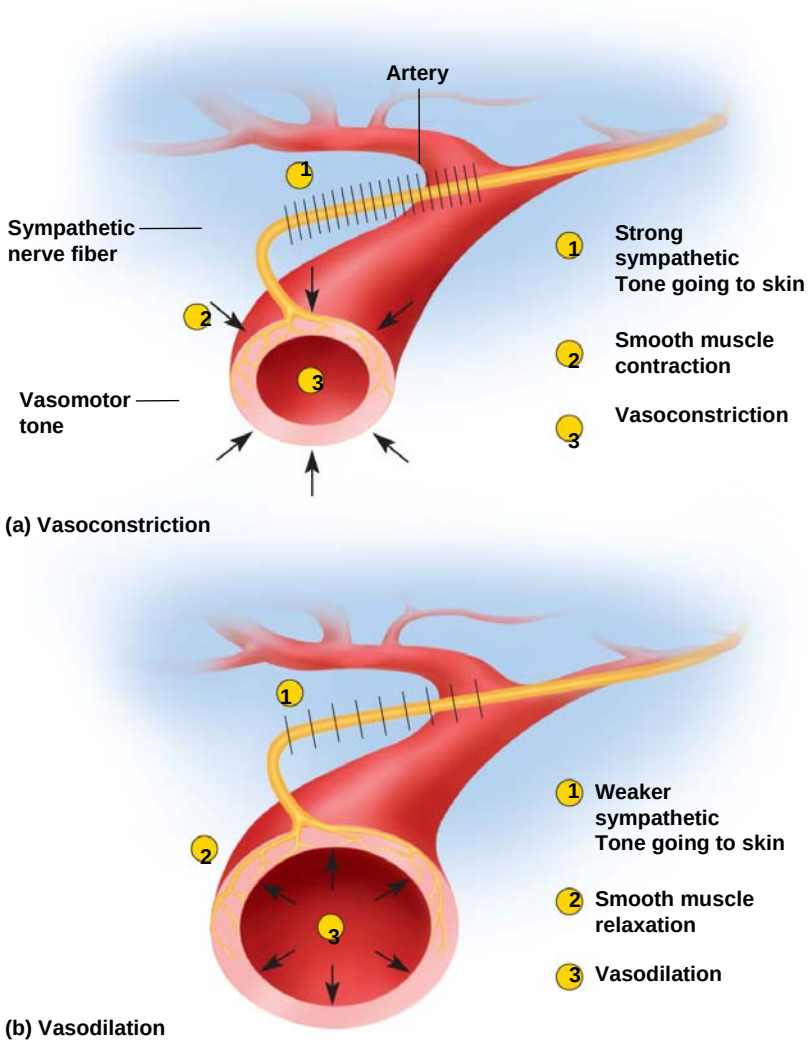
- eg. ANS innervation of salivary glands

  - parasympathetics increase salivary serous cell secretion
  - sympathetics increase salivary mucous cell secretion

# Regulation Without Dual Innervation

- some effectors receive **only sympathetic fibers**
  - adrenal medulla
  - arrector pili muscles
  - sweat glands
  - and many blood vessels throughout body
- How is blood flow, blood pressure, and routes of blood flow regulated with only sympathetic nerve fibers?
- (see next slide)

# Regulation Without Dual Innervation




Note: this illustration shows blood vessels in skin / at the same time different blood vessels in skeletal muscles will dilate

- control of blood pressure and routes of blood flow using only sympathetic innervation
- sympathetic vasomotor tone - a baseline firing frequency of sympathetics
  - keeps vessels in state of partial constriction
  - increase in firing frequency – **vasoconstriction**
  - decrease in firing frequency – **vasodilation**
  - can shift blood flow from one organ to another as needed
- <u>sympathetic division acting alone can exert opposite effects</u> on the target organ through control of blood vessels
  - during stress
    - blood vessels to skeletal muscles and heart dilate (not shown here)
    - blood vessels to skin constrict (illustrated here)

# Sympathetic Functions

ANS Function: blood vessels to skin vasoconstrict to minimize bleeding if injury occurs during stress or exercise

ANS Function: prioritizes blood vessels to skeletal muscles and heart in times of emergency

# Control of Autonomic Function (1 of 2)

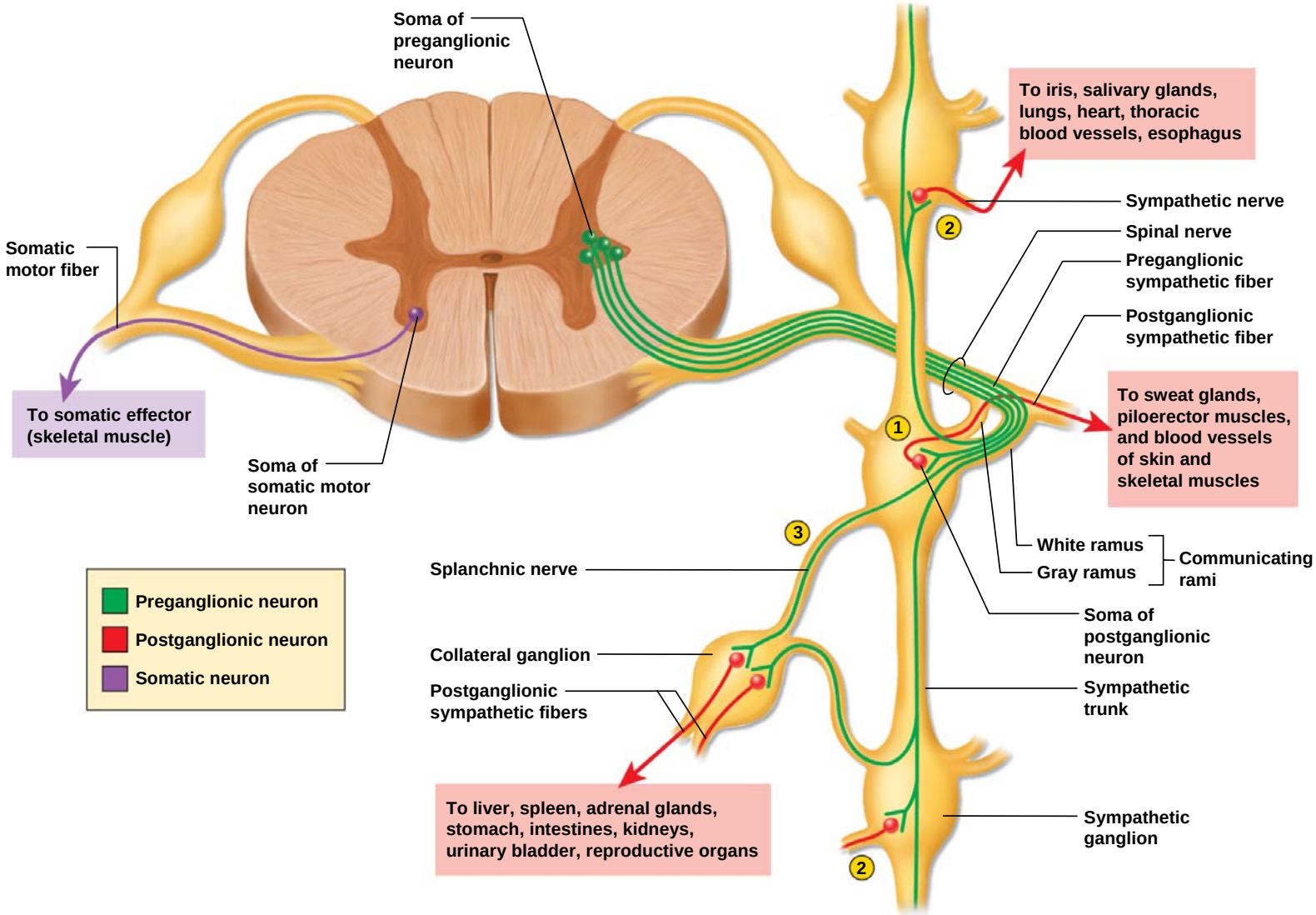
- ANS regulated by different levels of the CNS
  - **cerebral cortex** has an influence // prefrontal cortex hardwired to limbic system
    - anger, fear, anxiety
    - powerful emotions influence the ANS because of the <u>connections between our limbic system (emotional brain) and the hypothalamus</u>
  - **hypothalamus** - major visceral motor control center // exerts influence by connections to pituitary (hormones) or nerve tracks to nuclei in medulla oblongata (ANS)
    - nuclei for primitive functions – hunger, thirst, sex

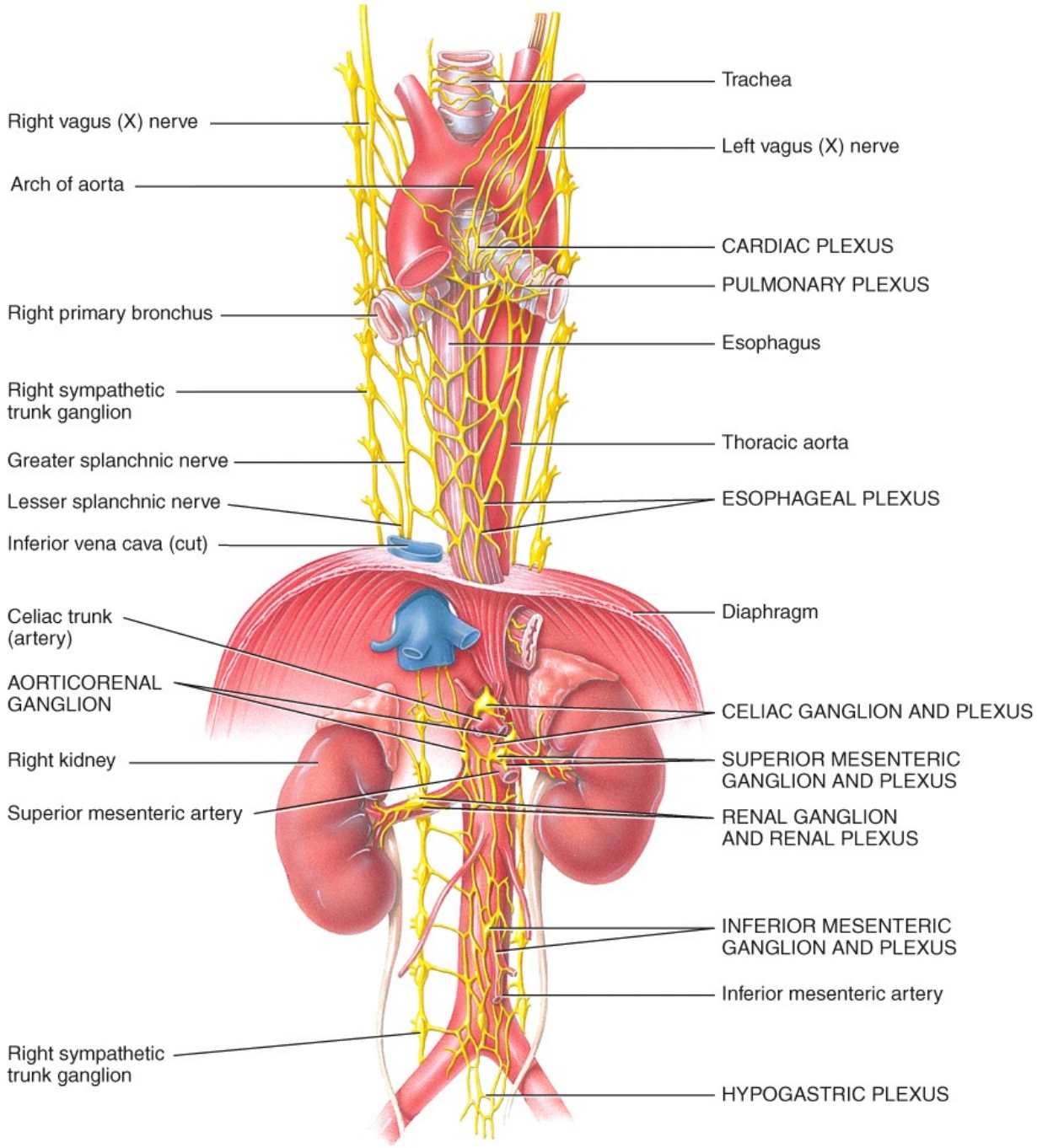
# Control of Autonomic Function (2 of 2)

- **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

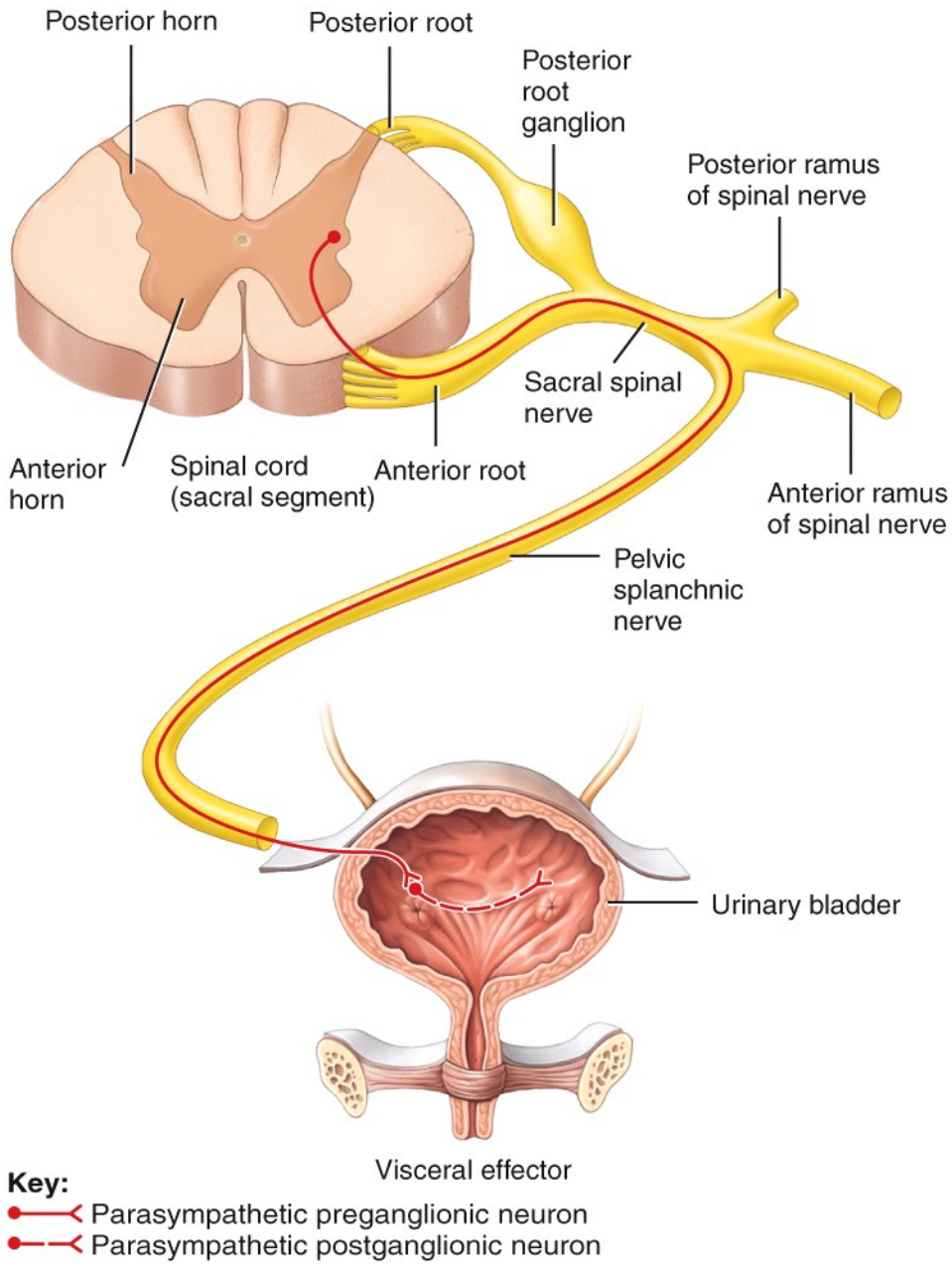
# Preganglionic Pathways

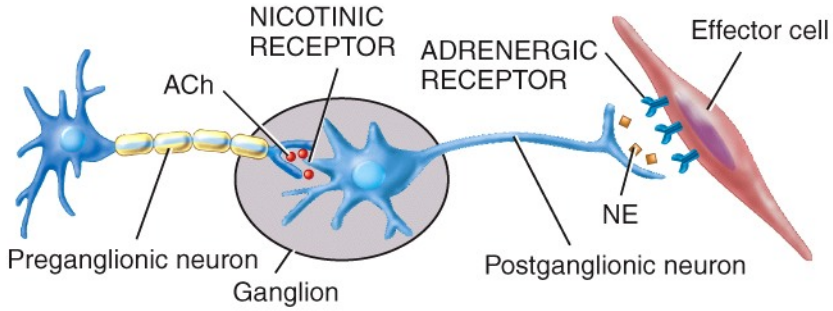




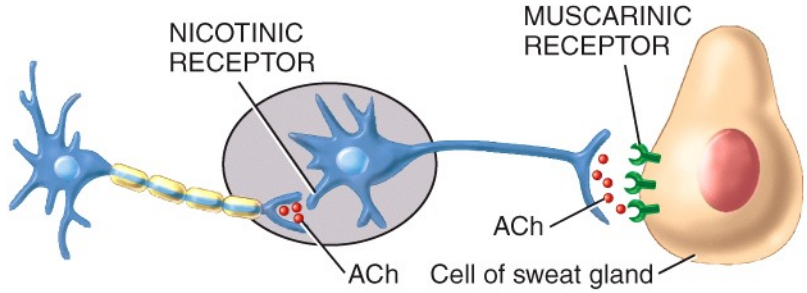



Anterior view

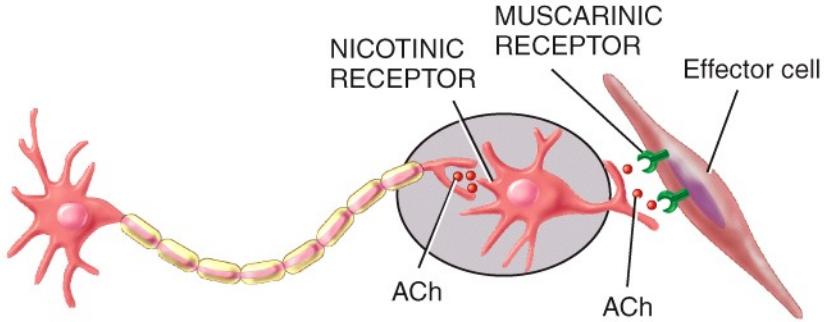

Posterior horn
Posterior root
Posterior root ganglion
Posterior ramus of spinal nerve
Sacral spinal nerve
Anterior horn
Spinal cord (sacral segment)
Anterior root
Anterior ramus of spinal nerve
Pelvic splanchnic nerve
Urinary bladder
Visceral effector
Key:
Parasympathetic preganglionic neuron
Parasympathetic postganglionic neuron



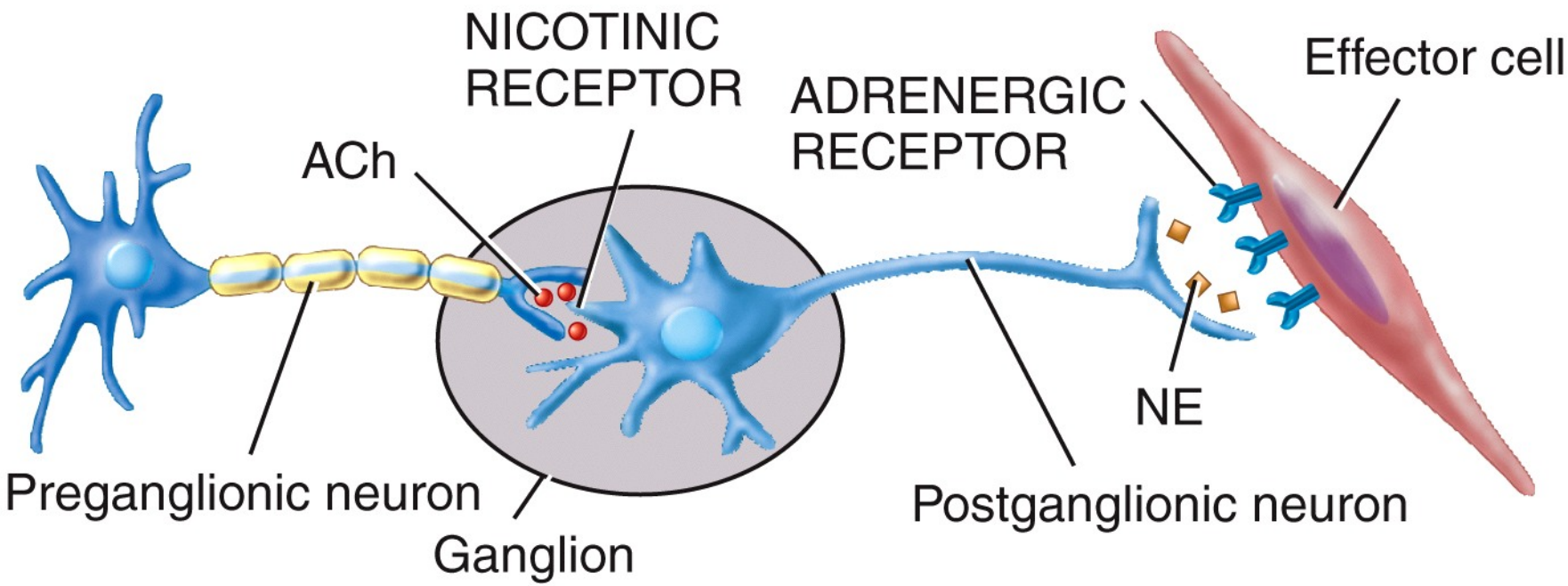

(a) Sympathetic division–innervation to most effector tissues



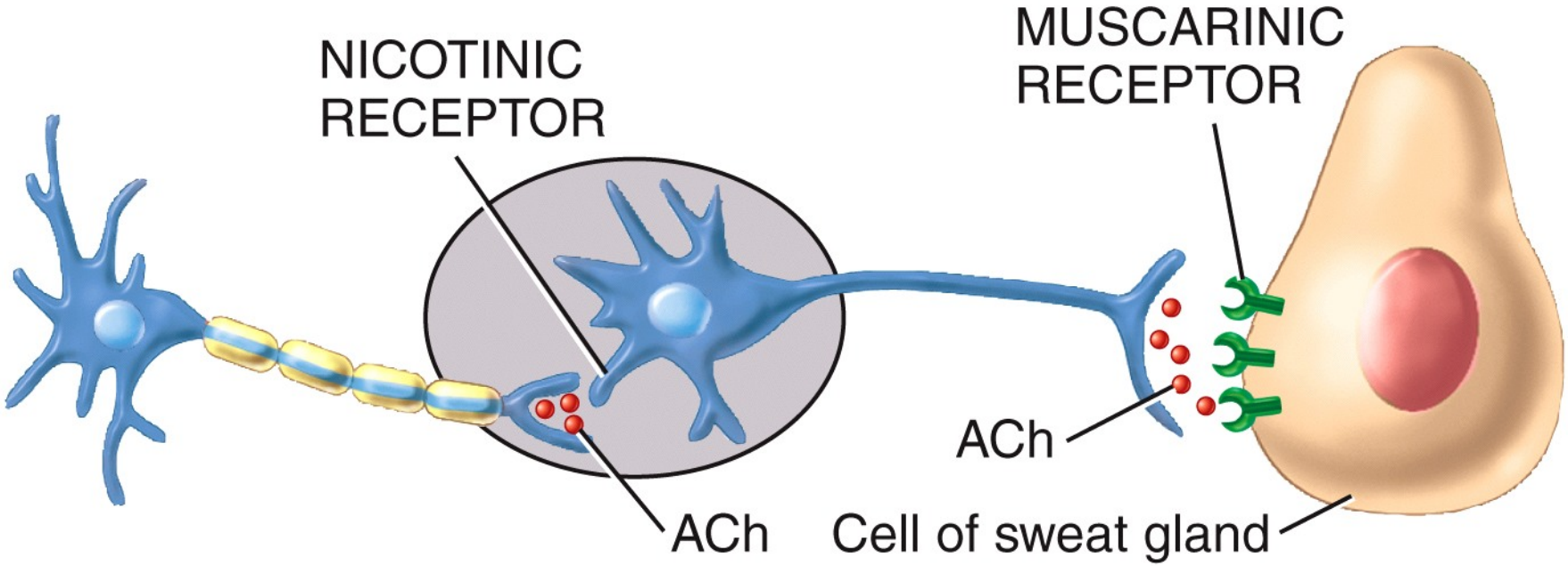

(b) Sympathetic division–innervation to most sweat glands



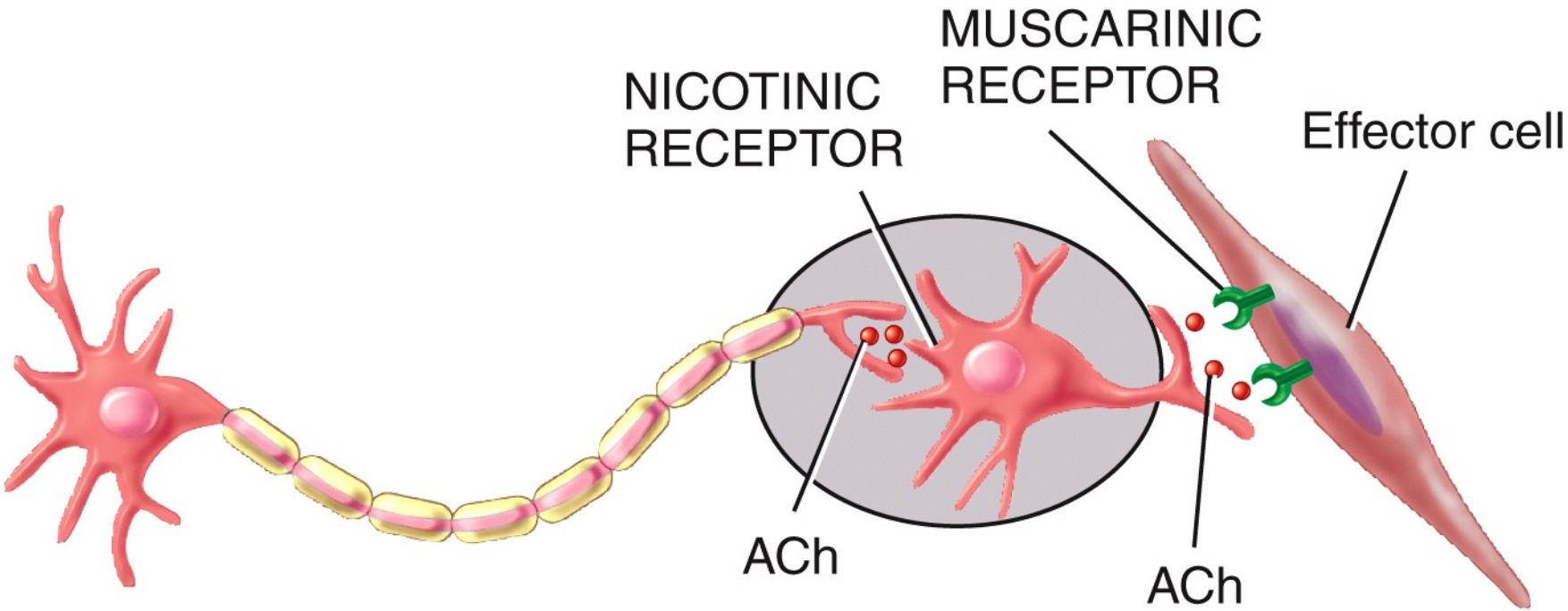

(c) Parasympathetic division




(a) Sympathetic division–innervation to most effector tissues

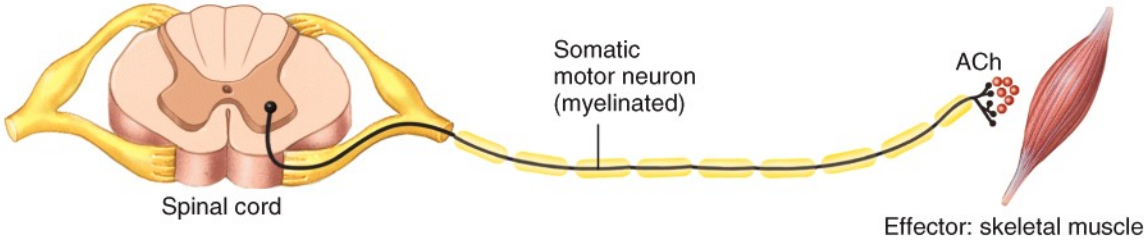



(b) Sympathetic division–innervation to most sweat glands

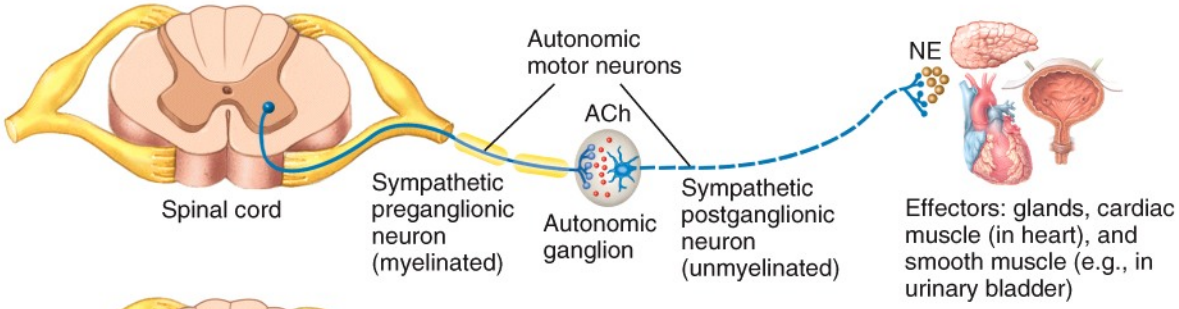


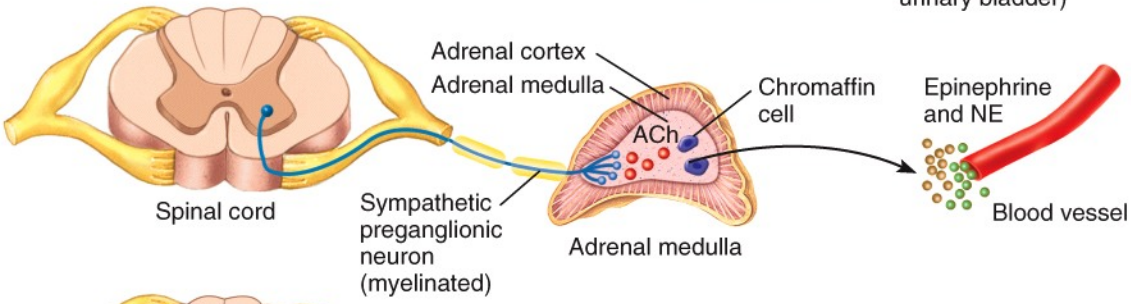

(c) Parasympathetic division

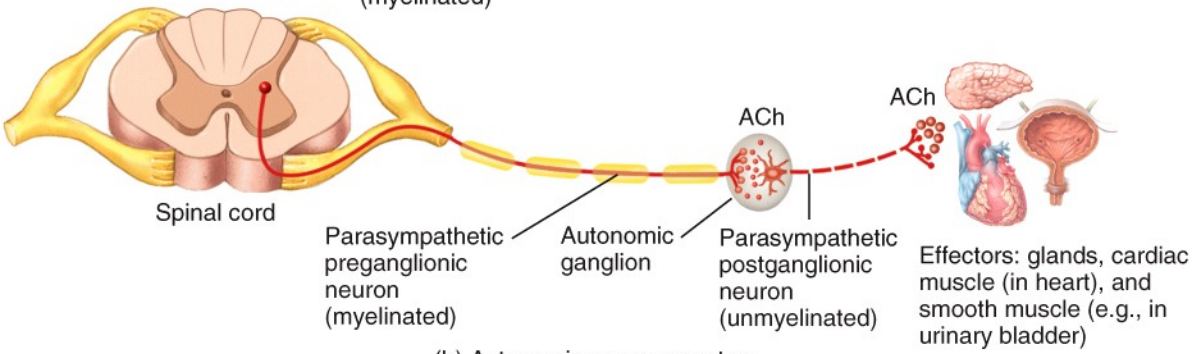
Blend Images/SuperStock



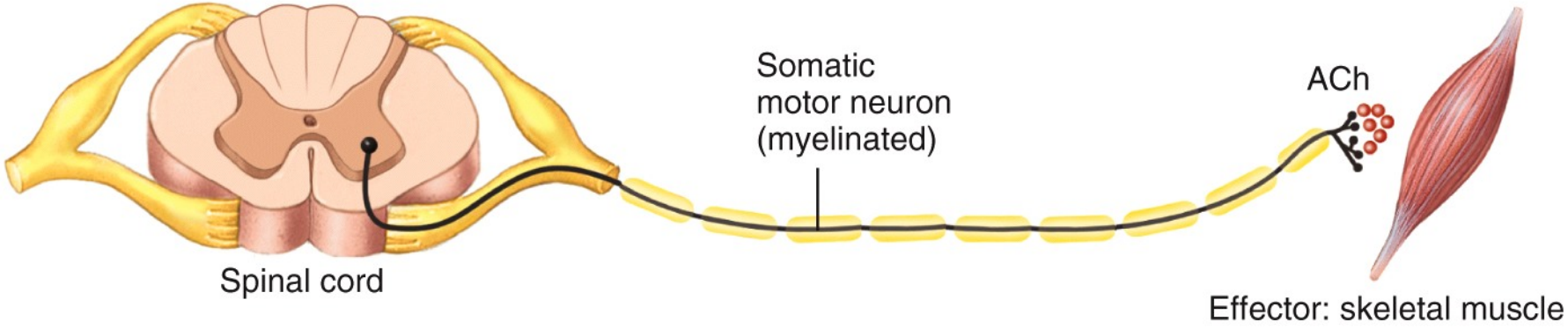

(a) Somatic nervous system



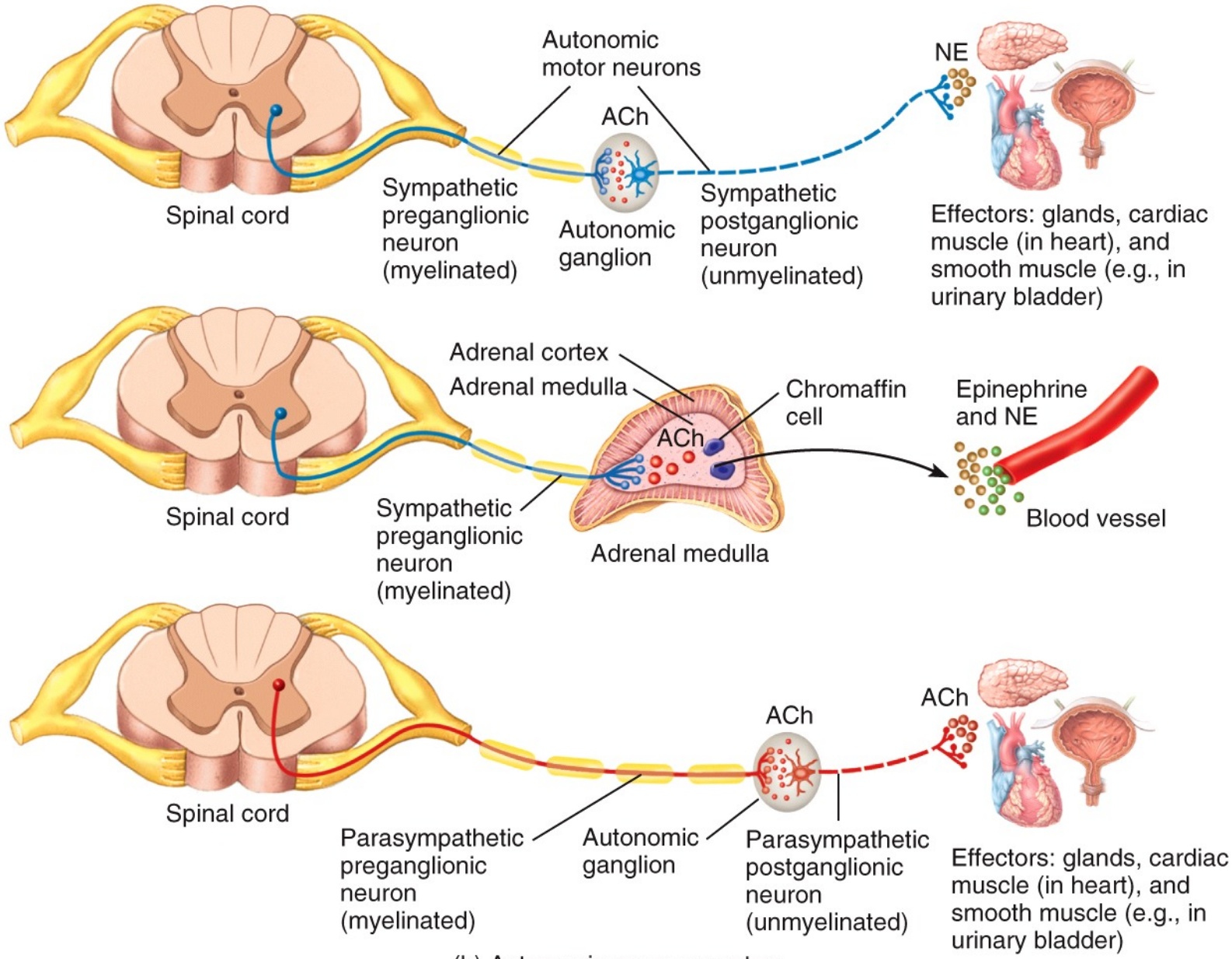



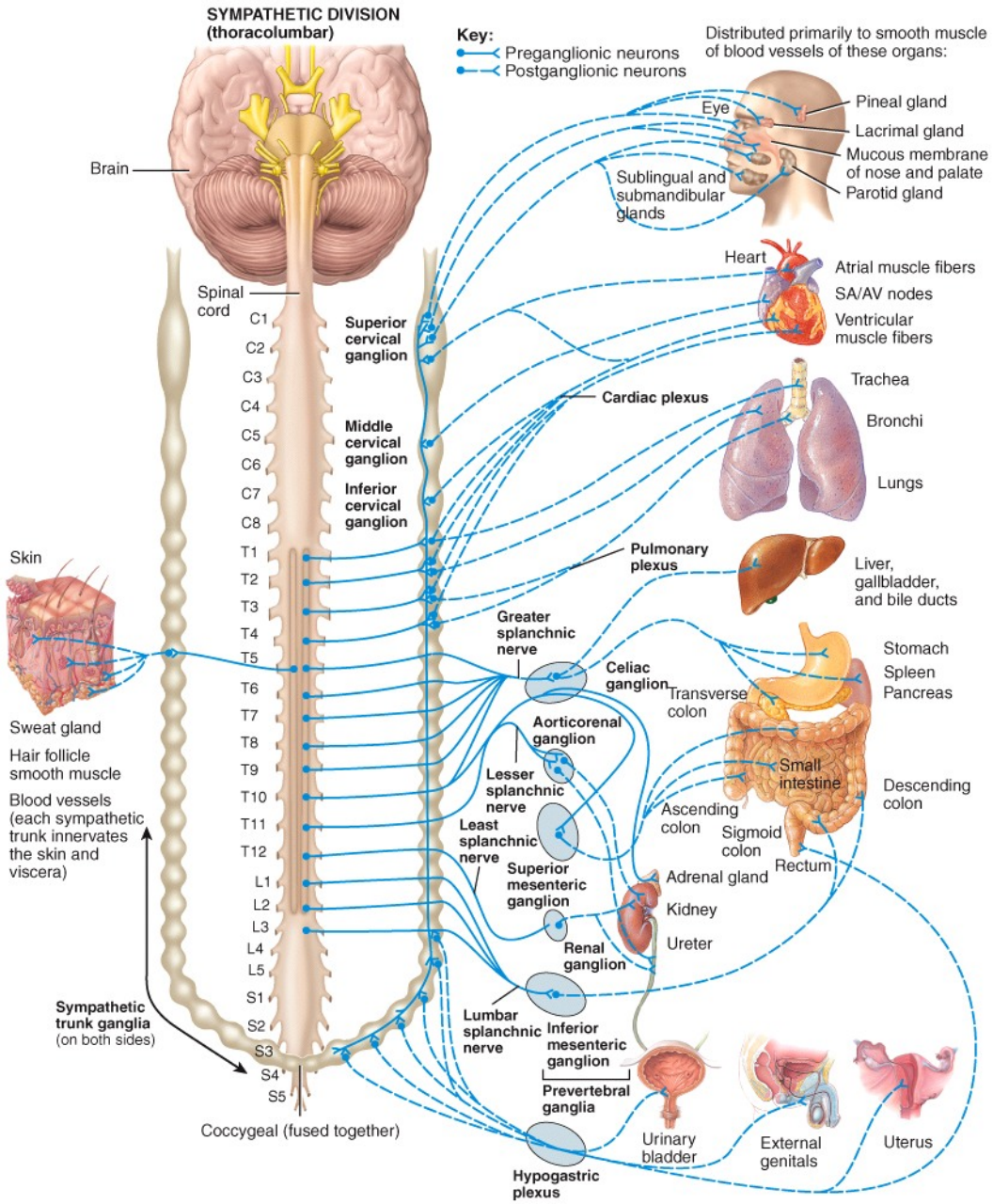

(b) Autonomic nervous system

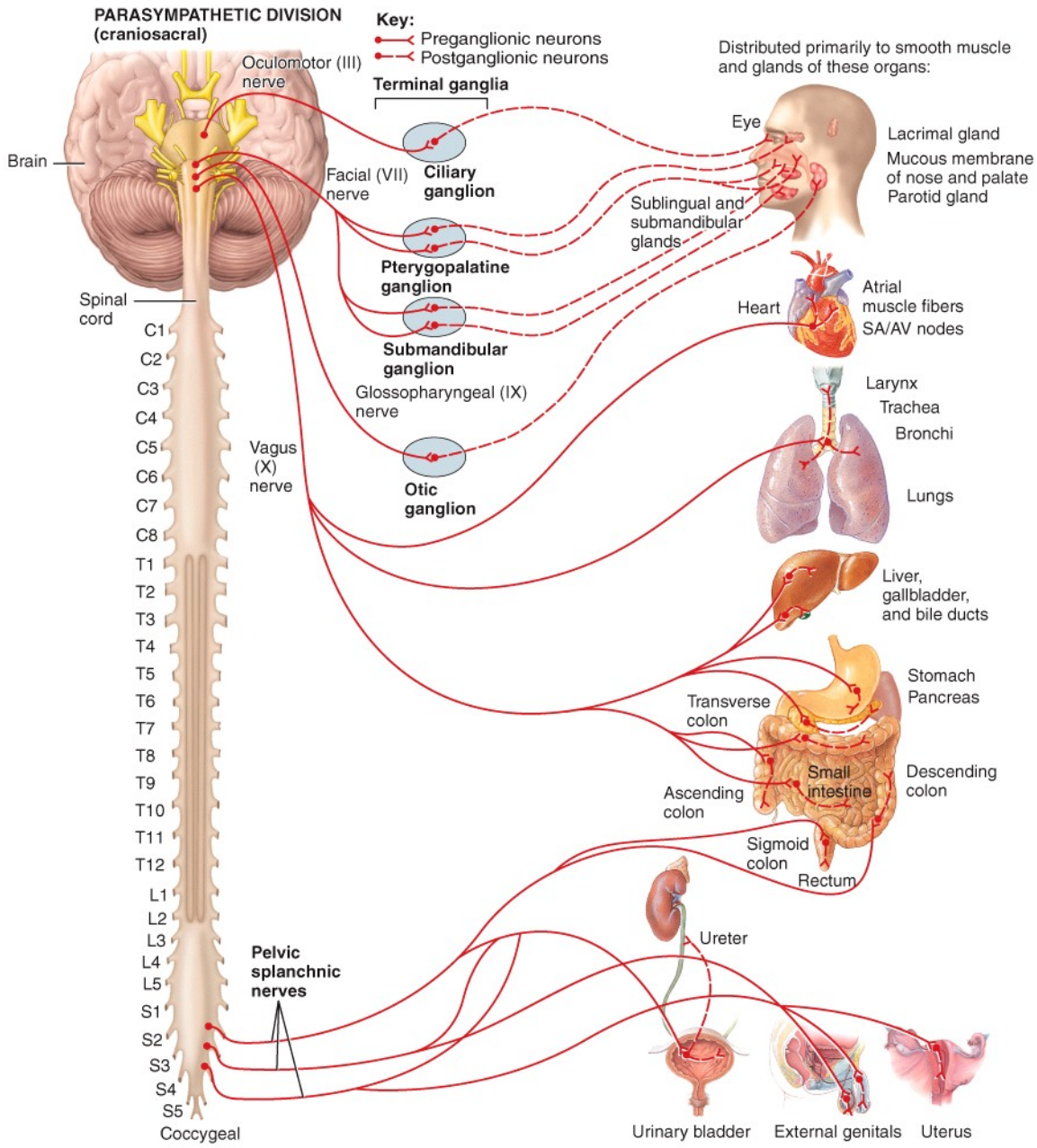


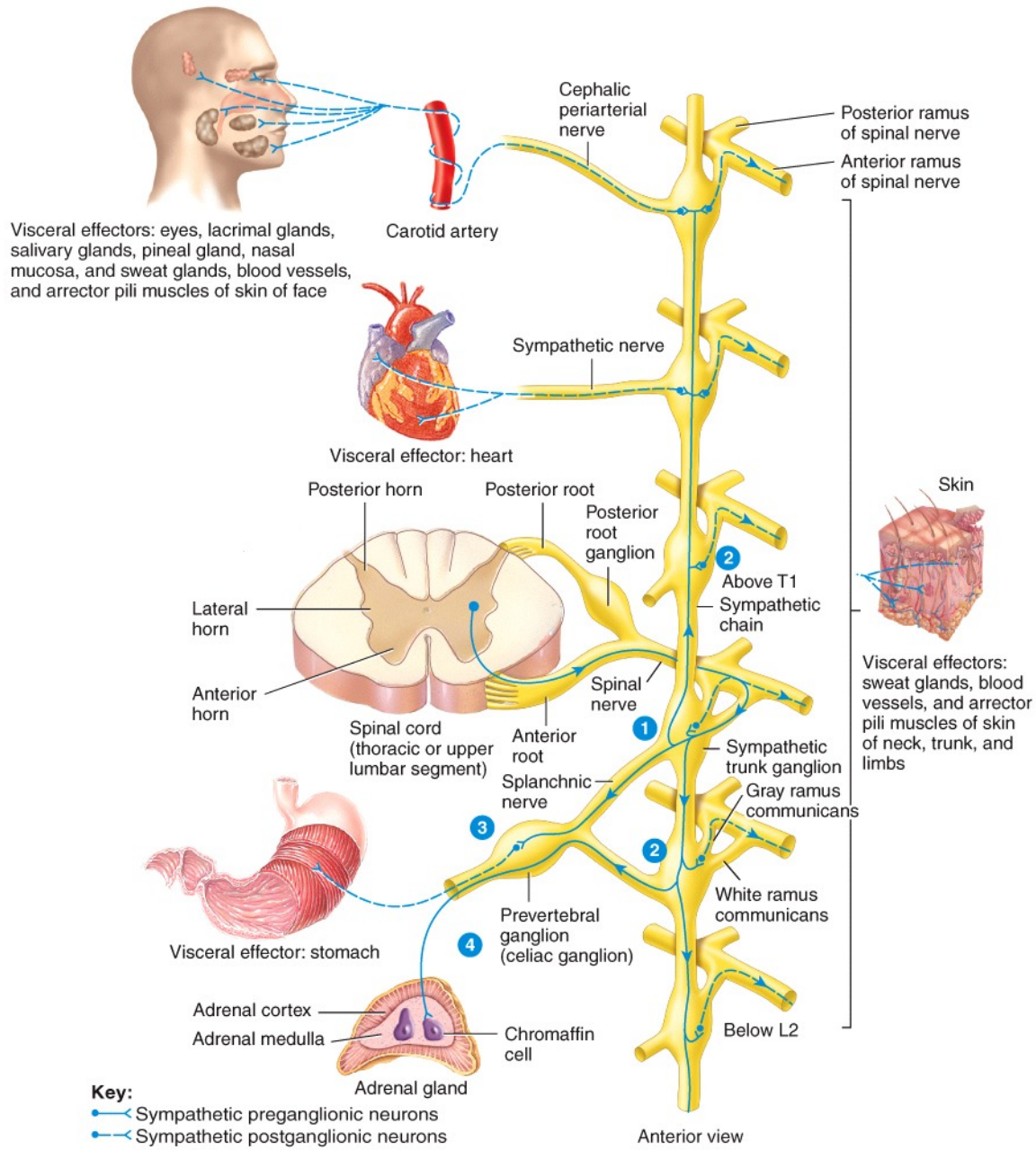

(a) Somatic nervous system




(b) Autonomic nervous system


SYMPATHETIC DIVISION
(thoracolumbar)
Key:
Preganglionic neurons
Postganglionic neurons
Distributed primarily to smooth muscle of blood vessels of these organs:
Brain
Spinal cord
C1
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
S1
S2
S3
S4
S5
Coccygeal (fused together)
Superior cervical ganglion
Middle cervical ganglion
Inferior cervical ganglion
Eye
Pineal gland
Lacrimal gland
Mucous membrane of nose and palate
Parotid gland
Sublingual and submandibular glands
Heart
Atrial muscle fibers
SA/AV nodes
Ventricular muscle fibers
Cardiac plexus
Trachea
Bronchi
Lungs
Pulmonary plexus
Liver, gallbladder, and bile ducts
Skin
Sweat gland
Hair follicle smooth muscle
Blood vessels (each sympathetic trunk innervates the skin and viscera)
Greater splanchnic nerve
Celiac ganglion
Stomach
Spleen
Pancreas
Transverse colon
Aorticorenal ganglion
Lesser splanchnic nerve
Least splanchnic nerve
Small intestine
Descending colon
Ascending colon
Sigmoid colon
Rectum
Superior mesenteric ganglion
Adrenal gland
Kidney
Ureter
Renal ganglion
Sympathetic trunk ganglia (on both sides)
Lumbar splanchnic nerve
Inferior mesenteric ganglion
Prevertebral ganglia
Urinary bladder
External genitals
Uterus
Hypogastric plexus


PARASYMPATHETIC DIVISION
(craniosacral)
Key:
Preganglionic neurons
Postganglionic neurons
Terminal ganglia
Distributed primarily to smooth muscle and glands of these organs:
Oculomotor (III) nerve
Brain
Facial (VII) nerve
Ciliary ganglion
Pterygopalatine ganglion
Submandibular ganglion
Glossopharyngeal (IX) nerve
Otic ganglion
Vagus (X) nerve
Spinal cord
C1
C2
C3
C4
C5
C6
C7
C8
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
L1
L2
L3
L4
L5
S1
S2
S3
S4
S5
Coccygeal
Pelvic splanchnic nerves
Eye
Lacrimal gland
Mucous membrane of nose and palate
Parotid gland
Sublingual and submandibular glands
Heart
Atrial muscle fibers
SA/AV nodes
Larynx
Trachea
Bronchi
Lungs
Liver, gallbladder, and bile ducts
Stomach
Pancreas
Transverse colon
Small intestine
Descending colon
Ascending colon
Sigmoid colon
Rectum
Ureter
Urinary bladder
External genitals
Uterus


Cephalic periarterial nerve
Posterior ramus of spinal nerve
Anterior ramus of spinal nerve
Visceral effectors: eyes, lacrimal glands, salivary glands, pineal gland, nasal mucosa, and sweat glands, blood vessels, and arrector pili muscles of skin of face
Carotid artery
Sympathetic nerve
Visceral effector: heart
Posterior horn
Posterior root
Posterior root ganglion
Skin
Above T1
Sympathetic chain
Lateral horn
Anterior horn
Spinal nerve
Spinal cord (thoracic or upper lumbar segment)
Anterior root
Sympathetic trunk ganglion
Visceral effectors: sweat glands, blood vessels, and arrector pili muscles of skin of neck, trunk, and limbs
Splanchnic nerve
Gray ramus communicans
White ramus communicans
Prevertebral ganglion (celiac ganglion)
Visceral effector: stomach
Adrenal cortex
Adrenal medulla
Chromaffin cell
Adrenal gland
Below L2
Key:
Sympathetic preganglionic neurons
Sympathetic postganglionic neurons
Anterior view