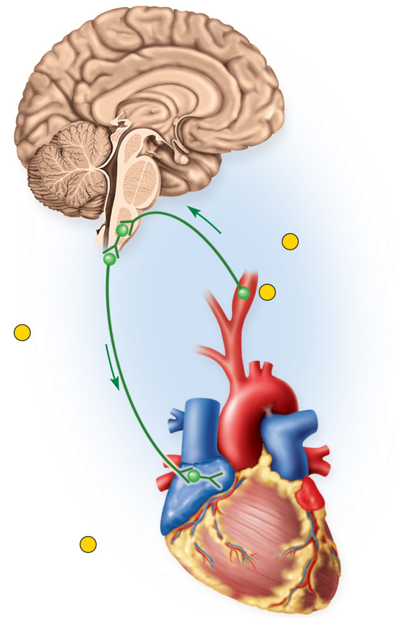
Chapter 15

# Structure and Function of the Autonomic Nervous System



# Autonomic Nervous System

- This is the nervous system that operates in comparative secrecy (it is not voluntary)
- ANS regulates homeostasis in response to a change in the "internal environment"
- Walter Cannon studied the ANS //  coined the expressions *homeostasis* and fright, *fight or flight response*
- Homeostasis can not be maintained without the ANS
- The endocrine system is the other system that regulates homeostasis
- The hypothalamus regulates both the endocrine and ANS
- An imbalance in homeostasis causes a disease state or death

# General Properties of ANS ★

- *ANS = motor nervous system* that controls glands, cardiac muscle, and smooth muscle
- Also called the visceral motor system
- Key Idea: ANS not responsible for the function of the organ but regulates the organ's degree of function (increase or decrease organ's function)
- Primary targets are organs // Viscera (organs) of thoracic and abdominal cavities
  - Also some structures in the body's cutaneous membrane
    - cutaneous blood vessels (i.e. thermoregulation)
    - sweat glands
    - piloerector muscles

# Properties of ANS

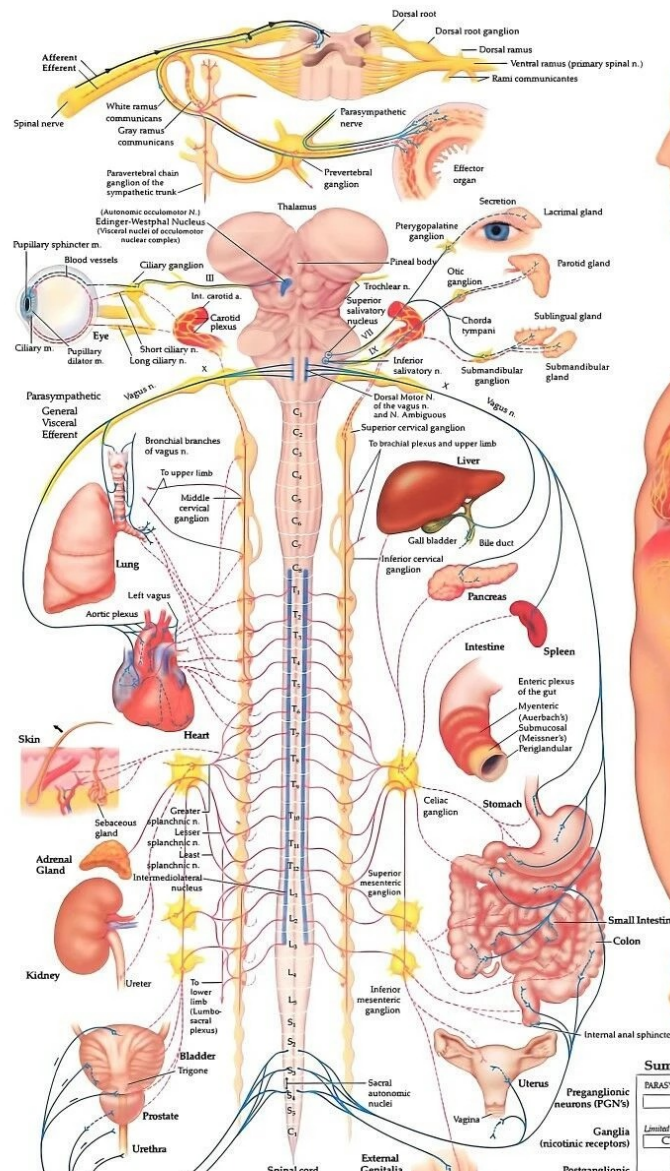
- ANS carries out actions involuntarily // without our conscious intent or awareness

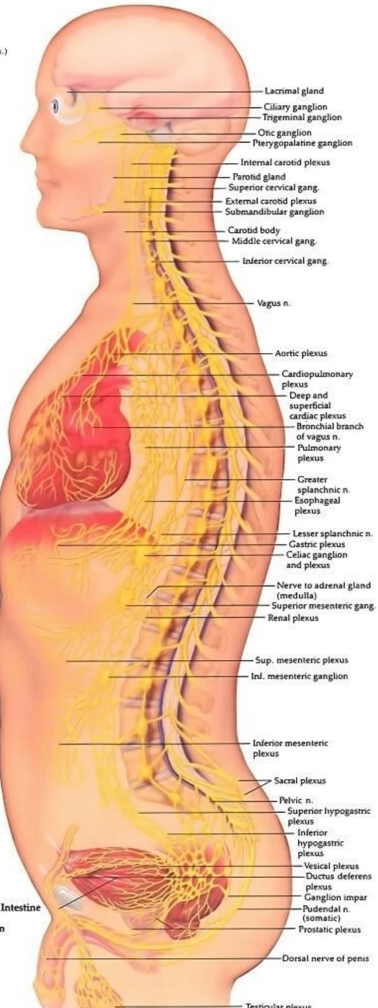
ANS is **used to adjust the organ's degree of function and not the function of the orgen**

To match organ's performance to the need of the organism // e.g. the heart has an internal pacemaker – but the ANS is used to increase or decrease heart rate in response to exercise or resting state

Example: Denervation hypersensitivity ***///*** exaggerated response of cardiac muscle and smooth muscle if ANS fibers are severed

# THE AUTONOMIC NERVOUS SYSTEM




—— Parasympathetic —— Preganglionic
—— Sympathetic - - - - Postganglionic


Art Direction by Christine D. Young and Medical Illustrations by Carl Clingman, in consultation with Kevin E. McKenna, Ph.D., Northwestern University Medical School. Chicago, Illinois

## Summary of Autonomic Nervous System Pharmacology

| | PARASYMPATHETIC | SYMPATHETIC | | |
|---|---|---|---|---|
| Preganglionic neurons (PGN's) | ALL CHOLINERGIC NEURONS | | | |
| | Ach* (Limited divergence) | Ach* | Ach* (Greater divergence) | Ach* |
| Ganglia (nicotinic receptors) | Cholinergic Neurons | Cholinergic Neurons | Noradrenergic Neurons | Adrenal Medulla |
| | Ach* | Ach* | Norepinephrine* | Epinephrine* via blood |
| Postganglionic neurons (PoGN's) | Muscarinic Receptors | Muscarinic Receptors | Alpha (α) & Beta (β) Adrenergic receptors | |
| Effector organ: | − Heart rate<br>− Heart contractility<br>+ G. I. smooth muscle<br>+ Bladder (micturition)<br>+ Exocrine glands | + Sweat glands<br>− Some blood vessels (dilatation) | + Heart rate (β)<br>+ Heart contractility (β)<br>+ Most blood vessels (α) (vasoconstriction)<br>− Airway smooth muscle | + Spleen<br>− G. I. tract (α)<br>+ Kidney (renin secretion) |

*Peptide co-transmitters

# Components of the Visceral Reflex Arc

stimulus – change in the internal environment

receptors – nerve endings that detect stretch, tissue damage, blood chemicals, body temperature, and other internal stimuli

afferent neurons – send stimulus to the CNS

inter-neurons – only in the CNS

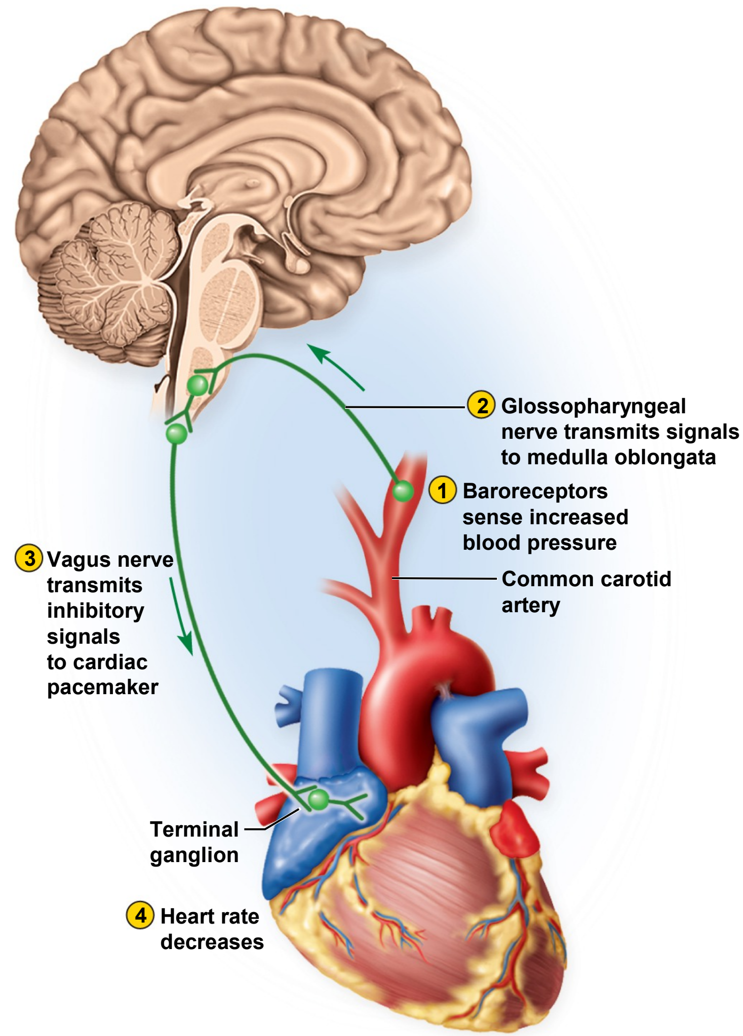
efferent neurons – carry motor signals away from the CNS to target tissue

the effectors – make adjustments in homeostasis by regulating these tissues /// cardiac, smooth muscle, or a gland

***ANS modify organ activity // the organs (i.e. the effectors) are not dependent upon ANS for their function!!!***

# Visceral Reflex In Response to High BP

- (1) high blood pressure detected by arterial stretch receptors
- (2) afferent neuron carries signal to CNS
  & interneurons process signals
- (3) efferent neurons carry signals to the heart
- (4) heart slows reducing blood pressure
- This is an example of a homeostatic negative feedback loop



# Divisions of ANS

- Two divisions
- Often both division innervate same target organs (i.e. called dual innervation) // in this case the ANS may have cooperative or antagonistic 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 /// rest and digest division
  - E.g. activated during digestion and waste elimination

# What is ANS tone?

- Autonomic tone – ANS is never "turned off" // occurs when both division send signals to same organ at the same time
  - *one division will dominate over the other division which then sets the "tone"*
  - parasympathetic tone // Example 1: maintains smooth muscle tone in intestines
    - Example 2: holds resting heart rate down to about 70 – 80 beats per minute // 100 beats per minute without any ANS influence
  - sympathetic tone /// example: keeps most blood vessels partially constricted /// this maintains peripheral resistance and blood pressure

# Opposite Effect on Different Organs At the Same Time

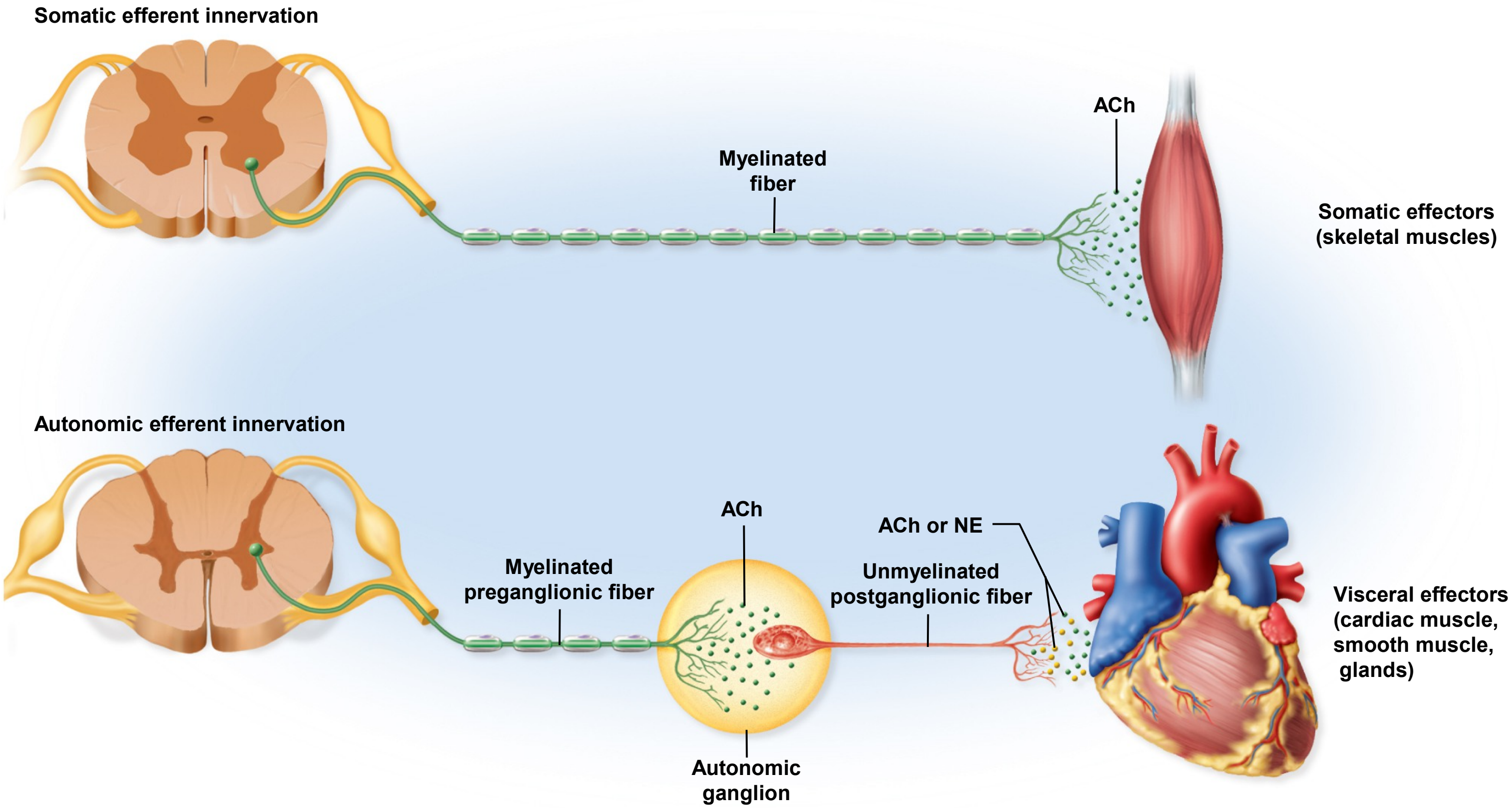
- Same ANS division may have an opposite effects on different organs.
  - **sympathetic division** excites the hearts but inhibits digestive system and urinary bladder activity
  - **parasympathetic** division inhibits the heart rate but excites the digestive and urinary bladder activity

# The ANS Neural Pathway

- ANS neural pathway uses **two neurons** to move AP between the spinal cord and the target organ
- Must cross a synapse /// this is the autonomic ganglia and acetylcholine is the neurotransmitter
- **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 in the PNS (i.e. nuclei are a collection of soma in the CNS)*

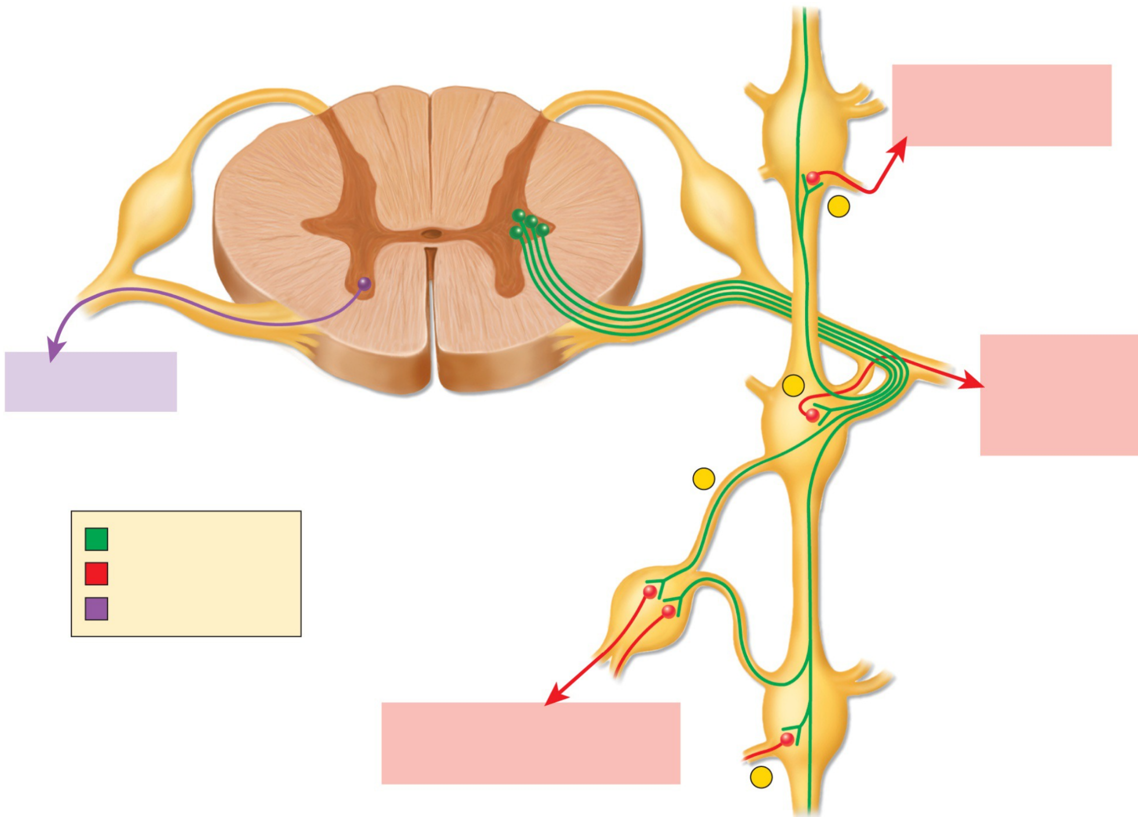
# What is the Difference Between Somatic and Autonomic Nervous System Pathways?




ANS – two neurons from CNS to effectors

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

# Sympathetic Nervous  System



# ANS 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 axons of the ANS reach effecter tissue by traveling in same route with the cranial or spinal nerve pathways
- Note: In a somatic motor pathway /// an upper and lower motor neuron is required to reach a skeletal muscle /// the lower motor neuron is a single myelinated axons from anterior horn to the skeletal muscle *(contrast to ANS pathway)*

# The Sympathetic Nervous System

- Called the thoracolumbar division because it arises from the thoracic and lumbar regions of the spinal cord
- Because preganglionic neurosomas are in lateral horns within the thoracic and lumbar regions of the vertebral column
- Also have nearby regions of gray matter adjacent to thoracic and lumbar regions of the vertebral column
- SNS characterized by having short preganglionic and long postganglionic fibers

# Sympathetic Nervous System

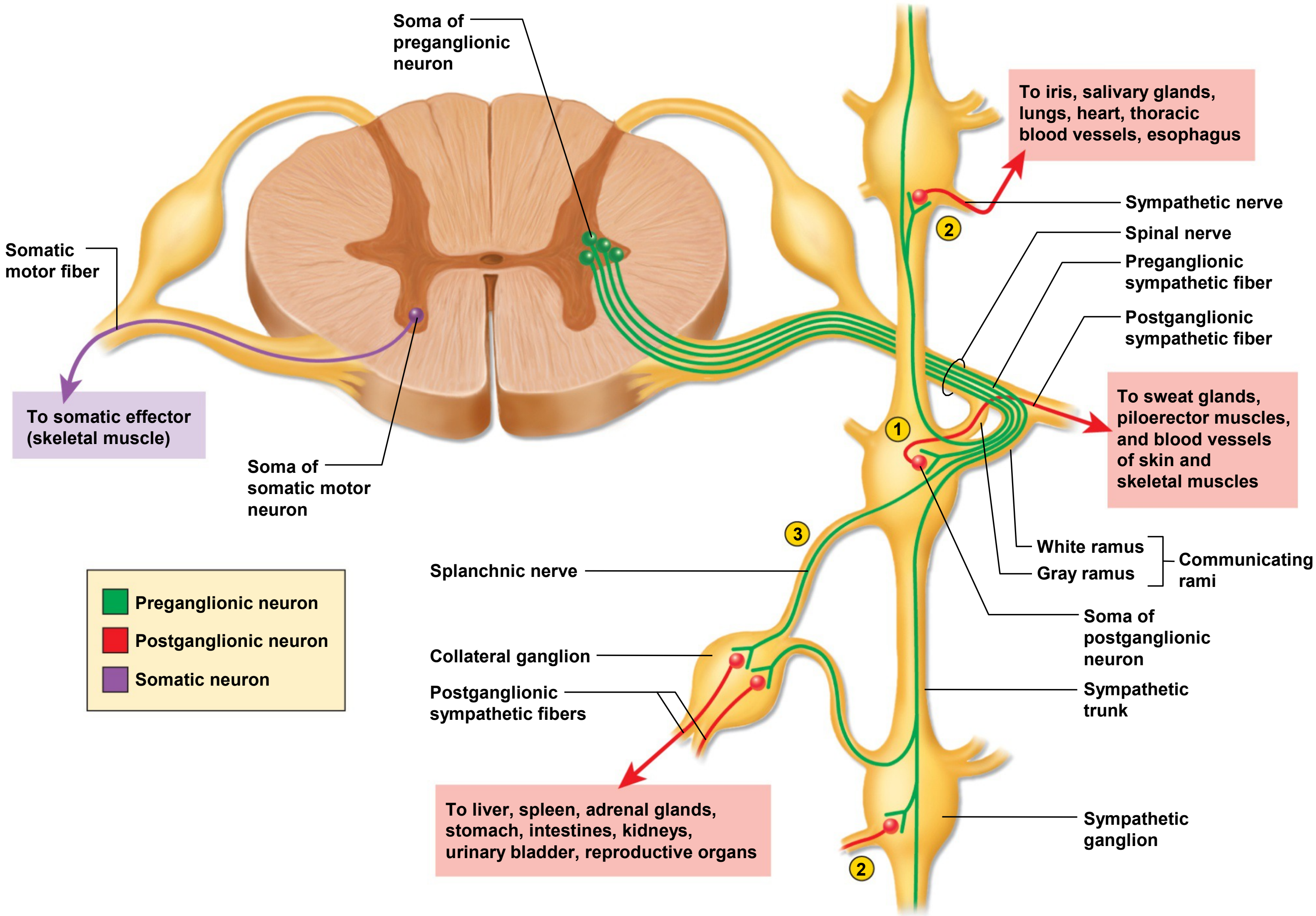
- These fibers exit spinal cord through spinal nerves T1 to L2
- Transit to nearby sympathetic chain of ganglia (also called the para-vertebral ganglia)
  - series of longitudinal ganglia adjacent to both sides of the vertebral column from cervical to coccygeal levels
  - usually 3 cervical, 11 thoracic, 4 lumbar, 4 sacral, and 1 coccygeal ganglion
  - sympathetic nerve fibers are distributed to every level of the body
  - sympathetic fibers move along multiple pathways

# Sympathetic Nervous System

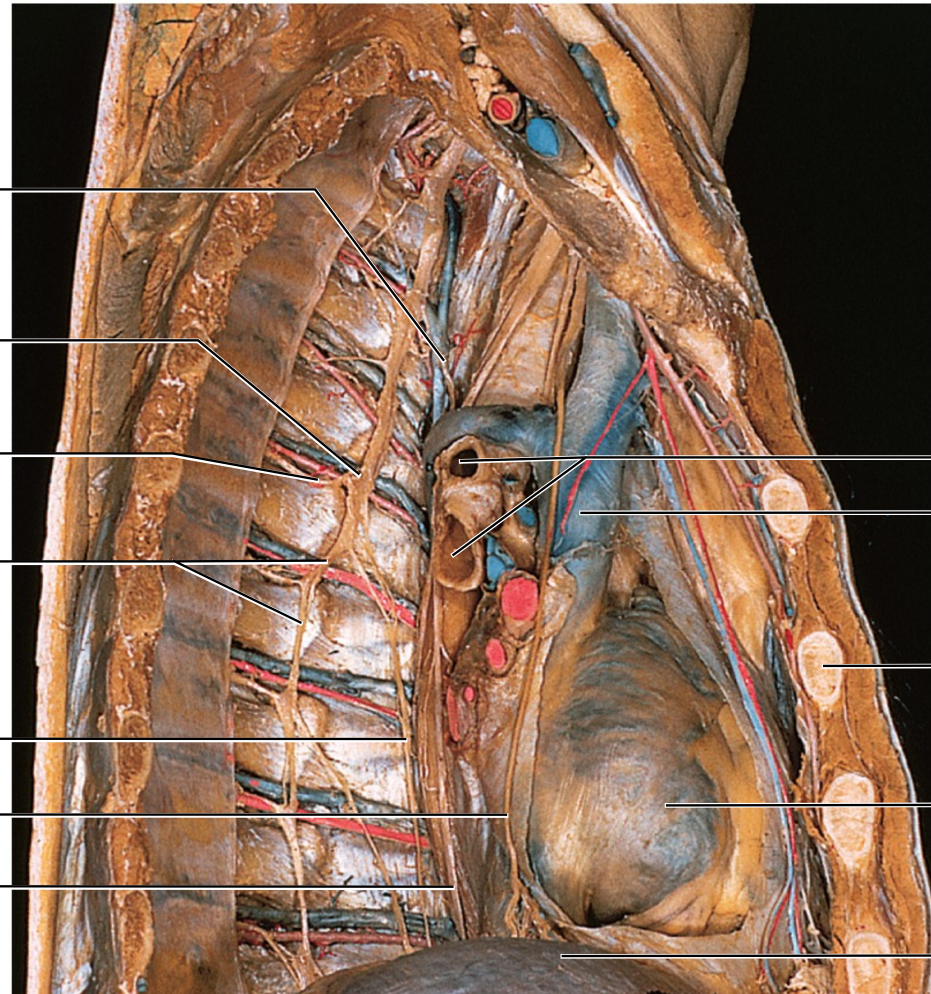
- each paravertebral ganglion is connected to a spinal nerve by two branches – communicating rami
- preganglionic fibers are <u>small</u> myelinated fibers that travel form spinal nerve to the ganglion by way of the <u>white communicating ramus (myelinated)</u>
- postganglionic fibers leave the ganglion by way of the <u>gray communicating ramus</u> (unmyelinated) /// forms a bridge back to the spinal nerve
  - <u>*postganglionic fibers extend the rest of the way to the target organ*</u>

# Preganglionic Pathways





# Sympathetic Chain Ganglia

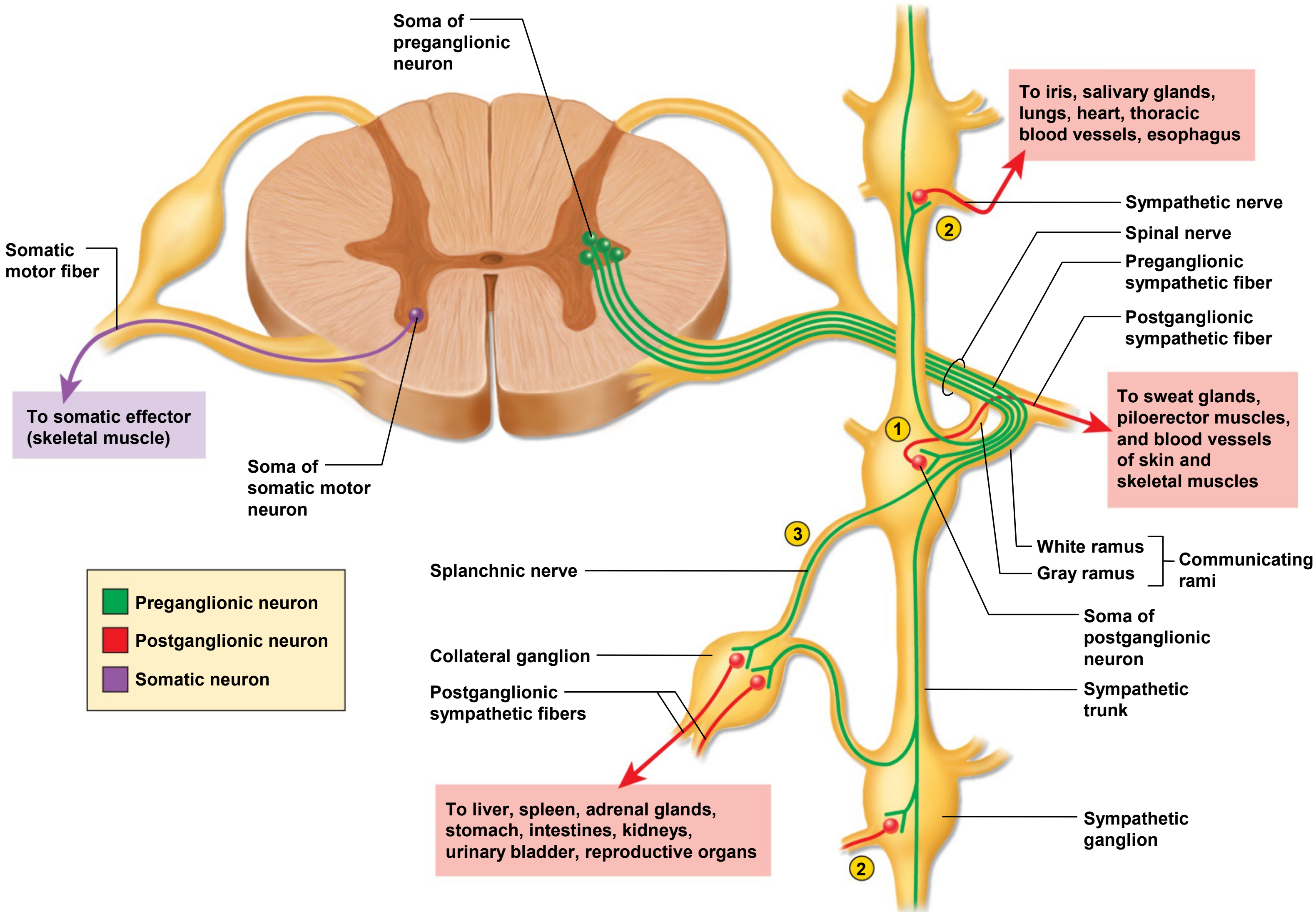


# Sympathetic Nervous System

- After entering the sympathetic chain /// the postganglionic fibers may follow any of three possible courses
  - #1 = some end in ganglia which they enter and synapse immediately with a postganglionic neuron
  - #2 = 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
  - #3 - Some pass through the sympathetic chain gaglia without a synapse 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

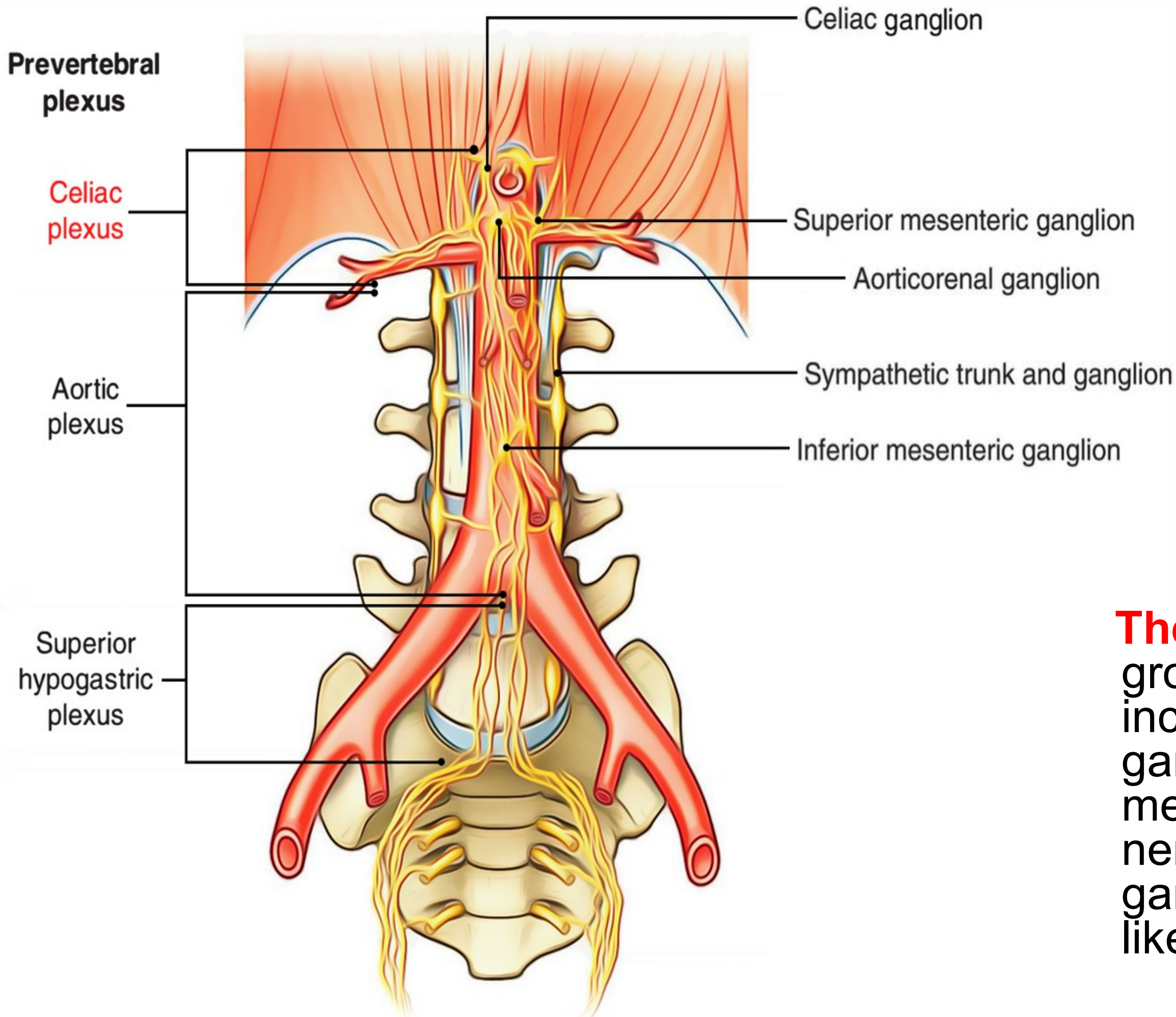
# Sympathetic Nervous System

- **splanchnic nerve route**
  - some fibers that arise from spinal nerves T5 to T12 pass through the sympathetic ganglia without a synapse
    - continue on as the splanchnic nerves
    - splanchnic nerve go to different set of ganglia – *collateral ganglia* where these preganglionic fibers then synapse

# 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 (lab objectives)
    - celiac
    - superior mesenteric
    - Inferior mesenteric
  - These nerves of postganglionic fibers follow similar named arteries to their target organs

# Plexus of Sympathetic Nervous System ★




**The solar plexus =** group of ganglia that includes the celiac ganglia and superior mesenteric ganglia // nerves from these ganglia radiate away like rays of the sun

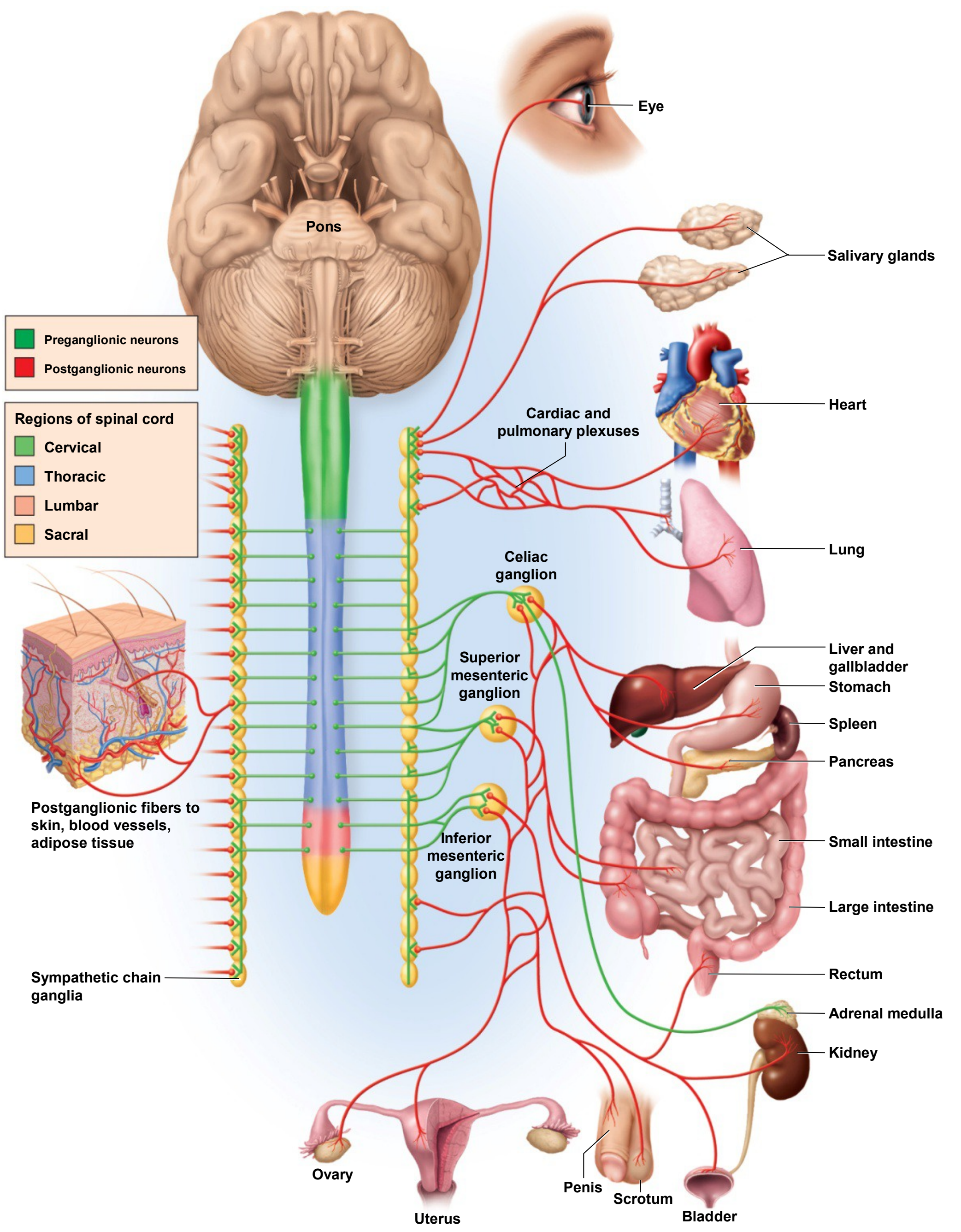
# What is Neuronal Divergence?

Neuronal divergence predominates in SNS

- 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

# SNS Efferent Pathways





## Summary of Sympathetic Innervation

- effectors in body walls 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

# Why is the Adrenal Gland Referred to as a Post-Ganlionic SNS Fiber?

- Paired adrenal (suprarenal) glands on superior poles of each kidney

- Adrenal gland is actually two separate glands with different functions

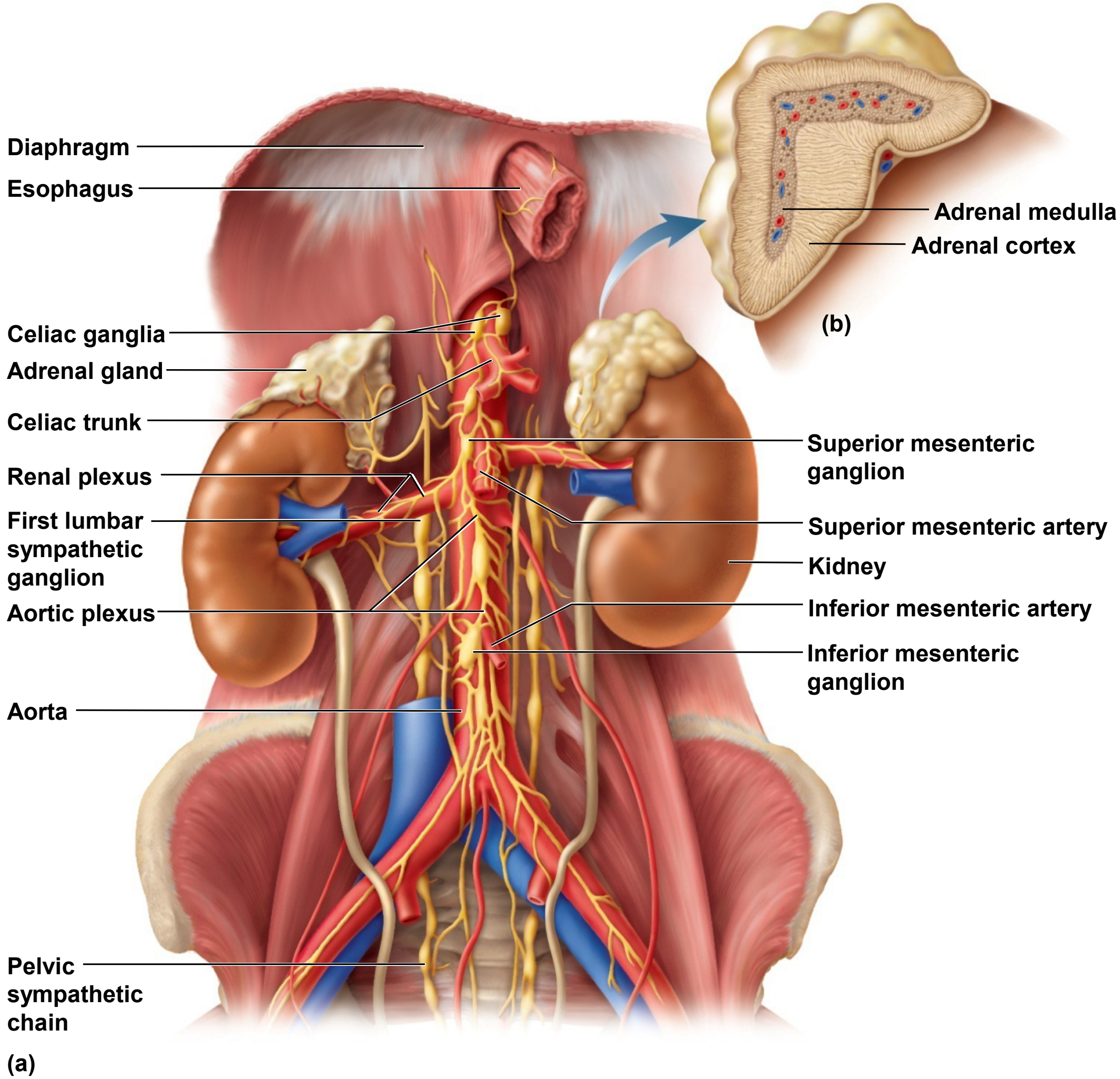
  - adrenal cortex (outer layer) // secretes steroid hormones (i.e. glucocorticoids, mineralcorticoids, estrogens, androgens)

  - adrenal medulla (inner core) // *essentially a sympathetic ganglion* --- *secretes epinephrine and norepinephrine into the blood*

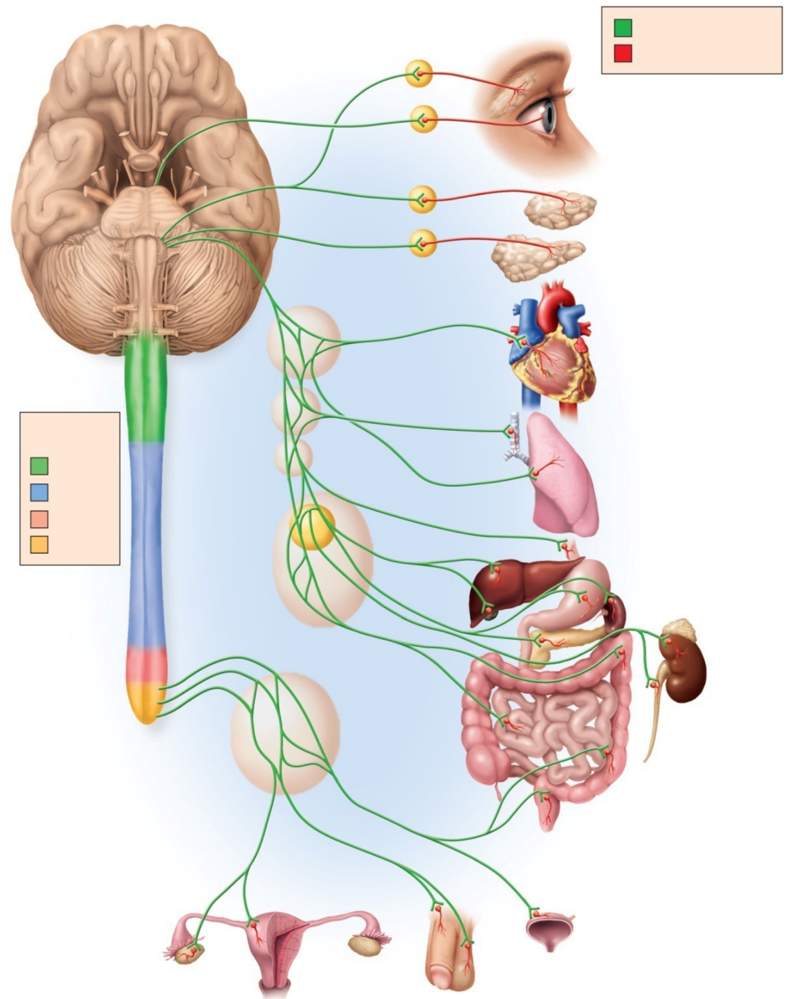
# Adrenal Glands

- 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 // some dopamine
- Sympathoadrenal system = the closely related functioning adrenal medulla and sympathetic nervous system

# Ganglia and Abdominal Aortic Plexus



# The Parasympathetic Nervous System



# Parasympathetic Division

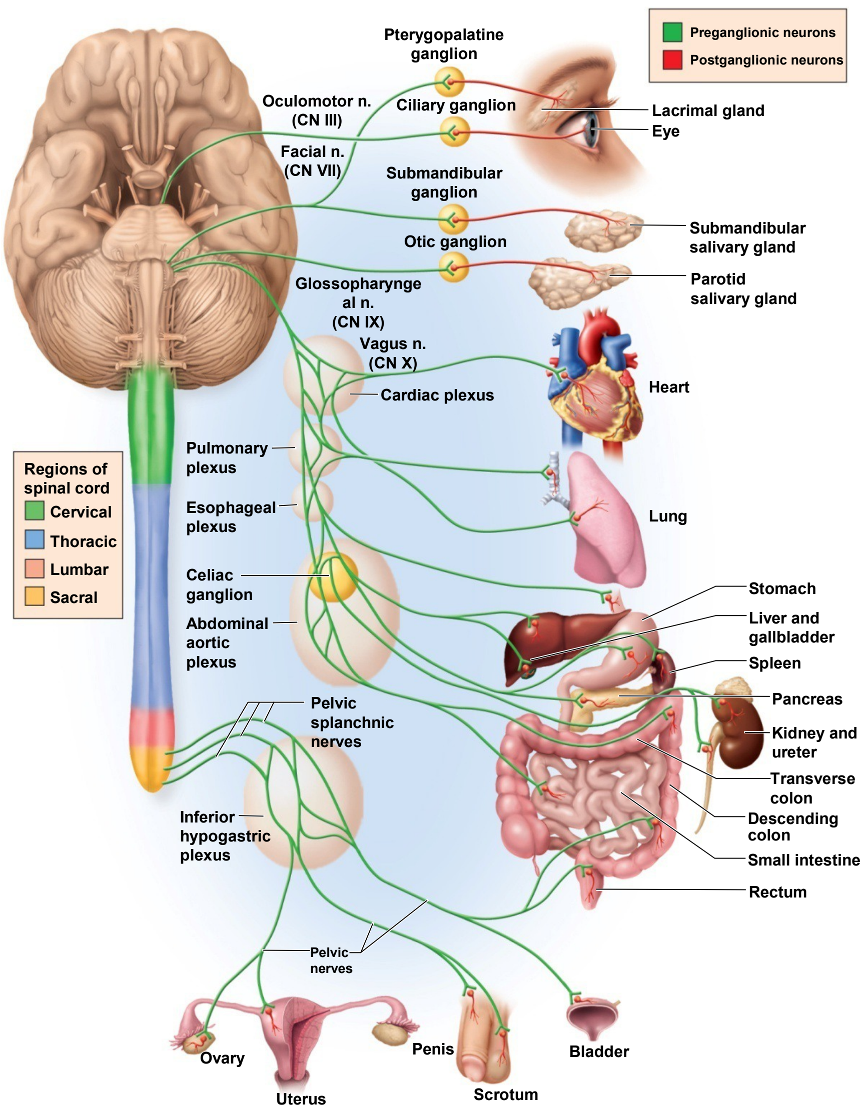
- **Parasympathetic division** is also called the **craniosacral division**
  - arises from the brain and sacral regions of the spinal cord
  - fibers travel in certain cranial and sacral nerves
- Origin of long preganglionic neurons
  - midbrain, pons, and medulla
  - sacral spinal cord segments S2-S4

# 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



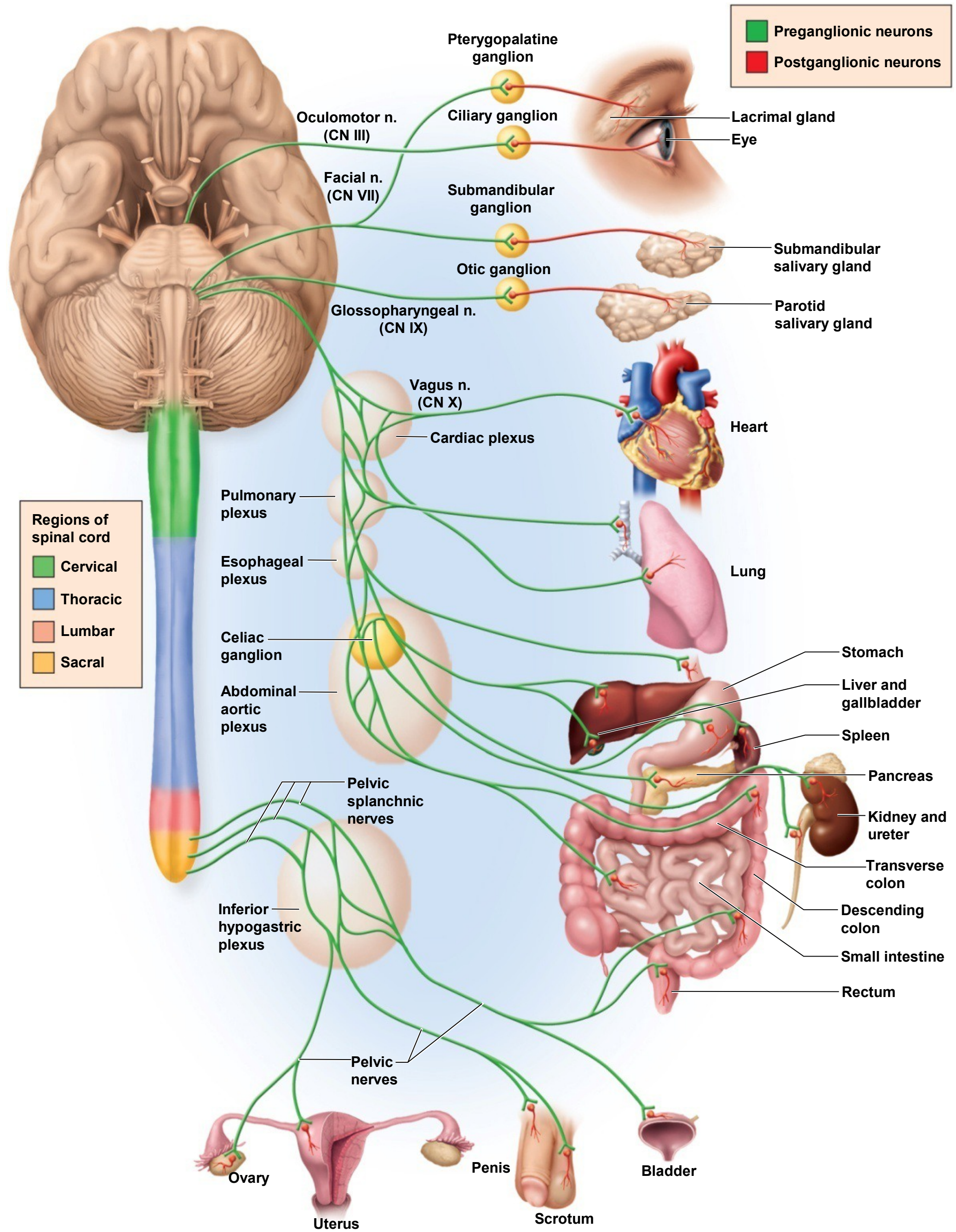


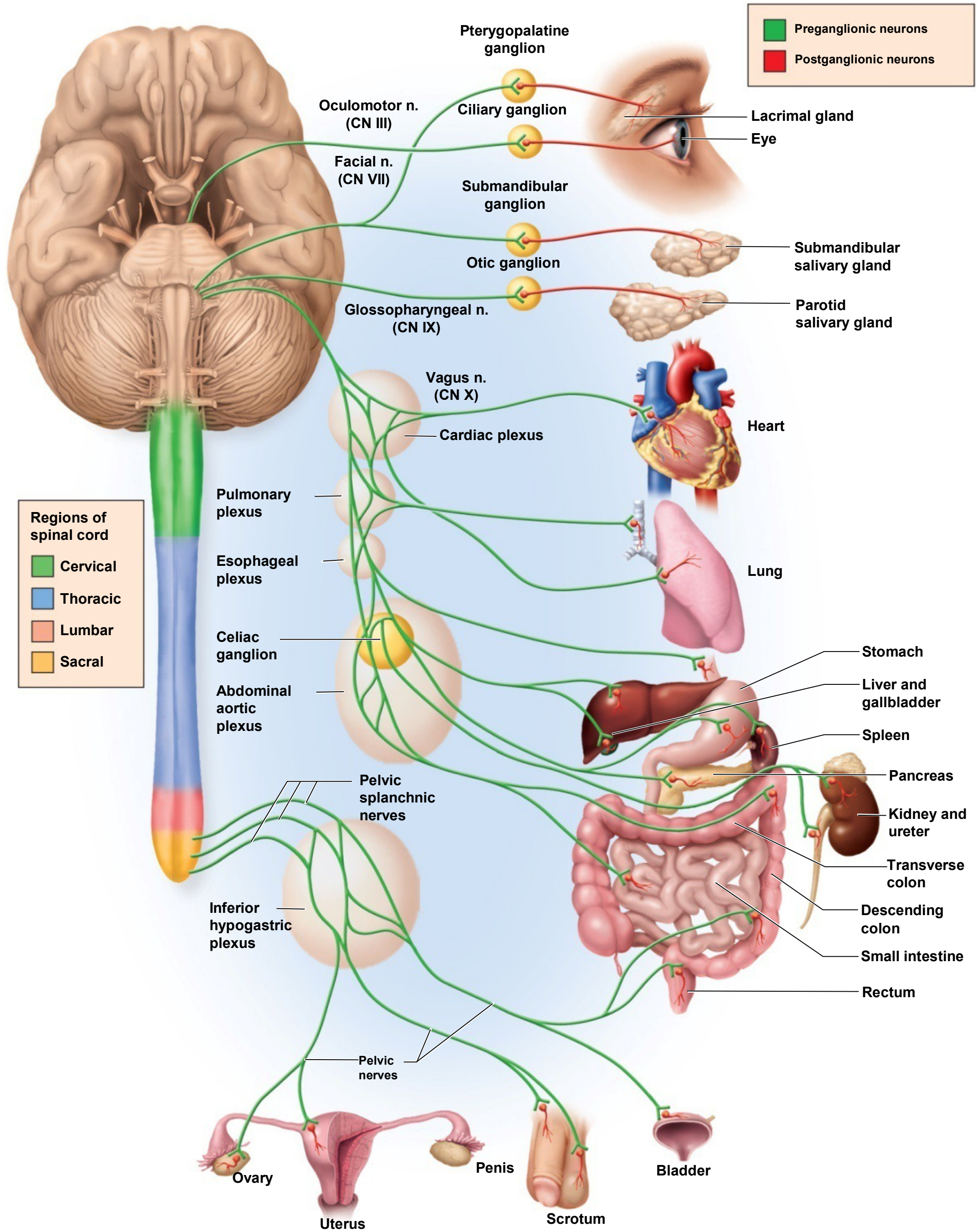

- **Oculomotor nerve (III)**
  - narrows pupil and focuses lens
- **Facial nerve (VII)**
  - tear, nasal and salivary glands
- **Glossopharyngeal nerve (IX)**
  - parotid salivary gland
- **Vagus nerve (X)**
  - viscera as far as proximal half of colon
  - cardiac, pulmonary, and esophageal plexus

# 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






Preganglionic neurons
Postganglionic neurons
Pterygopalatine ganglion
Oculomotor n. (CN III)
Ciliary ganglion
Lacrimal gland
Eye
Facial n. (CN VII)
Submandibular ganglion
Submandibular salivary gland
Otic ganglion
Glossopharyngeal n. (CN IX)
Parotid salivary gland
Vagus n. (CN X)
Heart
Cardiac plexus
Pulmonary plexus
Regions of spinal cord
Cervical
Thoracic
Lumbar
Sacral
Esophageal plexus
Lung
Celiac ganglion
Stomach
Liver and gallbladder
Abdominal aortic plexus
Spleen
Pancreas
Pelvic splanchnic nerves
Kidney and ureter
Transverse colon
Descending colon
Inferior hypogastric plexus
Small intestine
Rectum
Pelvic nerves
Ovary
Penis
Bladder
Uterus
Scrotum

# Neurotransmitters and Receptors of the ANS

- How can one division of the ANS create opposite outcomes (stimulate VS inhibit) in different tissues?

- Example: The SNS will increase activity in the heart but at the same time the SNS will inhibit or slow down activity in the GI tract?

This is possible because target tissues have different types of receptors for the same neurotransmitter

*Therefore – it is the receptor that determines the outcome and not necessarily the neurotransmitter!*

E.g. - Histamine will cause systemic blood vessels to dilate and respiratory bronchioles to constrict

# Where is Acetylcholine (Ach) Used in the ANS?

- ACh is secreted by all preganglionic neurons for both divisions of the ANS (ionotropic)
- Ach is secreted by the postganglionic parasympathetic neurons (may use either an ionotropic or metabotropic type receptor)
- Any fiber that secretes Ach is called a cholinergic fibers
- Any receptor that binds Ach is called a cholinergic receptor

# Two Acetylcholine (Ach) Receptors

## #1 = Nicotinic receptors

ionotropic receptor // sodium ion channel – ligand mode of action

always stimulates (e.g. neuromuscular junction)

receptor at all ANS ganglia /// these are on postganglionic neuron's soma

also at medulla of the adrenal gland

also at neuromuscular junctions

- **#2 = Muscarinic receptors**
  - possible receptor associated with neurotransmitter secreted by post ganglionic cholinergic fibers
  - this uses the metabotropic receptor (i.e. second messenger) mode of action / not an ion channel (note: metabotropic – always require two or more transmembrane proteins
  - cardiac muscle
  - smooth muscle
  - glands
  - <u>Note: affect can be either excitatory or inhibitory due to sub-classes of muscarinic receptors</u>

# There Are Two Type of Adrenergic Receptors

- Most sympathetic postganglionic neurons release norepinephrine
  - these are called adrenergic fibers // secrete NE
  - receptors called adrenergic receptors
  - *Note: there are some post ganglionic sympathetic fibers that secrete acetlycholine // these use muscarinic receptors! // cutaneous membrane structures = piloerector muscles, sweat glands, blood vessels*

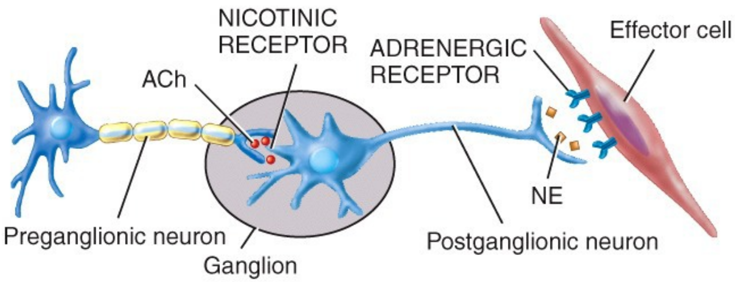
# Two Type of Adrenergic Receptors

– Two types of NE receptors (cAMP as a second messenger)

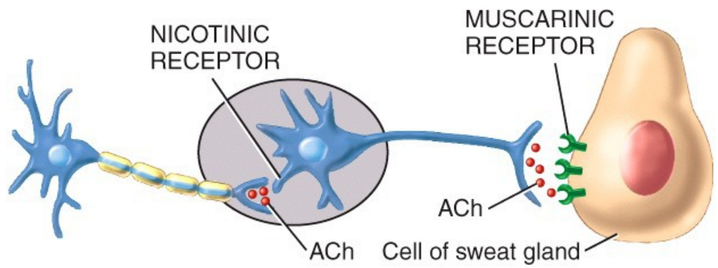
  - alpha-adrenergic receptors /// usually excitatory // 2 subclasses use different second messengers ($\alpha_1$ & $\alpha_2$)

  - beta-adrenergic receptors /// usually inhibitory // 2 subclasses with different effect

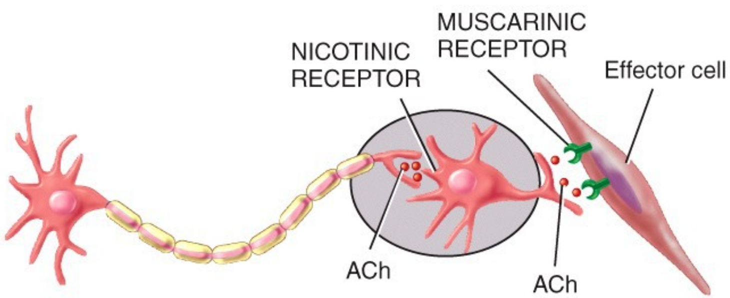
# Neurotransmitters and Receptors




(a) Sympathetic division–innervation to most effector tissues




(b) Sympathetic division–innervation to most sweat glands




(c) Parasympathetic division

Muscarinic receptors are metabotropic (i.e. second messenger) – outcome variable

NE has different classes of adrenergic receptors (e.g. alpha & beta) // outcome dependent on receptor type // with sub-classes

Nicotinic receptors are sodium ion channels that are always stimulatory (i.e. depolarize membrane

Merocrine sweat gland (thermoregulation) // cholenergic w metabotropic receptors

# Organization of the Autonomic Nervous System (ANS)

***Neurons are named according to the neurotransmitter they <u>RELEASE</u>.***

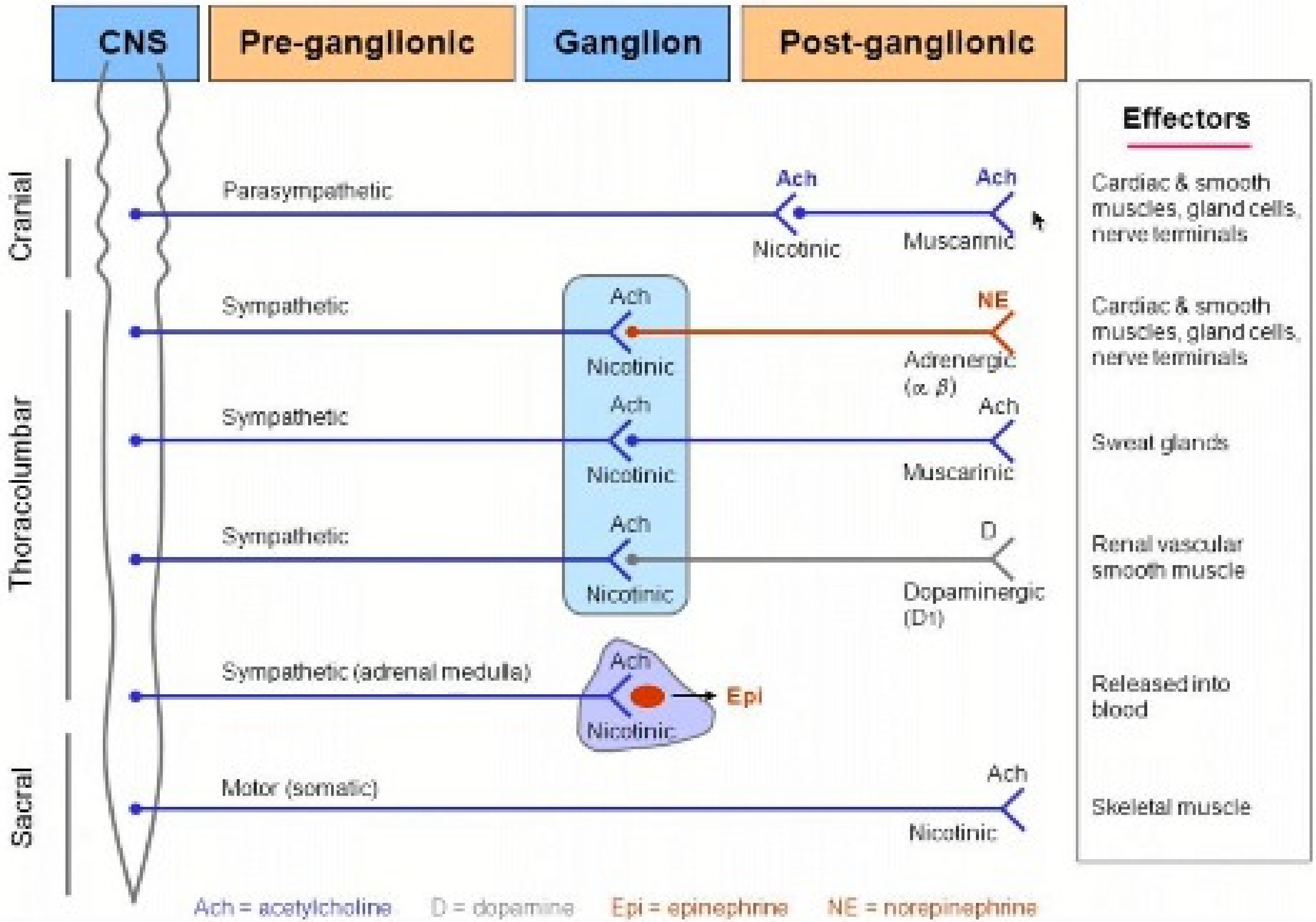


**TABLE 15.5** Effects of the Sympathetic and Parasympathetic Nervous Systems

| 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

- Autonomic effects on glandular secretion are 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

- Sympathetic effects tend to last longer than parasympathetic effects
  - ACh released by parasympathetic fibers is broken down quickly by enzymes in the synaptic cleft
  - NE released by sympathetic nerve fibers is reabsorbed by nerve
    - Some NE will diffuse to adjacent tissues // breakdown slower
    - Some NE will diffuse into bloodstream /// NE then circulate in blood and can "hit" other adrenergic receptors throughout body to pro-long SNS stimulation // slowest breakdown route

# Overview of ANS Function

- 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
    - Note: Nitric oxide is crucial in a penile erection /// Viagra increase nitric oxide

# 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 "influence" the same organ equally // one division dominates over the other division*

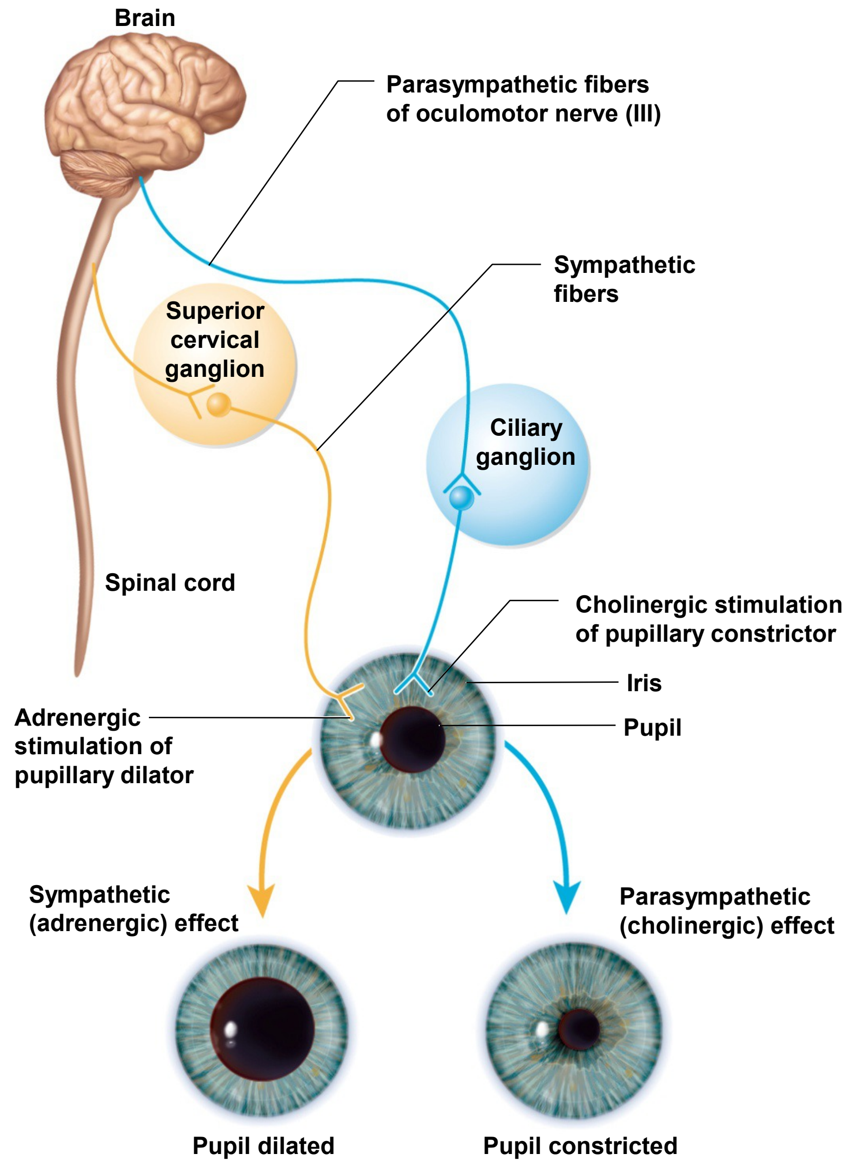
# Dual Innervation to Same Organ

- **Cooperative effects** - when the two divisions act on same organ to produce a “similar effect”
  - eg. ANS innervation of salivary glands
  - PNS increase salivary serous cell secretion
  - SNS increase salivary mucous cell secretion

# Dual Innervation to Same Organ

- 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



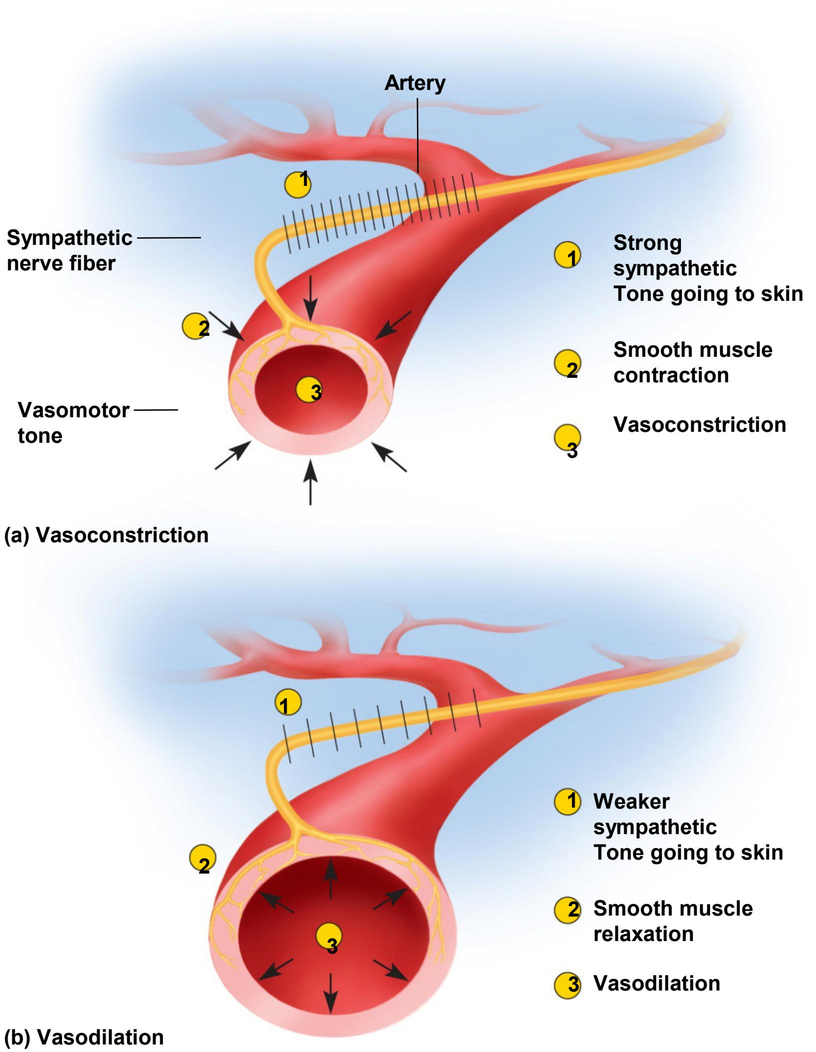

Dilate iris with radial fasicles.

Constrict iris with sphincter fasicles.

# Regulation With Single Division Innervation

- Some effectors receive **only sympathetic fibers**
  - adrenal medulla
  - arrector pili muscles
  - sweat glands
  - 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




How can we control blood pressure and distribution of blood flow using only sympathetic innervation?

This is possible because we first establish sympathetic vasomotor tone - a baseline firing frequency of sympathetic fibers....

- this keeps vessels in state of partial constriction
- If increase in firing frequency – causes more vasoconstriction
- If decrease in firing frequency – causes less vasoconstriction (which has same effect as vasodilation)

Note: this illustration shows blood vessels in skin with muscarinic receptors / at the same time different blood vessels in skeletal muscles will dilate due to NE binding to adrenergic receptors

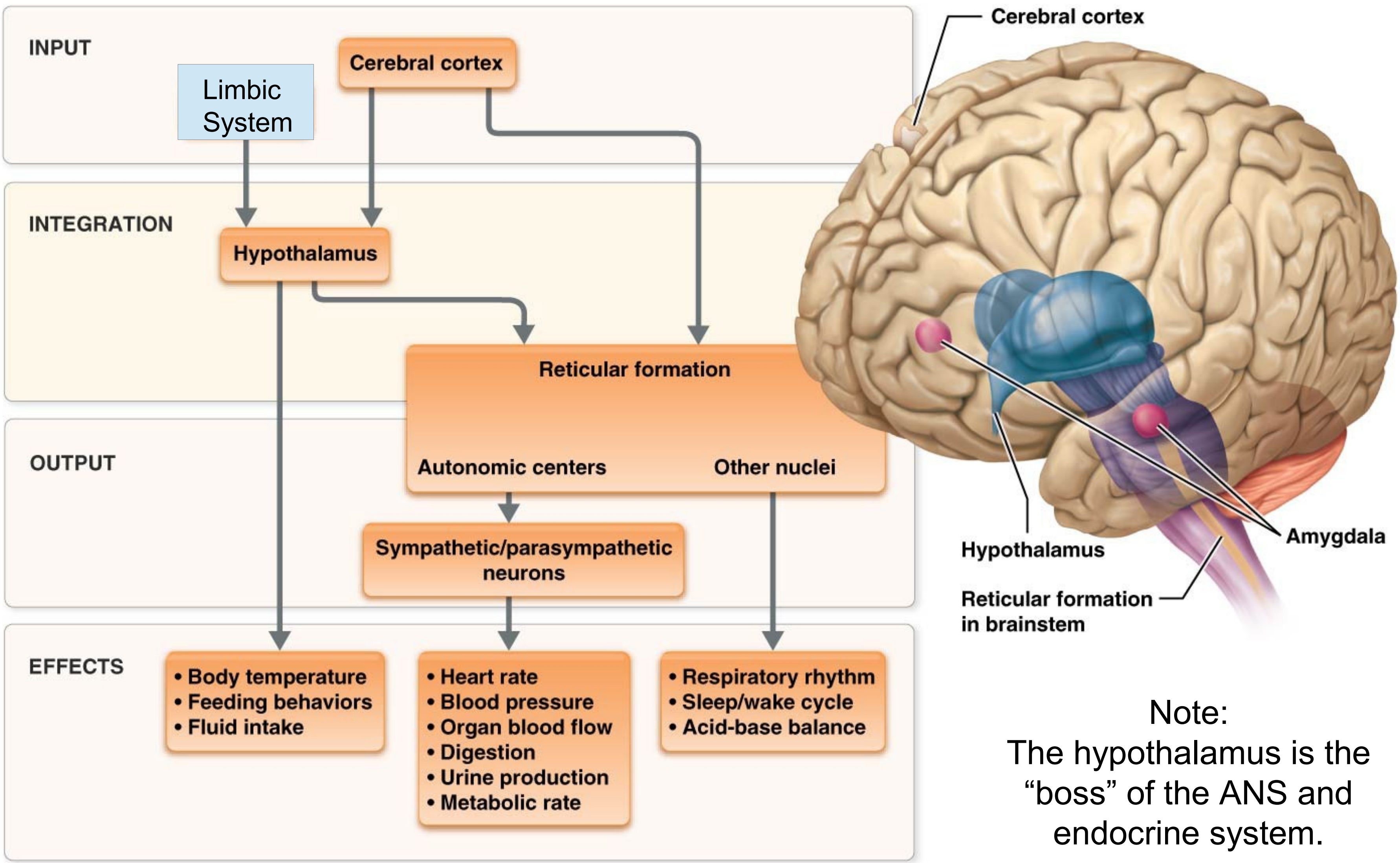
# Control of Autonomic Function (1 of 2)

- 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 connections between our limbic system (emotional brain) to the hypothalamus
  - **hypothalamus** - visceral motor control center // exerts influence by connections to pituitary (hormones) or nerve tracks to nuclei in medulla oblongata (ANS)
    - Medulla oblongata nuclei reglate primitive functions – e.g. 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 <u>control over skeletal muscle sphincters…</u>
  - if the spinal cord is damaged, the smooth muscle of bowel and bladder is controlled by autonomic reflexes built into the spinal cord

# Summary of nervous system control of homeostasis.




Note:
The hypothalamus is the "boss" of the ANS and endocrine system.