Vert Phys PCB3743

Autonomic Nervous System 1
Fox Chapter 9 part 1

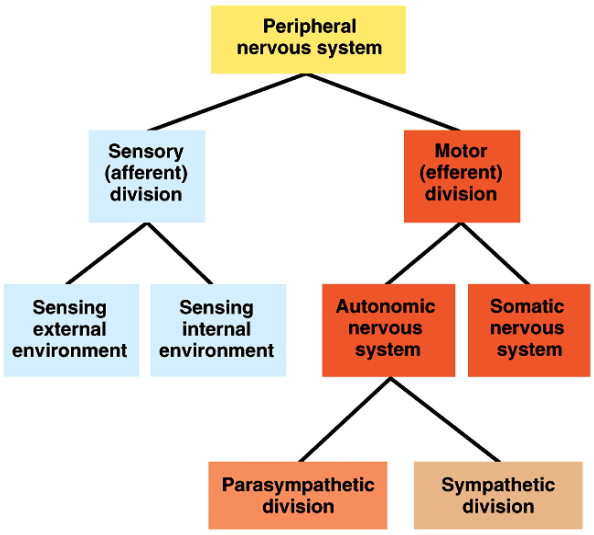
Anatomy and Neurochemistry

Fox Table 9.1

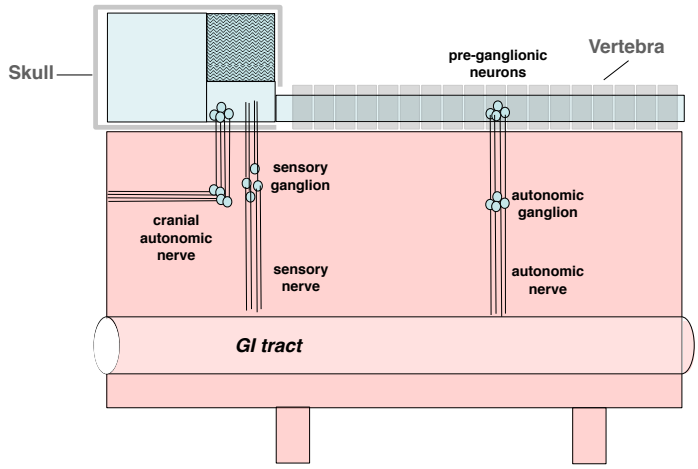
Table 9.1 | Comparison of the Somatic Motor System and the Autonomic Motor System

Feature	Somatic Motor	Autonomic Motor
Effector organs	Skeletal muscles	Cardiac muscle, smooth muscle, and glands
Presence of ganglia	No ganglia	Cell bodies of postganglionic autonomic fibers located in paravertebral, prevertebral (collateral), and terminal ganglia
Number of neurons from CNS to effector	One	Two
Type of neuromuscular junction	Specialized motor end plate	No specialization of postsynaptic membrane; all areas of smooth muscle cells contain receptor proteins for neurotransmitters
Effect of nerve impulse on muscle	Excitatory only	Either excitatory or inhibitory
Type of nerve fibers	Fast-conducting, thick (9–13μm), and myelinated	Slow-conducting; preganglionic fibers lightly myelinated but thin (3μm); postganglionic fibers unmyelinated and very thin (about 1.0μm)
Effect of denervation	Flaccid paralysis and atrophy	Muscle tone and function persist; target cells show denervation hypersensitivity

Functional hierarchy of the peripheral nervous system



Autonomic Nervous System

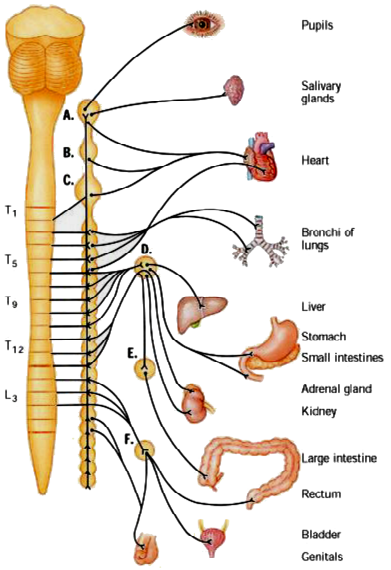


Sympathetic Nervous System

Nerves from spinal cord run to chain ganglia or collateral ganglia and then to glands and smooth muscle

mobilize energy
divert blood to muscle
prepare to fight/flee

"Fight or Flight"



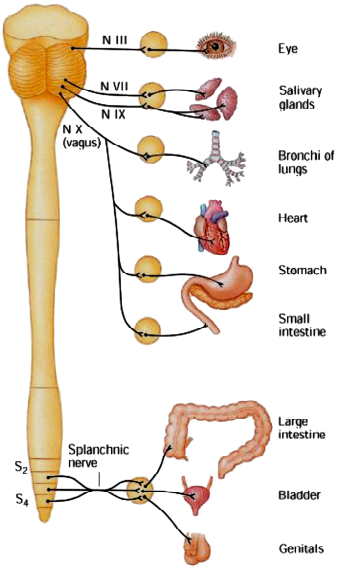
Parasympathetic Nervous System

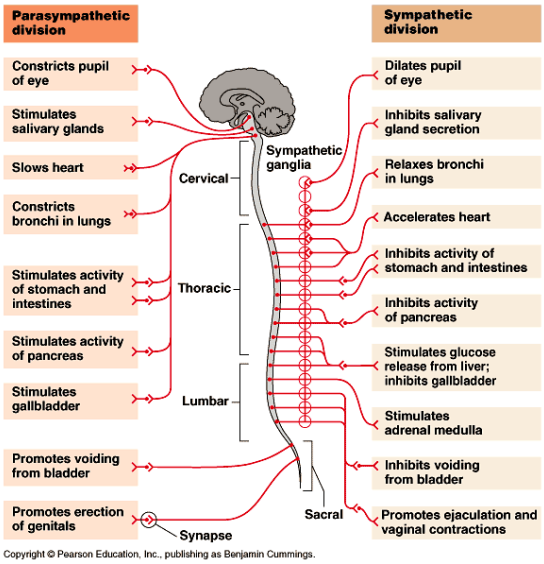
Nerves from brainstem and spinal cord run to glands and smooth muscle

Prepare for digestion, energy storage, divert blood flow to gut.

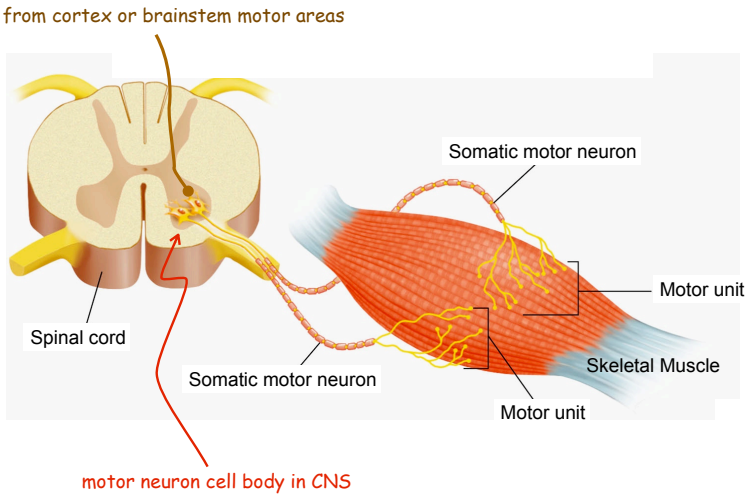
opposite effect of sympathetic NS (in most cases)

"Rest and Digest"





Somatic Motor System (voluntary):
Spinal motor neuron synapses onto target skeletal muscle

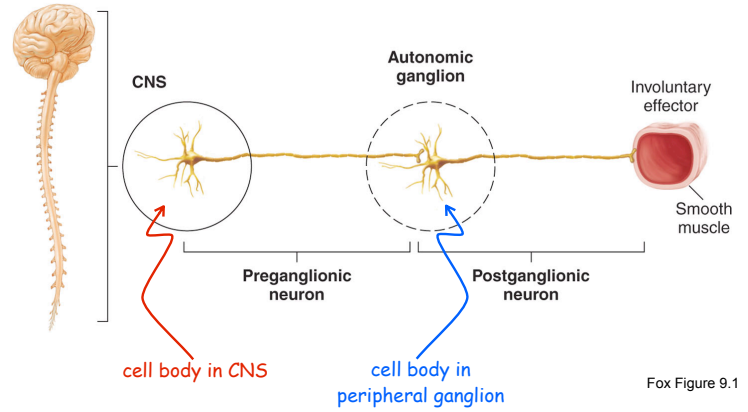


Fox Figure 12.4a

Autonomic Nervous System (involuntary):

Two-Step Projection:

1. Spinal/Brainstem pre-ganglionic neuron synapses onto post-ganglionic neuron
2. Post-ganglionic neuron synapses onto target smooth muscle
   (e.g. in blood vessel, glands)



Fox Figure 9.1

Comparison of Skeletal Muscle and Smooth Muscle

Skeletal Muscle	Smooth Muscle
Striated; actin and myosin arranged in sarcomeres	Not striated; more actin than myosin; actin inserts into dense bodies and cell membrane
Well-developed sarcoplasmic reticulum and transverse tubules	Poorly developed sarcoplasmic reticulum; no transverse tubules
Contains troponin in the thin filaments	Contains calmodulin, a protein that, when bound to Ca^{2+}, activates the enzyme myosin light-chain kinase
Ca^{2+} released into cytoplasm from sarcoplasmic reticulum	Ca^{2+} enters cytoplasm from extracellular fluid, sarcoplasmic reticulum, and perhaps mitochondria
Cannot contract without nerve stimulation; denervation results in muscle atrophy	Maintains tone in absence of nerve stimulation; visceral smooth muscle produces pacemaker potentials; denervation results in hypersensitivity to stimulation
Muscle fibers stimulated independently; no gap junctions	Gap junctions generally present
attached to tendons and bones; contracts to move skeleton.	wrapped around blood vessels, GI tract, glands; contracts to constrict vessels or squeeze glands.
receptors at neuromuscular junction	neurotransmitter receptors all over cell surface

Fox Table 12.8

Fox Figure 12.35a

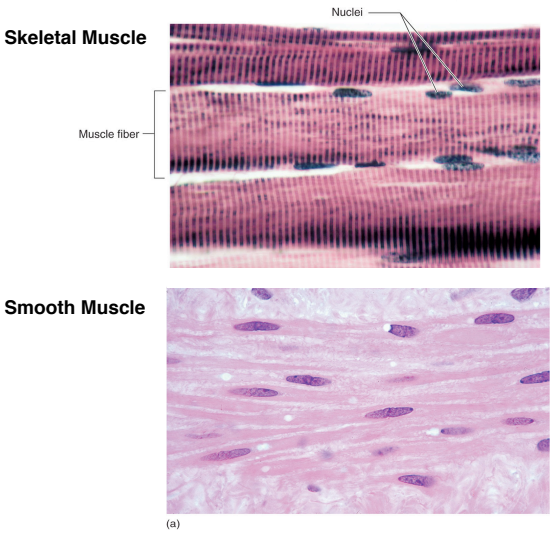


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Figure 12.35b

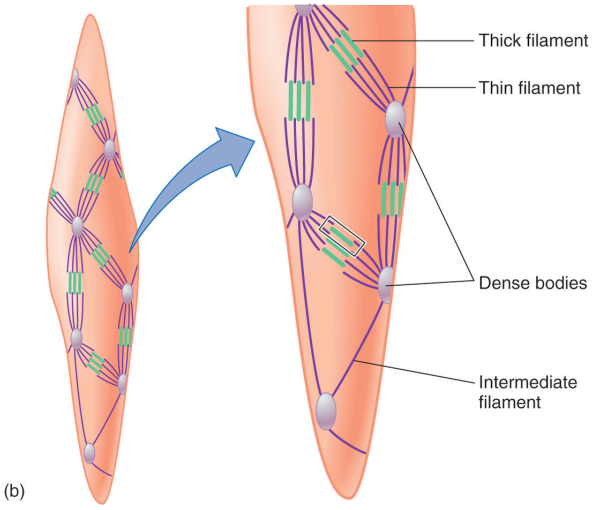

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Figure 12.35c

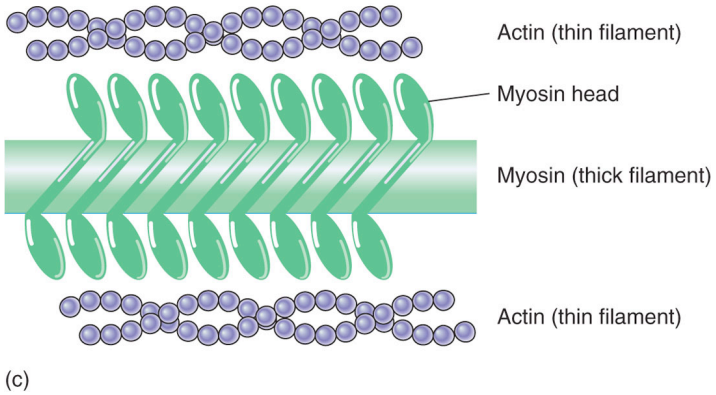
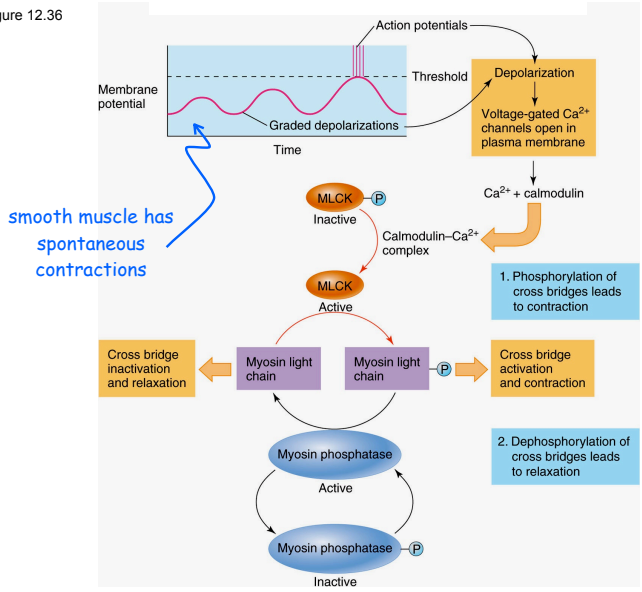


Figure 12.36



Sympathetic Nervous System: Anatomy

Sympathetic chain of paravertebral ganglia

- connected to spinal roots by **white ramus** (preganglionic going into ganglion) and **gray ramus** (postganglionic leaving out of ganglion)
- convergence of inputs leads to **mass activation** of postganglionic neurons
- postganglionic fibers join **spinal nerves**, innervate blood vessels et al. in skeletal muscles and skin.

Splanchnic Nerves

- Sympathetic preganglionic fibers below the diaphragm project to **collateral ganglia**
- Postganglionic fibers from collateral ganglia innervate digestive, urinary, reproductive organs

Medulla of Adrenal Gland

- modified sympathetic ganglion
- Preganglionic fibers stimulate medullary cells to secrete epinephrine and norepinephrine into the blood

Neurotransmitters

- Preganglionic nerves release **Acetylcholine (ACh)** to stimulate **nicotinic receptors** on postganglionic cells
- Postganglionic cells release **Norepinephrine (NE)** to stimulate or inhibit target tissues via **adrenergic receptors**
- There are some important exceptions: e.g. sympathetic fibers to sweat glands use ACh.

ramus - Latin for branch
splan - Greek for organ
medulla - Latin for middle

Sympathetic Nervous System: Anatomy

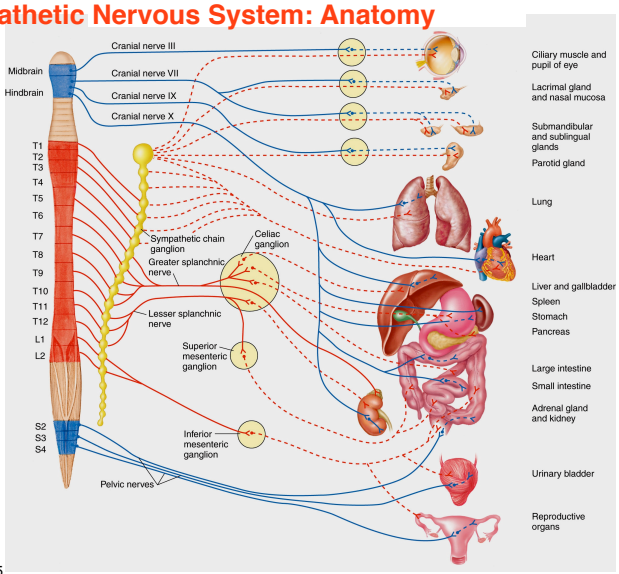


Figure 9.5

Fox Figure 9.2

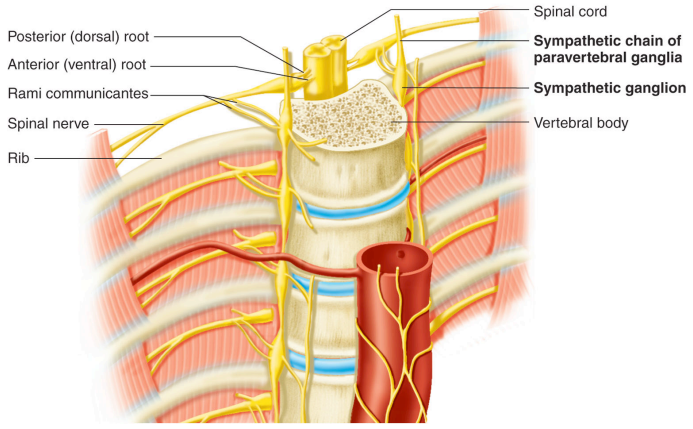


Figure 9.3

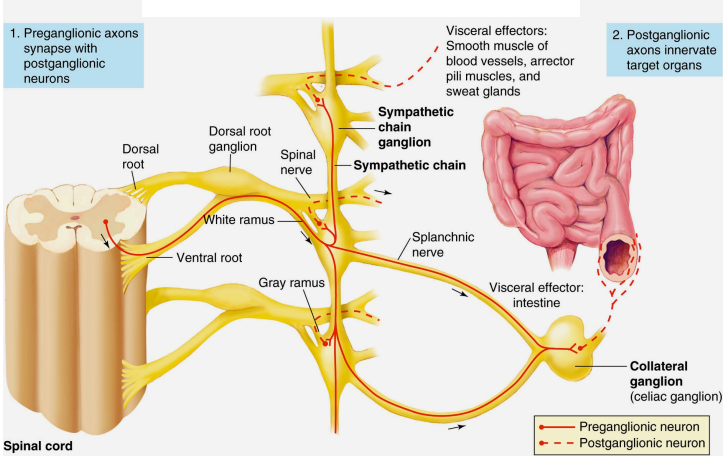


Figure 9.4

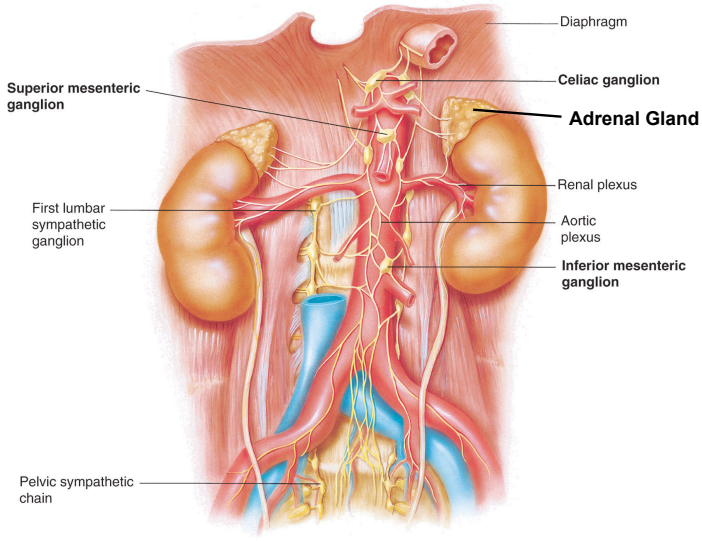


Table 9.2

Table 9.2 | The Sympathetic Division

Parts of Body Innervated	Spinal Origin of Preganglionic Fibers	Origin of Postganglionic Fibers
Eye	C8 and T1	Cervical ganglia
Head and neck	T1 to T4	Cervical ganglia
Heart and lungs	T1 to T5	Upper thoracic (paravertebral) ganglia
Upper extremities	T2 to T9	Lower cervical and upper thoracic (paravertebral) ganglia
Upper abdominal viscera	T4 to T9	Celiac and superior mesenteric (collateral) ganglia
Adrenal	T10 and T11	Not applicable
Urinary and reproductive systems	T12 to L2	Celiac and interior mesenteric (collateral) ganglia
Lower extremities	T9 to L2	Lumbar and upper sacral (paravertebral) ganglia

Sympathetic Nervous System: Neurotransmitters

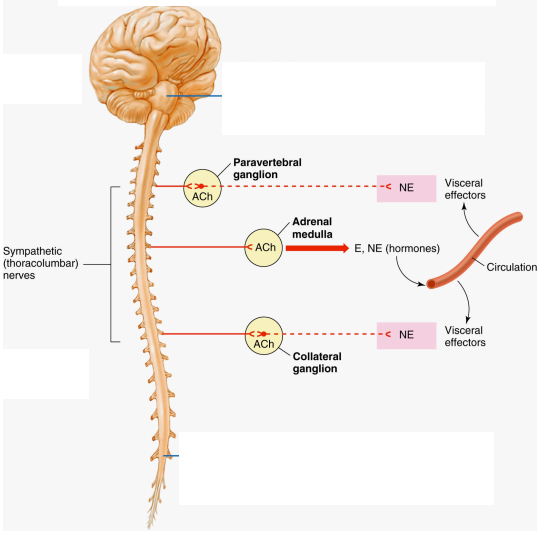


Figure 9.7

Parasympathetic Nervous System: Anatomy

Craniosacral Division
- preganglionic cells are in the brainstem and in the sacral level of the spinal cord
- preganglionic fibers travel in parasympathetic nerves, NOT spinal nerves
- (so, cutaneous (skin) effectors and blood vessels in skeletal muscle get sympathetic but NOT parasympathetic regulation)

Terminal Ganglia
- preganglionic fibers project to ganglia near or in the target organ
- postganglionic cells send short fibers from ganglia to target cells

Mixed Nerves
- Glossopharyngeal and Vagus Nerves also have sensory component to relay visceral sensation to brainstem (e.g. blood pressure, intestinal contents).

Neurotransmitters
- Preganglionic nerves release **Acetylcholine (ACh)** to stimulate **nicotinic receptors** on postganglionic cells
- Postganglionic cells release **Acetylcholine (ACh)** to stimulate or inhibit target tissues via **muscarinic receptors**

Parasympathetic Nervous System: Anatomy

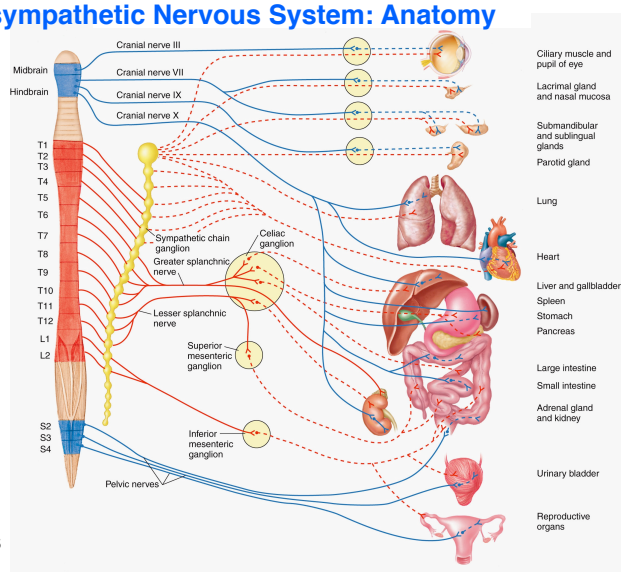


Figure 9.5

Figure 9.6

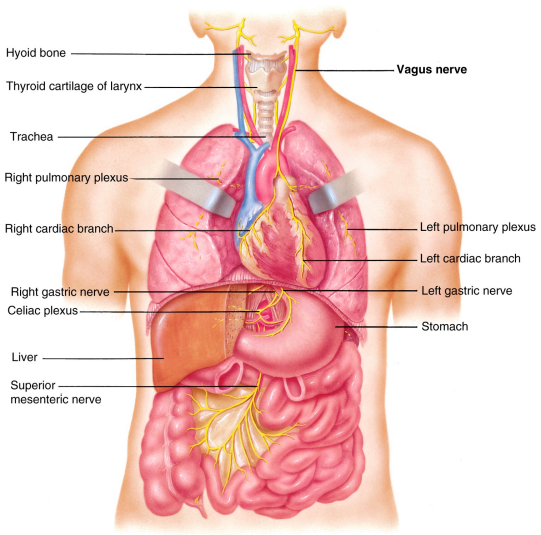


Table 9.3

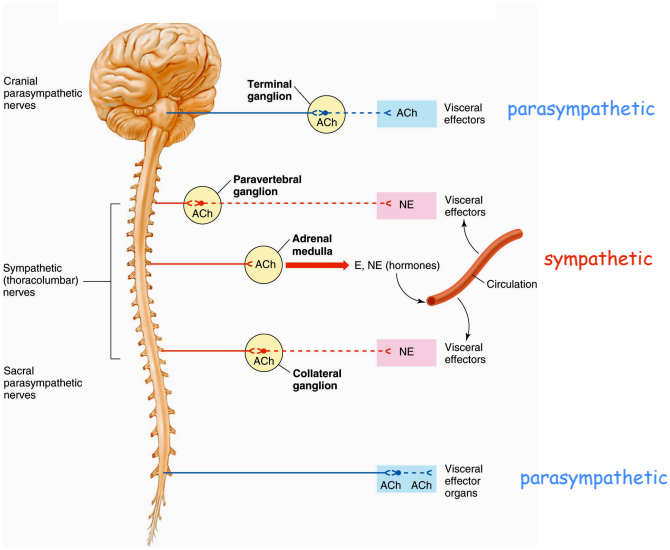
Table 9.3 | The Parasympathetic Division

Nerve	Origin of Preganglionic Fibers	Location of Terminal Ganglia	Effector Organs
Oculomotor (third cranial) nerve	Midbrain (cranial)	Ciliary ganglion	Eye (smooth muscle in iris and ciliary body)
Facial (seventh cranial)	Pons (cranial)	Pterygopalatine and submandibular ganglia	Lacrimal, mucous, and salivary glands
Glossopharyngeal (ninth cranial) nerve	Medulla oblongata (cranial)	Otic ganglion	Parotid gland
Vagus (tenth cranial) nerve	Medulla oblongata (cranial)	Terminal ganglia in or near organ	Heart, lungs, gastrointestinal tract, liver, pancreas
Pelvic spinal nerves	S2 to S4 (sacral)	Terminal ganglia near organs	Lower half of large intestine, rectum, urinary bladder, and reproductive organs

Autonomic Nervous System: Neurochemistry

- Both sympathetic and parasympathetic preganglionic neurons release ACh to stimulate **nicotonic receptors** on postganglionic cells
  *nicotinic receptors are blocked by **curare***
- Parasympathetic postganglionic neurons release ACh onto **muscarinic receptors**
  *muscarinic receptors are blocked by **atropine*** *belladona extract*
  muscanic receptors are G-protein-coupled receptors that have stimulatory or inhibitory effects on target organ, depending on the specific receptor subtype (M1-5)
- Sympathetic postganglionic neurons release NE (mostly) onto **adrenergic receptors**
  adrenergic receptors are G-protein-coupled receptors that have stimulatory or inhibitory effects on target organ, depending on the receptor subtype (alpha or beta)
  *adrenergic receptors are blocked by **alpha blockers** or **beta blockers.***
- Most target organs have **dual innervation** by sympathetic and parasympathetic fibers. The effects are usually **antagonistic** (but can be complementary, or cooperative).
- Some organs receive **only sympathetic innervation**: adrenal medulla, skin (arrector pili & sweat glands), and most blood vessels.

Figure 9.7



Autonomic Nervous System: Anatomy

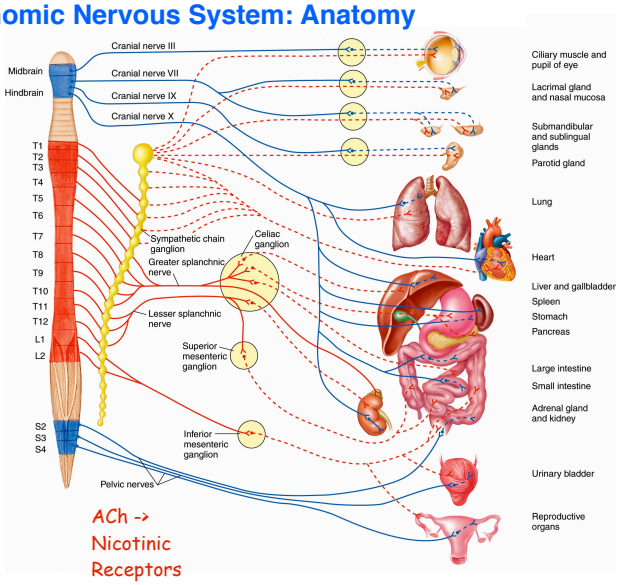


Figure 9.5

Table 9.4

Table 9.4 | Effects of Autonomic Nerve Stimulation on Various Effector Organs

Effector Organ	Sympathetic Effect	Parasympathetic Effect
Eye		
Iris (radial muscle)	Dilation of pupil	—
Iris (sphincter muscle)	—	Constriction of pupil
Ciliary muscle	Relaxation (for far vision)	Contraction (for near vision)
Glands		
Lacrimal (tear)	—	Stimulation of secretion
Sweat	Stimulation of secretion	—
Salivary	Saliva becomes thick	Increased secretion; saliva becomes thin
Stomach	—	Stimulation of secretion
Intestine	—	Stimulation of secretion
Adrenal medulla	Stimulation of hormone secretion	—
Heart		
Rate	Increased	Decreased
Conduction	Increased rate	Decreased rate
Strength	Increased	—
Blood Vessels	Mostly constriction; affects all organs	Dilation in a few organs (e.g., penis)
Lungs		
Bronchioles (tubes)	Dilation	Constriction
Mucous glands	Inhibition of secretion	Stimulation of secretion

Table 9.4 | Effects of Autonomic Nerve Stimulation on Various Effector Organs

Effector Organ	Sympathetic Effect	Parasympathetic Effect
Lungs		
Bronchioles (tubes)	Dilation	Constriction
Mucous glands	Inhibition of secretion	Stimulation of secretion
Gastrointestinal Tract		
Motility	Inhibition of movement	Stimulation of movement
Sphincters	Closing stimulated	Closing inhibited
Liver	Stimulation of glycogen hydrolysis	—
Adipose (Fat) Cells	Stimulation of fat hydrolysis	—
Pancreas	Inhibition of exocrine secretions	Stimulation of exocrine secretions
Spleen	Contraction	—
Urinary Bladder	Muscle tone aided	Contraction
Arrector Pili Muscles	Erection of hair and goose bumps	—
Uterus	If pregnant: contraction; if not pregnant: relaxation	—
Penis	Ejaculation	Erection (due to vasodilation)

Figure 9.9a

e.g. smooth muscle of airways

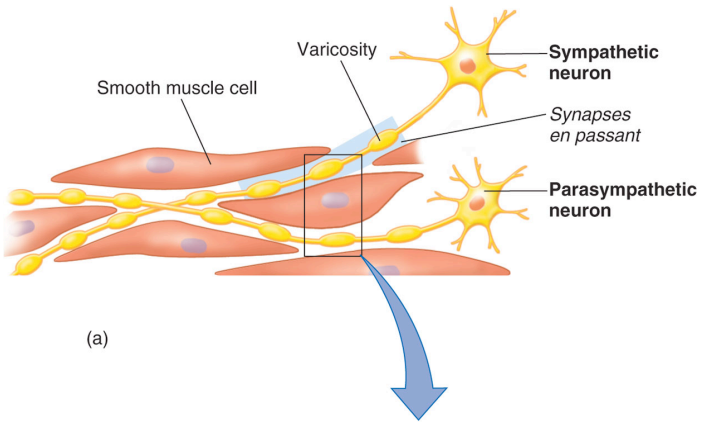


Figure 9.9b

e.g. smooth muscle of airways

sympathetic relaxation and **dilation** of airways

parasympathetic **constriction** of airways

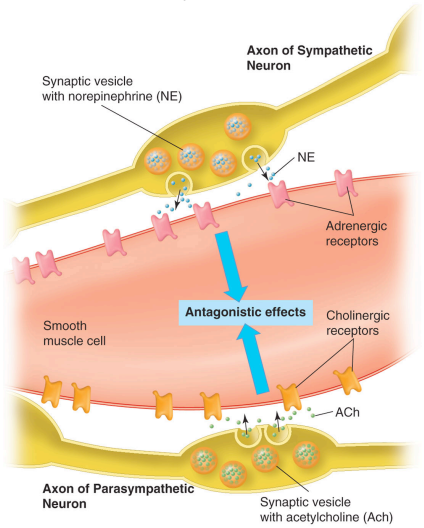
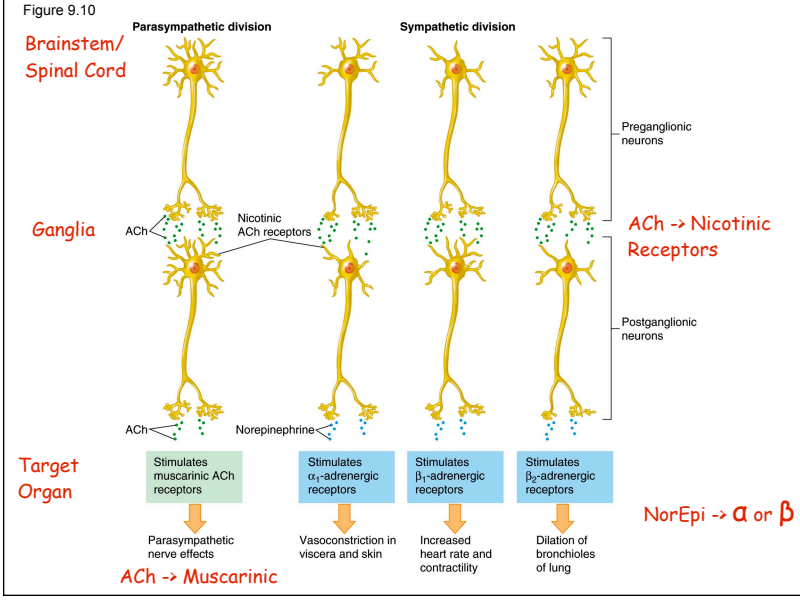


Figure 9.10



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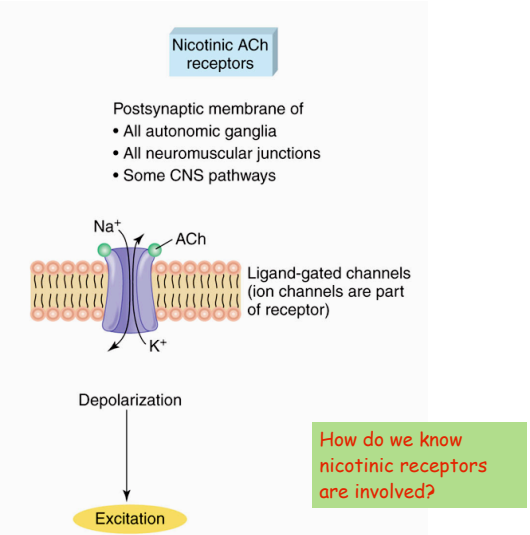

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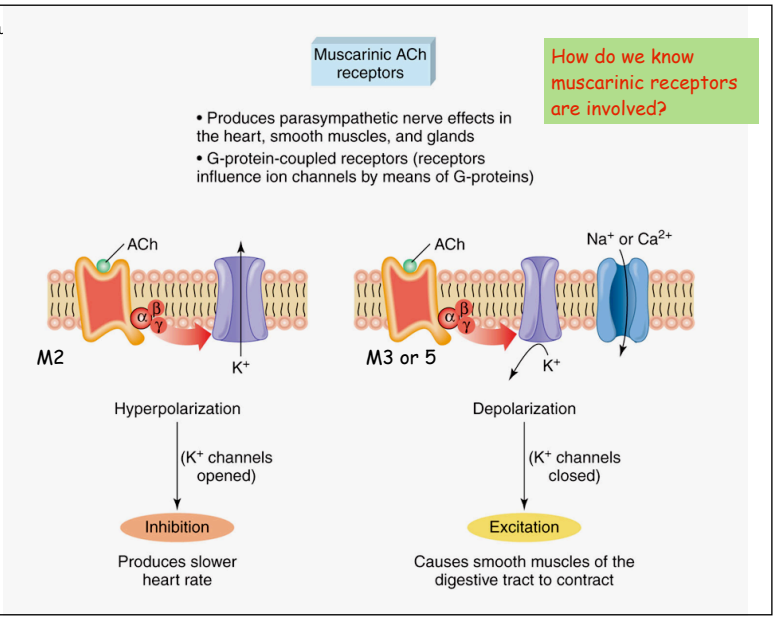


Table 9.6

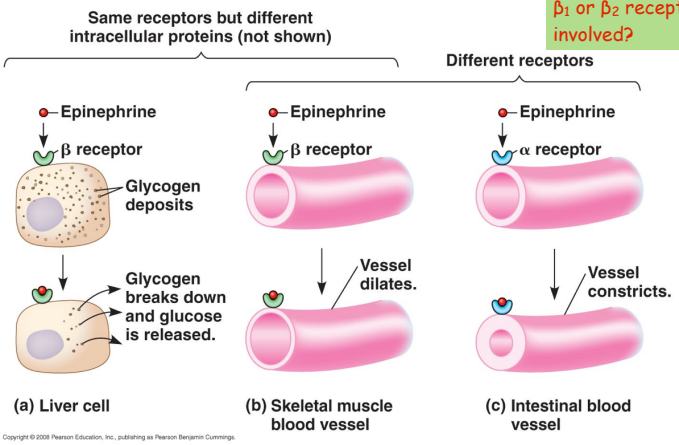
Table 9.6 | Cholinergic Receptors and Responses to Acetylcholine

Receptor	Tissue	Response	Mechanisms
Nicotinic	Skeletal muscle	Depolarization, producing action potentials and muscle contraction	ACh opens cation channel in receptor
Nicotinic	Autonomic ganglia	Depolarization, causing activation of postganglionic neurons	ACh opens cation channel in receptor
Muscarinic (M_3, M_1)	Smooth muscle, glands	Depolarization and contraction of smooth muscle, secretion of glands	ACh activates G-protein coupled receptor, opening Ca^{2+} channels and increasing cytosolic Ca^{2+}
Muscarinic (M_2)	Heart	Hyperpolarization, slowing rate of spontaneous depolarization	ACh activates G-protein coupled receptor, opening channels for K^+

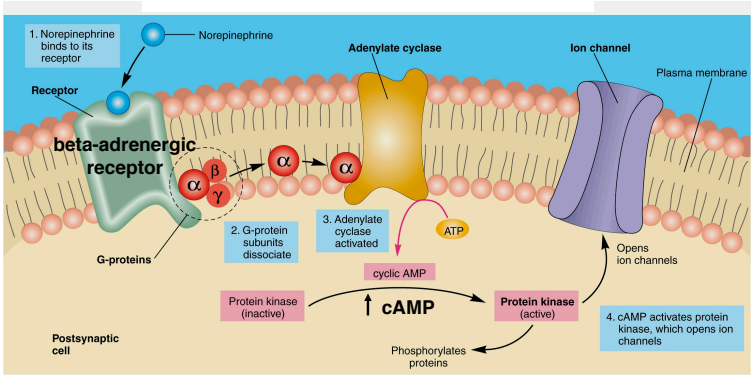
Source: Simplified from table 6-2, p. 119 of Goodman and Gilman's *The Pharmacological Basis of Therapeutics.* Ninth edition. J.E. Hardman et al., eds. 1996 and table 6-3, p. 156 of the Eleventh edition, 2006. McGraw-Hill.

Epinephrine (Adrenalin) secreted from Adrenal Gland & Autonomic Neurons during stress (one NT -> multiple effects)

How do we know a or β_1 or β_2 receptors are involved?



G-Proteins can affect second messenger signaling (e.g. cAMP levels in the cytoplasm)



Fox Figure 7.31

Table 9.5

$beta_1$ $beta_2$

Table 9.5 | Selected Adrenergic Effects in Different Organs

Organ	Adrenergic Effects of Sympathoadrenal System	Adrenergic Receptor
Eye	Contraction of radial fibers of the iris dilates the pupils	$alpha_1$
Heart	Increase in heart rate and contraction strength	$beta_1$
Skin and visceral vessels	Arterioles constrict due to smooth muscle contraction	$alpha_1$
Skeletal muscle vessels	Arterioles constrict due to sympathetic nerve activity	$alpha_1$
	Arterioles dilate due to hormone epinephrine	$beta_2$
Lungs	Bronchioles (airways) dilate due to smooth muscle relaxation	$beta_2$
Stomach and intestine	Contraction of sphincters slows passage of food	$alpha_1$
Liver	Glycogenolysis and secretion of glucose	$alpha_1$ $beta_2$

Source: Simplified from table 6-1, pp. 110–111, of Goodman and Gilman's *The Pharmacological Basis of Therapeutics.* Ninth edition. J.E. Hardman et al., eds. 1996. McGraw-Hill.

Table 9.7 | Adrenergic and Cholinergic Effects of Sympathetic and Parasympathetic Nerves

	Effect of			
	Sympathetic		Parasympathetic	
Organ	Action	Receptor*	Action	Receptor*
Eye				
Iris				
Radial muscle	Contracts	α_1	—	—
Circular muscle	—	—	Contracts	M
Heart				
Sinoatrial node	Accelerates	β_1	Decelerates	M
Contractility	Increases	β_1	Decreases (atria)	M

Table 9.7 | Adrenergic and Cholinergic Effects of Sympathetic and Parasympathetic Nerves

	Effect of			
	Sympathetic		Parasympathetic	
Organ	Action	Receptor*	Action	Receptor*
Vascular Smooth Muscle				
Skin, splanchnic vessels	Contracts	α,β	—	—
Skeletal muscle vessels	Relaxes	β_2	—	—
	Relaxes	M**	—	—
Bronchiolar Smooth Muscle	Relaxes	β_2	Contracts	M
Gastrointestinal Tract				
Smooth muscle				
Walls	Relaxes	β_2	Contracts	M
Sphincters	Constricts	α_1	Relaxes	M
Secretion	Decreases	α_1	Increases	M
Myenteric plexus	Inhibits	α_1	—	—