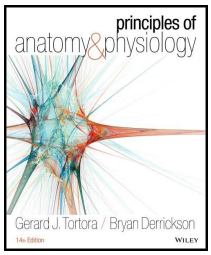


Principles of Anatomy and Physiology

14th Edition

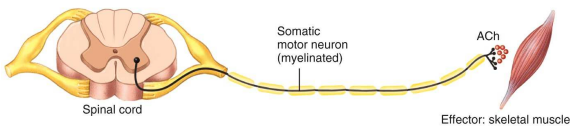
CHAPTER 15
The Autonomic Nervous System

Comparison of Somatic and Autonomic Nervous Systems

- **The somatic nervous system** includes both sensory and motor neurons. Sensory neurons are related to touch, pain, temperature, and proprioception (sense of self position), sight, hearing, taste, smell and equilibrium. Motor neurons innervate skeletal muscles.
- **The autonomic nervous system** receives input from sensory receptors located in organs, blood vessels, muscles and the nervous system.

Comparison of Somatic and Autonomic Nervous Systems

The axon of a single, myelinated somatic motor neuron extends from the central nervous system to the skeletal muscle fiber it innervates.

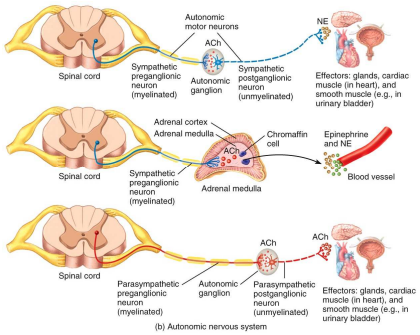


(a) Somatic nervous system

Comparison of Somatic and Autonomic Nervous Systems

Most autonomic motor pathways consist of two motor neurons in series. The first (**preganglionic neuron**) has its cell body in the central nervous system. The axon extends to an autonomic ganglion. The second (**postganglionic neuron**) has its unmyelinated axon extending from the ganglion to the effector (smooth muscle, cardiac muscle, or gland).

Comparison of Somatic and Autonomic Nervous Systems



(b) Autonomic nervous system

Comparison of Somatic and Autonomic Nervous Systems

The autonomic nervous system is divided into two divisions: The **sympathetic nervous system** is often referred to as the **fight-or-flight division** because its stimulation leads to increased alertness and metabolism to be ready for an emergency. The **parasympathetic nervous system** is referred to as the **rest-and-digest** division as its stimulation slows down most body activity.

Comparison of Somatic and Autonomic Nervous Systems

TABLE 15.1

Comparison of the Somatic and Autonomic Nervous Systems

	SOMATIC NERVOUS SYSTEM	AUTONOMIC NERVOUS SYSTEM
Sensory input	From somatic senses and special senses.	Mainly from interoceptors; some from somatic senses and special senses.
Control of motor output	Voluntary control from cerebral cortex, with contributions from basal ganglia, cerebellum, brain stem, and spinal cord.	Involuntary control from hypothalamus, limbic system, brain stem, and spinal cord; limited control from cerebral cortex.
Motor neuron pathway	One-neuron pathway: Somatic motor neurons extending from CNS synapse directly with effector.	Usually two-neuron pathway: Preganglionic neurons extending from CNS synapse with postganglionic neurons in autonomic ganglion, and postganglionic neurons extending from ganglion synapse with visceral effector. Alternatively, preganglionic neurons may extend from CNS to synapse with chromaffin cells of adrenal medullae.
Neurotransmitters and hormones	All somatic motor neurons release only acetylcholine (ACh).	All sympathetic and parasympathetic preganglionic neurons release ACh. Most sympathetic postganglionic neurons release NE; those to most sweat glands release ACh. All parasympathetic postganglionic neurons release ACh. Chromaffin cells of adrenal medullae release epinephrine and norepinephrine (NE).
Effectors	Skeletal muscle.	Smooth muscle, cardiac muscle, and glands.
Responses	Contraction of skeletal muscle.	Contraction or relaxation of smooth muscle; increased or decreased rate and force of contraction of cardiac muscle; increased or decreased secretions of glands.

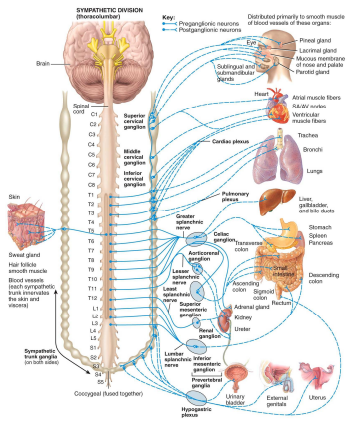
Anatomy of Autonomic Motor Pathways

Each division of the autonomic nervous system has two motor neurons: The **preganglionic** (cell body in the brain or spinal cord) and the **postganglionic** (cell body and dendrites located in an autonomic ganglion where it synapses with preganglionic axons).

Anatomy of Autonomic Motor Pathways

In the **sympathetic division**, the cell bodies of **preganglionic neurons** are in the lateral horns of the gray matter in the 12 thoracic and first 2 or 3 lumbar segments.

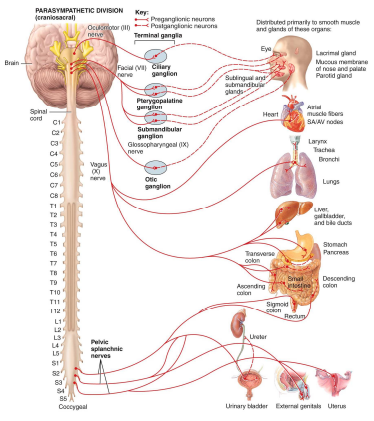
Anatomy of Autonomic Motor Pathways



Anatomy of Autonomic Motor Pathways

In the **parasympathetic division**, cell bodies of the **preganglionic neurons** are in the nuclei of four cranial nerves (III, VII, IX and X) in the brain stem and in the lateral gray matter of sacral segments 2–4 of the spinal cord.

Anatomy of Autonomic Motor Pathways



Anatomy of Autonomic Motor Pathways

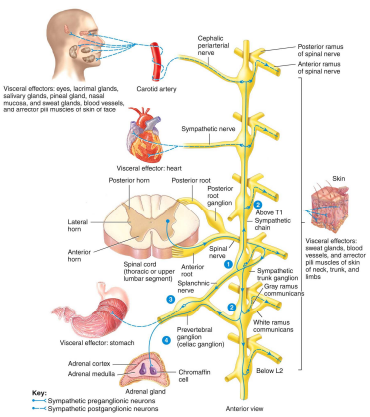
- There are two types of **autonomic ganglia**: **sympathetic** and **parasympathetic**. Sympathetic ganglia are sites of synapses between sympathetic preganglionic and postganglionic neurons.
- There are 2 major types of sympathetic ganglia: **Sympathetic trunk ganglia** (lie in a vertical row on either side of the vertebral column) and **prevertebral ganglia** (lie anterior to the vertebral column and close to the large abdominal arteries).

Anatomy of Autonomic Motor Pathways

After axons of sympathetic preganglionic neurons enter sympathetic trunk ganglia, they may connect with postganglionic neurons in one of 4 ways.

1. An axon may synapse with postganglionic neurons in the first ganglion it reaches.
2. An axon may ascend or descend to a higher or lower ganglion before synapsing with postganglionic neurons.
3. An axon may continue, without synapsing, through the sympathetic trunk ganglion to end at a prevertebral ganglion and synapse with postganglionic neurons.
4. An axon may also pass, without synapsing, through the sympathetic trunk ganglion and a prevertebral ganglion and then extend to the adrenal medullae.

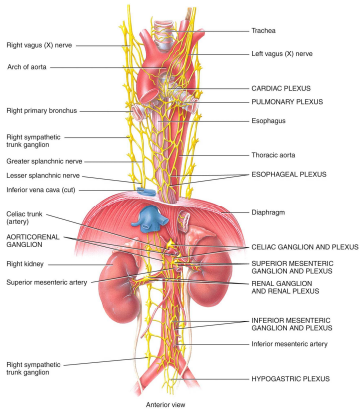
Anatomy of Autonomic Motor Pathways



Anatomy of Autonomic Motor Pathways

The abdomen and pelvis also contain major autonomic plexuses which are often named after the artery along which they are distributed. These include the **celiac (solar) plexus**, the **superior mesenteric plexus**, the **inferior mesenteric plexus**, the **renal plexus** and the **hypogastric plexus**.

Anatomy of Autonomic Motor Pathways



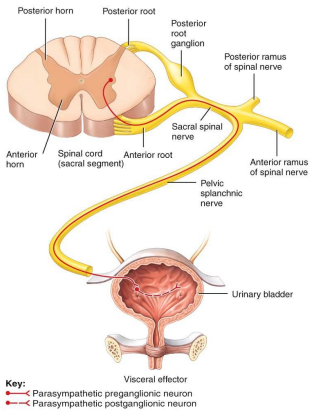
Anatomy of Autonomic Motor Pathways

- Cell bodies of the **sympathetic preganglionic neurons** are part of the lateral gray horns of all thoracic segments and of the first two lumbar segments of the spinal cord.
- The paired **sympathetic trunk ganglia** are anterior and lateral to the vertebral column. Usually, there are 2 cervical, 11 or 12 thoracic, 4 or 5 lumbar, 4 or 5 sacral sympathetic trunk ganglia and 1 coccygeal ganglion.

Anatomy of Autonomic Motor Pathways

Cell bodies of the **parasympathetic preganglionic neurons** are located in nuclei in the brain stem and in the lateral gray matter of the 2nd through 4th sacral segments of the spinal cord. There is a **cranial parasympathetic outflow** that extends from the brain stem in 4 cranial nerves. The **sacral parasympathetic outflow** extends from the 2nd through 4th sacral spinal nerves.

Anatomy of Autonomic Motor Pathways



Anatomy of Atonomic Motor Pathways

Anatomy Overview:

Nervous System: Organization of the ANS

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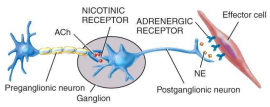
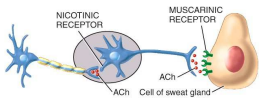
ANS Neurotransmitters and Receptors

Based on the neurotransmitter they produce and release, autonomic neurons are considered as either **cholinergic** or **adrenergic**. Cholinergic neurons release the neurotransmitter **acetylcholine**, while adrenergic neurons release **norepinephrine (noradrenalin)**. Cholinergic receptors include **nicotinic receptors** and **muscarinic receptors**.

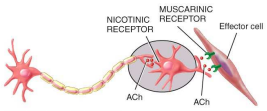
ANS Neurotransmitters and Receptors



(a) Sympathetic division–innervation to most effector tissues



(b) Sympathetic division–innervation to most sweat glands



(c) Parasympathetic division

Physiology of the ANS

TABLE 15.2

Location and Responses of Adrenergic and Cholinergic Receptors

TYPE OF RECEPTOR	MAJOR LOCATIONS	EFFECTS OF RECEPTOR ACTIVATION
CHOLINERGIC	Integral proteins in postsynaptic plasma membranes; activated by the neurotransmitter acetylcholine.	
Nicotinic	Plasma membrane of postganglionic sympathetic and parasympathetic neurons.	Excitation → impulses in postganglionic neurons.
	Chromaffin cells of adrenal medullae.	Epinephrine and norepinephrine secretion.
	Sarcolemma of skeletal muscle fibers (motor end plate).	Excitation → contraction.
Muscarinic	Effectors innervated by parasympathetic postganglionic neurons.	In some receptors, excitation; in others, inhibition.
	Sweat glands innervated by cholinergic sympathetic postganglionic neurons.	Increased sweating.
	Skeletal muscle blood vessels innervated by cholinergic sympathetic postganglionic neurons.	Inhibition → relaxation → vasodilation.

Physiology of the ANS

TABLE 15.2

Location and Responses of Adrenergic and Cholinergic Receptors

TYPE OF RECEPTOR	MAJOR LOCATIONS	EFFECTS OF RECEPTOR ACTIVATION
ADRENERGIC	Integral proteins in postsynaptic plasma membranes; activated by the neurotransmitter norepinephrine and the hormones norepinephrine and epinephrine.	
α_1	Smooth muscle fibers in blood vessels that serve salivary glands, skin, mucosal membranes, kidneys, and abdominal viscera; radial muscle in iris of eye; sphincter muscles of stomach and urinary bladder.	Excitation → contraction, which causes vasoconstriction, dilation of pupil, and closing of sphincters.
	Salivary gland cells.	Secretion of K^+ and water.
	Sweat glands on palms and soles.	Increased sweating.
α_2	Smooth muscle fibers in some blood vessels.	Inhibition → relaxation → vasodilation.
	Cells of pancreatic islets that secrete the hormone insulin (beta cells).	Decreased insulin secretion.
	Pancreatic acinar cells.	Inhibition of digestive enzyme secretion.
	Platelets in blood.	Aggregation to form platelet plug.
β_1	Cardiac muscle fibers.	Excitation → increased force and rate of contraction.
	Juxtaglomerular cells of kidneys.	Renin secretion.
	Posterior pituitary.	Antidiuretic hormone (ADH) secretion.
	Adipose cells.	Breakdown of triglycerides → release of fatty acids into blood.
β_2	Smooth muscle in walls of airways; in blood vessels that serve heart, skeletal muscle, adipose tissue, and liver; and in walls of visceral organs, such as urinary bladder.	Inhibition → relaxation, which causes dilation of airways, vasodilation, and relaxation of organ walls.
	Ciliary muscle in eye.	Inhibition → relaxation.
	Hepatocytes in liver.	Glycogenolysis (breakdown of glycogen into glucose).
β_3	Brown adipose tissue.	Thermogenesis (heat production).

Physiology of the ANS

In general, the sympathetic and parasympathetic divisions of the autonomic nervous system are antagonistic to each other.

Physiology of the ANS

TABLE 15.3

Comparison of Sympathetic and Parasympathetic Divisions of the ANS

	SYMPATHETIC (THORACOLUMBAR)	PARASYMPATHETIC (CRANIOSACRAL)
Distribution	Wide regions of body: skin, sweat glands, arrector pili muscles of hair follicles, adipose tissue, smooth muscle of blood vessels.	Limited mainly to head and to viscera of thorax, abdomen, and pelvis; some blood vessels.
Location of preganglionic neuron cell bodies and site of outflow	Lateral gray horns of spinal cord segments T1–L2. Axons of preganglionic neurons constitute thoracolumbar outflow.	Nuclei of cranial nerves III, VII, IX, and X and lateral gray matter of spinal cord segments S2–S4. Axons of preganglionic neurons constitute craniosacral outflow.
Associated ganglia	Sympathetic trunk ganglia and prevertebral ganglia.	Terminal ganglia.
Ganglia locations	Close to CNS and distant from visceral effectors.	Typically near or within wall of visceral effectors.
Axon length and divergence	Preganglionic neurons with short axons synapse with many postganglionic neurons with long axons that pass to many visceral effectors.	Preganglionic neurons with long axons usually synapse with four to five postganglionic neurons with short axons that pass to single visceral effector.
White and gray rami communicantes	Both present; white rami communicantes contain myelinated preganglionic axons; gray rami communicantes contain unmyelinated postganglionic axons.	Neither present.
Neurotransmitters	Preganglionic neurons release acetylcholine (ACh), which is excitatory and stimulates postganglionic neurons; most postganglionic neurons release norepinephrine (NE); postganglionic neurons that innervate most sweat glands and some blood vessels in skeletal muscle release ACh.	Preganglionic neurons release ACh, which is excitatory and stimulates postganglionic neurons; postganglionic neurons release ACh.
Physiological effects	Fight-or-flight responses.	Rest-and-digest activities.

Physiology of the ANS

TABLE 15.4

Effects of Sympathetic and Parasympathetic Divisions of the ANS

VISCERAL EFFECTOR	EFFECT OF SYMPATHETIC STIMULATION (α OR β ADRENERGIC RECEPTORS, EXCEPT AS NOTED)*	EFFECT OF PARASYMPATHETIC STIMULATION (MUSCARINIC ACh RECEPTORS)
GLANDS		
Adrenal medullae	Secretion of epinephrine and norepinephrine (nicotinic ACh receptors).	No innervation.
Lacrimal (tear)	Slight secretion of tears (α).	Secretion of tears.
Pancreas	Inhibits secretion of digestive enzymes and the hormone insulin (α_2); promotes secretion of the hormone glucagon (β_2).	Secretion of digestive enzymes and the hormone insulin.
Posterior pituitary	Secretion of antidiuretic hormone (ADH) (β_1).	No innervation.
Pineal	Increases synthesis and release of melatonin (β).	No innervation.
Sweat	Increases sweating in most body regions (muscarinic ACh receptors); sweating on palms and soles (α_1).	No innervation.
Adipose tissue†	Lipolysis (breakdown of triglycerides into fatty acids and glycerol) (β_1); release of fatty acids into blood (β_1 and β_3).	No innervation.
Liver†	Glycogenolysis (conversion of glycogen into glucose); gluconeogenesis (conversion of noncarbohydrates into glucose); decreased bile secretion (α and β_2).	Glycogen synthesis; increased bile secretion.
Kidney, juxtaglomerular cells†	Secretion of renin (β_1).	No innervation.
CARDIAC (HEART) MUSCLE		
	Increased heart rate and force of atrial and ventricular contractions (β_1).	Decreased heart rate; decreased force of atrial contraction.
SMOOTH MUSCLE		
Iris, radial muscle	Contraction → dilation of pupil (α_1).	No innervation.
Iris, circular muscle	No innervation.	Contraction → constriction of pupil.
Ciliary muscle of eye	Relaxation to adjust shape of lens for distant vision (β_2).	Contraction for close vision.
Lungs, bronchial muscle	Relaxation → airway dilation (β_2).	Contraction → airway constriction.
Gallbladder and ducts	Relaxation to facilitate storage of bile in the gallbladder (β2).	Contraction → release of bile into small intestine.

Physiology of the ANS

TABLE 15.4 CONTINUED

Effects of Sympathetic and Parasympathetic Divisions of the ANS

VISCERAL EFFECTOR	EFFECT OF SYMPATHETIC STIMULATION (α OR β ADRENERGIC RECEPTORS, EXCEPT AS NOTED)*	EFFECT OF PARASYMPATHETIC STIMULATION (MUSCARINIC ACh RECEPTORS)
Stomach and intestines	Decreased motility and tone (α_1, α_2, β_2); contraction of sphincters (α_1).	Increased motility and tone; relaxation of sphincters.
Spleen	Contraction and discharge of stored blood into general circulation (α_1).	No innervation.
Ureter	Increases motility (α_1).	Increases motility (?).
Urinary bladder	Relaxation of muscular wall (β_2); contraction of internal urethral sphincter (α_1).	Contraction of muscular wall; relaxation of internal urethral sphincter.
Uterus	Inhibits contraction in nonpregnant women (β_2); promotes contraction in pregnant women (α_1).	Minimal effect.
Sex organs	In males: contraction of smooth muscle of ductus (vas) deferens, prostate, and seminal vesicle resulting in ejaculation (α_1).	Vasodilation; erection of clitoris (females) and penis (males).
Hair follicles, arrector pili muscle	Contraction → erection of hairs resulting in goose bumps (α_1).	No innervation.

Physiology of the ANS

TABLE 15.4 CONTINUED

Effects of Sympathetic and Parasympathetic Divisions of the ANS

VISCERAL EFFECTOR	EFFECT OF SYMPATHETIC STIMULATION (α OR β ADRENERGIC RECEPTORS, EXCEPT AS NOTED)*	EFFECT OF PARASYMPATHETIC STIMULATION (MUSCARINIC ACh RECEPTORS)
VASCULAR SMOOTH MUSCLE		
Salivary gland arterioles	Vasoconstriction, which decreases secretion of saliva (α_1).	Vasodilation, which increases secretion of saliva.
Gastric gland arterioles	Vasoconstriction, which inhibits secretion (α_1).	Secretion of gastric juice.
Intestinal gland arterioles	Vasoconstriction, which inhibits secretion (α_1).	Secretion of intestinal juice.
Coronary (heart) arterioles	Relaxation → vasodilation (β_2); contraction → vasoconstriction (α_1, α_2); contraction → vasoconstriction (muscarinic ACh receptors).	Contraction → vasoconstriction.
Skin and mucosal arterioles	Contraction → vasoconstriction (α_1).	Vasodilation, which may not be physiologically significant.
Skeletal muscle arterioles	Contraction → vasoconstriction (α_1); relaxation → vasodilation (β_2); relaxation → vasodilation (muscarinic ACh receptors).	No innervation.
Abdominal viscera arterioles	Contraction → vasoconstriction (α_1, β_2).	No innervation.
Brain arterioles	Slight contraction → vasoconstriction (α_1).	No innervation.
Kidney arterioles	Constriction of blood vessels → decreased urine volume (α_1).	No innervation.
Systemic veins	Contraction → constriction (α_1); relaxation → dilation (β_2).	No innervation.

*Subcategories of α and β receptors are listed if known.

†Grouped with glands because they release substances into the blood.

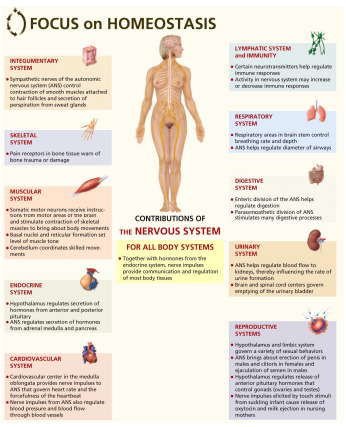
Integration and Control of Autonomic Functions

- Functions such as heart rate and force of ventricular contraction, blood pressure and blood vessel diameter are controlled by autonomic reflexes that occur when nerve impulses pass through an **autonomic reflex arc**.
- The reflex arc is composed of a **receptor, a sensory neuron, an integrating center, motor neurons** and **an effector**.

The Nervous System and Homeostasis

The nervous system is associated with virtually all functions of the body. It is intimately involved in maintaining homeostasis throughout the body.

The Nervous System and Homeostasis



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