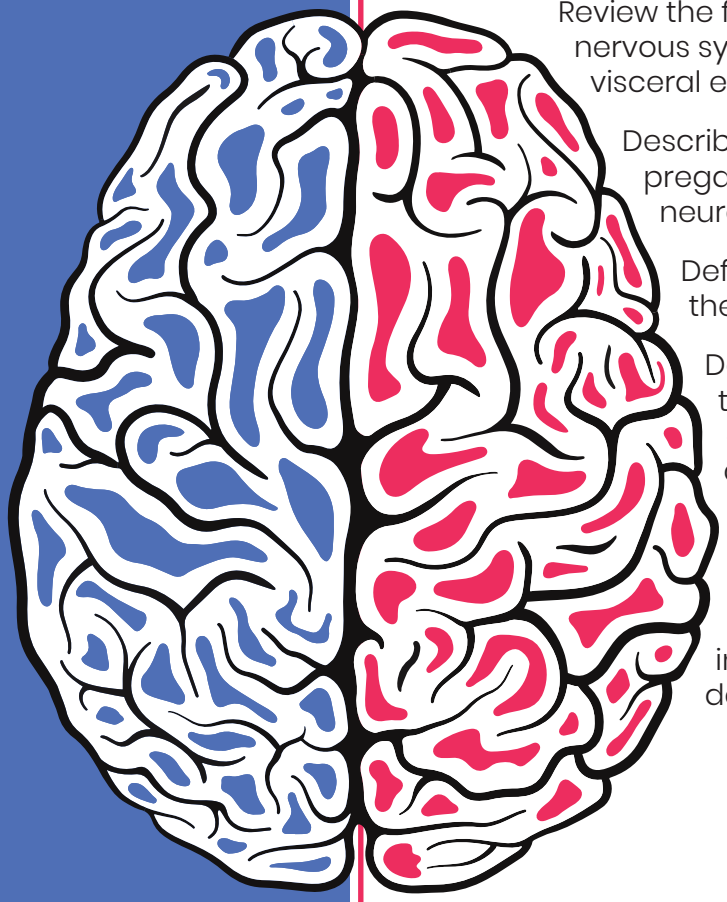
MEDICAL SCHOOL COMPANION

4

AUTONOMIC NERVOUS SYSTEM



Objectives

Review the functional organization of the autonomic nervous system, including visceral afferent and visceral efferent pathways.

Describe the location and distributions of preganglionic and postganglionic visceral motor neurons.

Define the different types of motor ganglia and their role in the autonomic nervous system.

Describe the functional organization and the distributions of the sympathetic and parasympathetic divisions of the autonomic nervous system.

Explain the sympathetic and parasympathetic pathways to the head.

Describe lesions of the sympathetic innervation to the head and the development of Horner's syndrome.

AUTONOMIC NERVOUS SYSTEM

General Organization of the Nervous System

The nervous system can be organized both **anatomically** and **functionally**:

1. **Anatomically**, the nervous system is divided into two parts: (1) **central nervous system** (CNS) consisting of the brain and spinal cord, and (2) **peripheral nervous system** (PNS) consisting of spinal nerves, cranial nerves, and their associated **ganglia**. Spinal nerves are discussed in the upper and lower limb and spinal cord chapters. Cranial nerves are covered in the brainstem chapter.

2. **Functionally**, the nervous system is divided into **somatic** and **visceral systems**. Each of these two systems contain both efferent (motor) and afferent (sensory) neurons.

    a. **Somatic pathways** provide innervation for **voluntary control of skeletal muscles** and **conscious perception** of sensory functions (touch, two-point discrimination, vibration, pain, temperature, proprioception) from peripheral receptors, located mostly in skin, muscles, tendons, and joint capsules. These pathways form the **somatic nervous system.**

    b. **Visceral (autonomic) pathways** provide innervation for **involuntary contraction of smooth and cardiac muscle, secretomotor** innervation to glands, and **sensory** perception from visceral structures. These visceral pathways form the **autonomic nervous system**.

Functional Organization of the Autonomic Nervous System

The **autonomic (visceral) nervous system (ANS)** functions to control internal visceral systems, maintaining homeostasis of the internal environment. The ANS consists of neural circuits that span both the **CNS** and **PNS**. Like the somatic nervous system, the ANS contains afferent and efferent neurons. These neurons operate primarily at involuntary levels. The ANS pathways regulate cardiovascular, respiratory, digestive, urinary, reproductive systems and many other autonomic reflex functions.

Note: The activity of the ANS is monitored and controlled by higher brain centers such as the **hypothalamus** via descending hypothalamic fiber tracts which synapse on and activate the preganglionic neurons located in preganglionic nuclei within the gray matter of the spinal cord or brainstem. These central and peripheral pathways will be described in this section.

Visceral Afferent Pathways

Visceral afferent neurons (pseudounipolar neurons) of the ANS have their cell bodies located within **sensory ganglia** of either spinal or cranial nerves. Visceral afferents provide the reflex circuitry from **chemoreceptors** (carotid bodies) and **baroreceptors** (aortic arch) utilized in respiratory control or regulation of blood pressure, respectively. Axons of visceral afferent nerves (hunger, nausea, pain, and bladder, rectal, and sexual functions) course in the cardiac, thoracic, abdominal, and pelvic sympathetic nerves.

Visceral pain most often results from pressure and stretch or ischemia. Viscera do not respond to burning or cutting. These visceral sensory pathways also provide important autonomic reflex innervations for digestive, urinary, sexual, and reproductive functions. These reflexes have neural connections with the spinal cord and brainstem.

Visceral afferent pain is an important part of the clinical analysis of a patient. It is more vague than somatic pain and is often expressed as **referred pain** corresponding to sensory dermatomes.

Visceral Efferent Pathways

The **visceral efferent outflow** of the ANS from the CNS is divided into two distinctively different pathways and divisions: **sympathetic (thoracolumbar) and parasympathetic (craniosacral) divisions**. These two divisions are discussed below and are markedly different in many ways. Each has its own pharmacological properties, neurotransmitters, physiological functions, and different neural circuits. However, they do share some common anatomical distributions.

▷ Clinical Application

An important principle to remember is that these two divisions, collectively, are responsible for innervating only three target tissues: (1) **smooth muscle**, (2) **cardiac muscle**, and (3) **glands**. The remainder of this chapter will describe the visceral motor system.

Neurons of the Visceral Motor System

The **visceral motor outflow** of the ANS from the CNS is organized different than the somatic motor outflow which consists of only a single neuron from the CNS to the motor endplate. Visceral efferent outflow is formed by a two-neuron circuit that courses between the CNS and the targets in the PNS. The first neuron in the circuit is the **preganglionic neuron**, and the second neuron is the **postganglionic neuron**.

1. **Preganglionic neurons:** The preganglionic (myelinated) neurons have their cell bodies located in the **CNS** within the **gray matter** of the **spinal cord** or in **motor autonomic nuclei** of the **brainstem**. Preganglionic axons exit the CNS with spinal or cranial nerves and synapse on postganglionic neurons in the peripheral nervous system.
2. **Postganglionic neurons**: The postganglionic neurons (unmyelinated) have their cell bodies located within **motor ganglia** in the PNS. The postganglionic axons exit the motor ganglia and continue their peripheral course to reach the targets (smooth muscle, cardiac muscle, and glands).

The basic circuits formed by these two visceral motor neurons are illustrated in Figure 4.2.

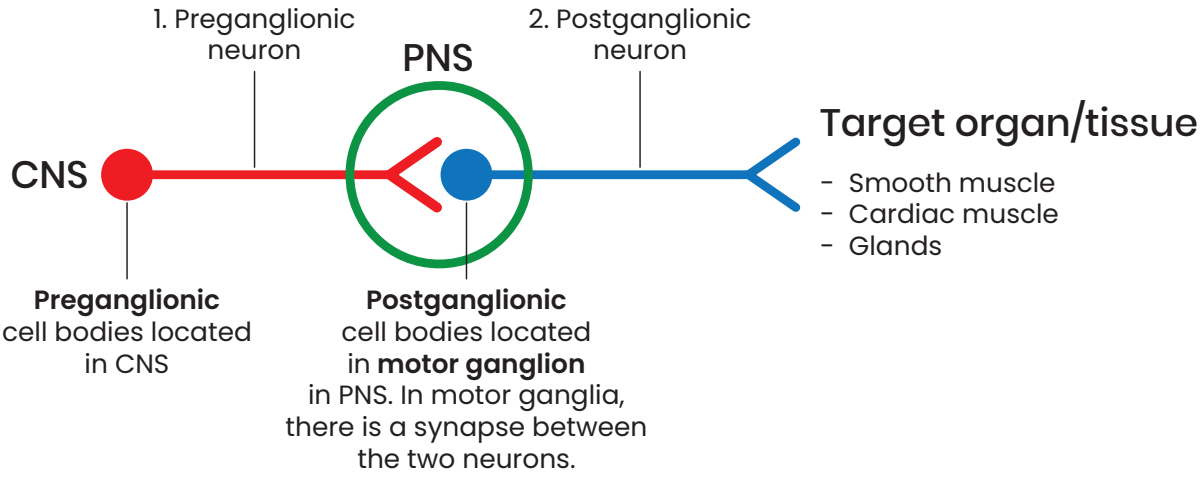


FIGURE 4.1 Visceral Efferent Neurons

Overview of Ganglia

Ganglia are defined as a collection of neuron cell bodies of common function located in the PNS. Ganglia are divided into two functional types: **sensory and motor.** Motor and sensory neurons located in ganglia in the PNS develop from **neural crest cells.** This same collection of nerve cell bodies in the CNS are called nuclei.

1. **Sensory ganglia** contain cell bodies of **pseudounipolar (unipolar) sensory neurons** (somatic afferent and visceral afferent). There is **no synapse** in a sensory ganglion. Sensory ganglia are associated with both spinal and cranial nerves.

    a. **Spinal nerves: Dorsal root ganglia** (DRG) are located on the dorsal roots of most of the 31 spinal nerves.

    b. **Cranial nerves:** Sensory ganglia are located along the course of certain cranial nerves (V, VII,VIII, IX and X) and are individually named for the associated cranial nerves (these are identified in the brainstem chapter).

3. **Motor autonomic ganglia** (Fig. 4.1)contain the cell bodies of **postganglionic neurons** (visceral efferent) of the ANS. In contrast to sensory ganglia, motor ganglia will always **have a synapse** between the preganglionic and postganglionic neurons within the ganglia.

    There are **three types** of autonomic motor ganglia in the PNS:

    a. **Chain** (paravertebral): **Chain ganglia** are segmentally located along the bilateral **sympathetic chain** that borders the vertebral column. The chain descends from the cervical region through the thorax and abdomen and terminates in the pelvic floor.

    b. **Collateral** (prevertebral or preaortic): In the abdomen, **collateral** sympathetic ganglia are located at the origins of the major branches of the abdominal aorta. In the pelvis, collateral sympathetic ganglia are scattered around the pelvic viscera or on the pelvic floor. Note that all collateral ganglia are located in the abdomen and pelvis below the diagram.

    c. **Terminal: Terminal parasympathetic** ganglia are located in the wall of or on the surface of the viscera innervated.

Sympathetic and Parasympathetic Divisions of the Autonomic Nervous System

The visceral motor efferent outflow of the ANS is divided into two distinct divisions: **sympathetic and parasympathetic divisions.** These two systems differ in organization, the location of preganglionic and postganglionic nerve cell bodies, neurotransmitters, and function. Not all, but most, target structures receive dual innervation from the sympathetic and parasympathetic systems, with each usually providing antagonistic functions.

When comparing sympathetics vs parasympathetics, these are 3 main things to focus on:

1. Location of pre- and postganglionic cell bodies.
2. Target structures
3. General effects of sympathetic or parasympathetic activation on these targets.
4. They usually have antagonistic effects.

Sympathetic (Thoracolumbar) Division

The **sympathetic nervous system** provides innervation to visceral structures located in the body wall, head, thorax, abdomen, and pelvis. It is important to note that sympathetic pathways provide most of the innervation to **vascular smooth muscle**. The effects of sympathetic motor innervation are often associated with the fight or flight response. These pathways are most active during stressful or fear-inducing situations. Acetylcholine (ACh) is the neurotransmitter for the preganglionic neurons, and norepinephrine for the postganglionic neurons (except for sweat glands(ACh).

Major Sympathetic Functions

- Pupil dilation
- Bronchodilation
- Cardiac acceleration
- Inhibition of peristalsis
- Constriction of smooth muscle sphincters of Gi Tract
- Sweating
- Piloerection
- Stimulation of glucose release
- Systemic vasoconstriction
- Emission
- Reduces glandular secretions

The sympathetic visceral motor neurons are illustrated in Figure 4.2.

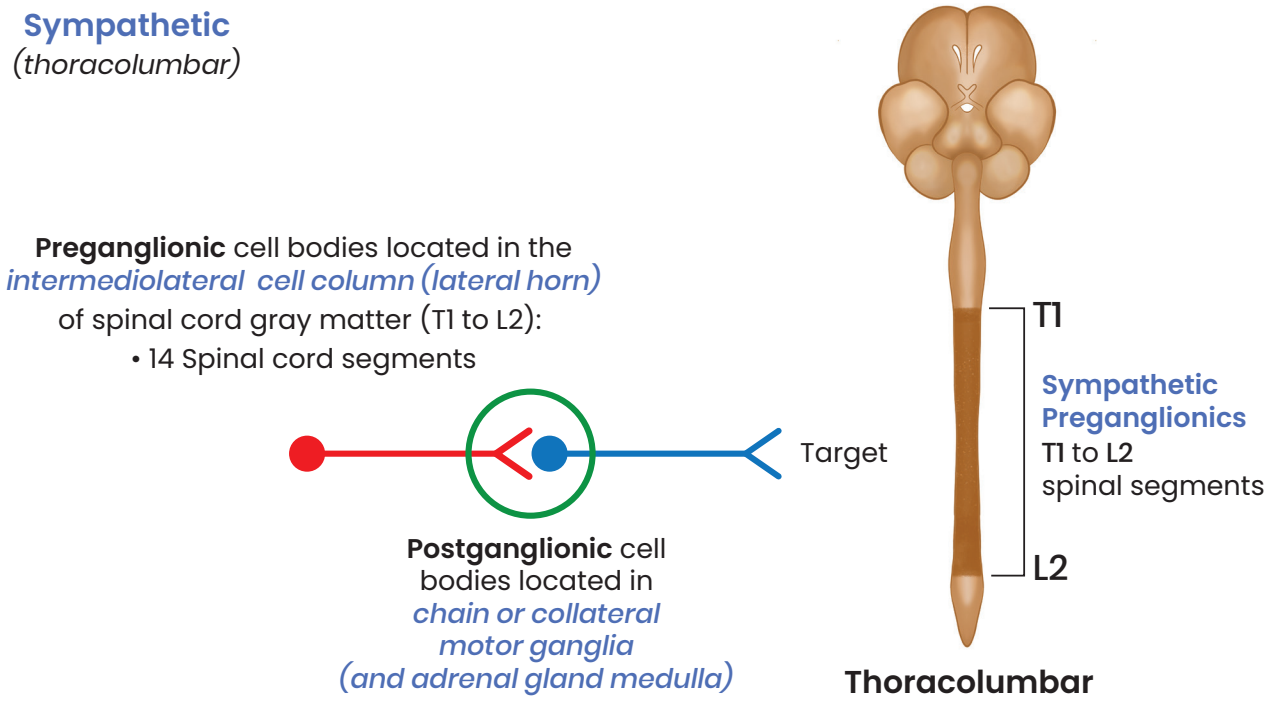


FIGURE 4.2 Sympathetic Nervous System

Overview of the Sympathetic Efferent Outflow

1. The **preganglionic nerve cell bodies** of the sympathetic nervous system are located in the **lateral horn (intermediolateral cell column) gray matter** of 14 spinal cord segments **(T1–L2)**.

    a. The **preganglionic axons** exit the spinal cord through the (1) ventral roots of spinal nerves, (2) spinal nerves, (3) ventral rami, and (4) white rami communicantes to enter the sympathetic chain of the PNS.

    b. These preganglionic neurons will synapse with postganglionics in either the **chain ganglia, collateral ganglia,** or the **adrenal medulla**.

2. The **postganglionic sympathetic nerve cell bodies** are located in either **chain** or **collateral motor sympathetic ganglia** in the PNS and the adrenal gland (its medulla is a sympathetic ganglion). The postganglionic axons leave these ganglia and course to their target tissues.

    a. The postganglionic neurons of the chain ganglia will innervate visceral structures in the **body wall, thorax,** and **head.**

    b. The preganglionic axons that synapse in collateral ganglia pass through the sympathetic chain without a synapse and will synapse on postganglionics in collateral ganglia. These preganglionics are called **thoracic** or **lumbar splanchnic nerves.** The postganglionic neurons from the collateral ganglia innervate visceral structures in the **abdomen, pelvis,** and **perineum**.

Important clinical patterns of sympathetic innervation are shown in the table below:

Table 4.1: Distribution Patterns of Sympathetic Innervation

Circuits Utilizing Chain ganglia	Circuits Utilizing Collateral ganglia
1. **Body wall** (limbs and trunk) visceral structures	4. **Foregut** and **midgut** viscera of abdomen
2. **Head** visceral structures	5. **Hindgut, pelvic** and **perineal** viscera
3. **Thoracic** viscera	

Table 4.2: Functional Distribution of Sympathetic Nervous System

Preganglionic Cell Bodies in spinal cord segments of CNS	Postganglionic Cell Bodies in ganglia of PNS	Innervation – Target
		
T1 – L2	Chain ganglia	Vascular and arrector pili smooth muscle and sweat glands of the **body wall** and **limbs**
T1 – T2	Chain ganglia	Smooth muscle and glands of **head**
T1 – T5	Chain ganglia	Smooth and cardiac muscle and glands of **thoracic viscera** (heart, lungs, esophagus)
T5 – T12: **Thoracic splanchnic* nerves**	Collateral ganglia (aorticorenal, celiac, superior mesenteric)	Smooth muscle and glands of **foregut** (**FG**) and **midgut** (**MG**), kidneys, and gonads
L1 – L2: **Lumbar splanchnic* nerves**	Collateral ganglia (inferior mesenteric & pelvic ganglia)	Smooth muscle and glands of **pelvic** and **hindgut viscera** and **male genital tract** (emission)

*** Splanchnic = Visceral**

Distribution of Sympathetic (Fig. 4.3) System (Thoracolumbar)

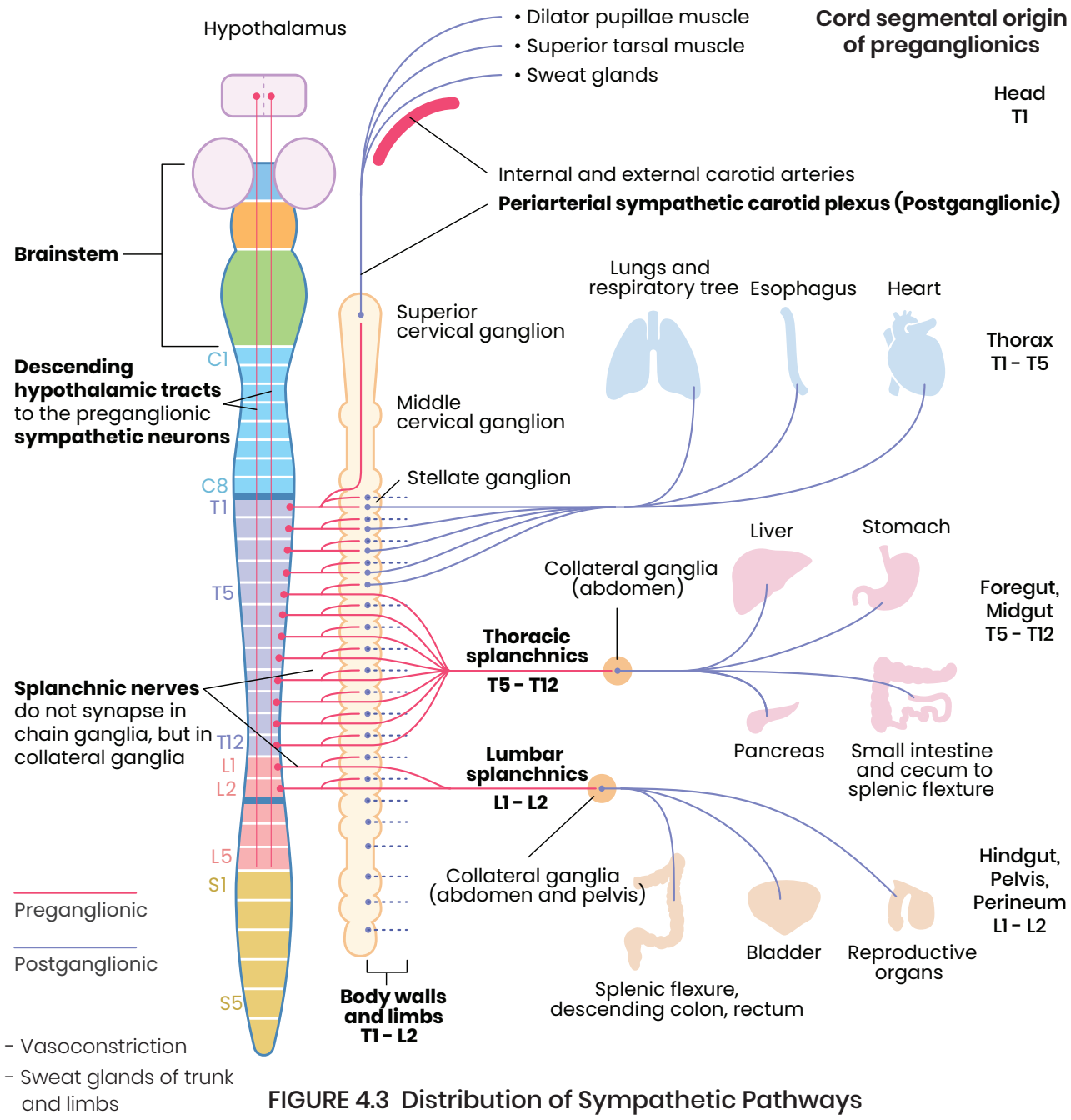


FIGURE 4.3 Distribution of Sympathetic Pathways

Horner syndrome: (ipsilateral)

1. Slight ptosis
2. Miosis
3. Anhidrosis

Three-Neuron pathway to head:

1. **First neuron** - Hypothalamus
2. **Second neuron** - T1 (preganglionics)
3. **Third neuron** - superior cervical ganglion (postganglionics)

Central Horner: Lesion of descending hypothalamic tract.

1. Brainstem
2. Spinal cord (C1 - T1 or T2)

Peripheral Horner:

1. Sympathetic chain compression
2. Carotid artery aneurysm

Route of Exit of Preganglionic Sympathetic Fiber Outflow from the Spinal Cord to the Sympathetic Chain

Note the following sequence of preganglionic axon outflow from the lateral horn of the spinal cord to the sympathetic chain (Fig. 4.4). Note that lesions can occur anywhere along this pathway.

1. Lateral horn (intermediolateral column) gray matter (T1-L2)
2. Spinal nerve ventral roots
3. Spinal nerve and ventral rami
4. White rami communicates
5. Sympathetic chain

The preganglionic outflow from the spinal cord to the sympathetic chain is illustrated in the figure below:

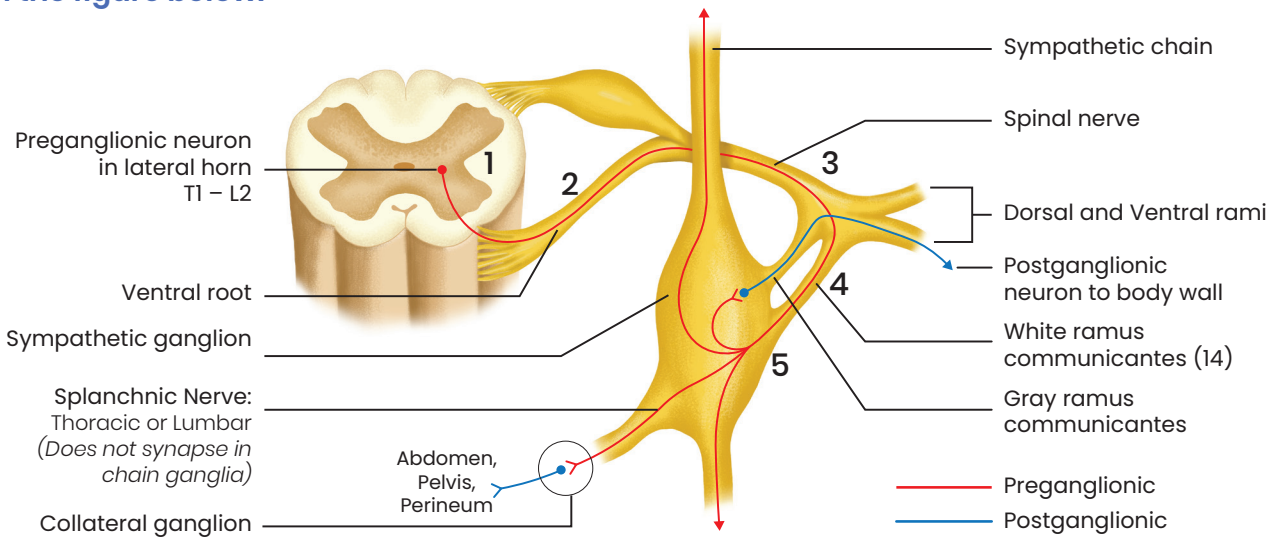


FIGURE 4.4 Efferent Outflow From Spinal Cord

Route of Preganglionic Fiber Outflow from the Sympathetic Chain Ganglia To Targets

After entering the sympathetic chain, there are several routes preganglionic fibers can take in relationship to the sympathetic chain to synapse with postganglionic neurons for supply to the targets.

1. Distribution to Head, Thorax, and Body Wall, and Limbs:

a. Preganglionic fibers between T1-L2 will synapse with postganglionics in the chain at their level of entrance.

b. Other preganglionics between T1-T2 will enter the chain and ascend or descend the chain to synapse with postganglionics in the chain at higher or lower ganglion levels.

c. After synapsing in chain ganglia, these postganglionic fibers leave the chain and course different routes to provide innervation to the head, thorax, and body wall and limbs.

2. Distribution to Abdomen, Pelvis, and Perineum

a. Other preganglionic fibers will pass through the chain ganglia **without synapse** and form **thoracic (T5–T12) splanchnic nerves** or **lumbar (L1–L2) splanchnic nerves.**

b. These **splanchnic preganglionic** fibers exit the sympathetic chain to synapse with postganglionics within **collateral ganglia** in the abdomen and pelvis. The postganglionics provide innervation to visceral targets in the abdomen, pelvis, and perineum.

Parasympathetic (Craniosacral) Division

The distribution of the **parasympathetic nervous system** provides autonomic innervation to the viscera of the head, thorax, abdomen and pelvis with **minimal** innervation to vascular smooth muscle. Note there are no parasympathetic innervations to the body wall and limbs. The functions of the parasympathetic system are generally in opposition to sympathetic functions. The neurotransmitter for both preganglionic and postganglionic neurons is ACh.

Major Parasympathetic Functions

- Pupil constriction
- Erection
- Bronchial constriction
- Decrease heart rate
- Increases peristalsis of gut tube
- Empties bladder and rectum
- Increases glandular secretion

The parasympathetic visceral neurons are shown in Figure 4.5.

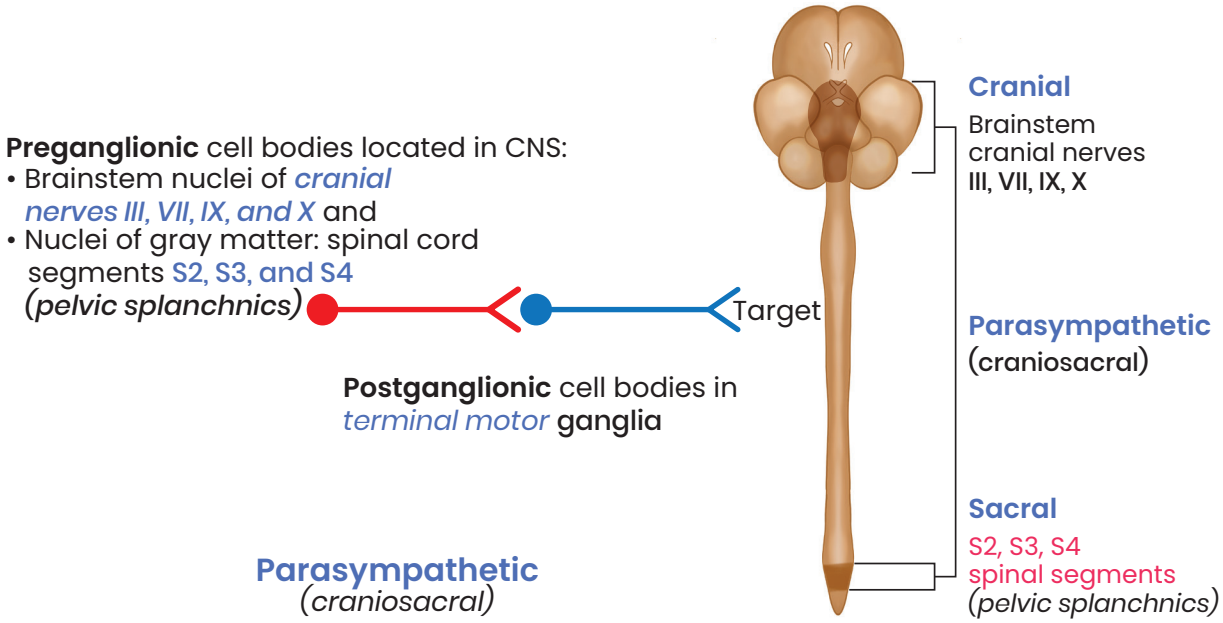


FIGURE 4.5 Parasympathetic Nervous System

General Organization of Parasympathetic Efferent Outflow

A. The **parasympathetic preganglionic neuron cell bodies** are found in one of two places within the central nervous system:

   1. **Brainstem**: Preganglionic parasympathetic cell bodies are located in parasympathetic motor nuclei of four cranial nerves located in the brainstem: **III, VII, IX, and X** (described in brainstem chapters).

   2. **Spinal Cord:** In the lateral aspect of the gray matter of the sacral spinal cord, preganglionic parasympathetic cell bodies are found at sacral levels: **S2, S3, and S4 (pelvic splanchnics).**

B. The **parasympathetic postganglionic neuron cell bodies** are located in **terminal motor ganglia** within the PNS. Except in the head, terminal ganglia are usually located on the surface of the viscera or embedded in the wall of the target viscera.

Distribution of Parasympathetic Innervation to Regions of Body

Pattern of Parasympathetic Distribution:

1. **Head**
2. **Thorax** and upper **abdomen** (foregut, midgut)
3. Lower **abdomen** (hindgut) and **pelvis**

The distribution of the parasympathetic pathways is outlined below:

1. **Cranial nerves III, VII, and IX:**

   Ganglia: Cranial nerves III, VII, and IX utilize ciliary, submandibular, pterygopalatine, and otic motor terminal ganglia in the head, respectively.
   Target: Supplies smooth muscle (III) of the orbit and glands (VII, IX) of the head (Except sweat glands).

2. **Cranial nerve X:**

   Ganglia: CN X utilizes terminal ganglia located within the wall or on the surface of the target viscera.
   Target: Supplies smooth and cardiac muscles and glands of thoracic, foregut, and midgut viscera

3. **Pelvic splanchnic nerves (S2, S3, and S4):**

   Ganglia: Utilize terminal ganglia located within the wall or on the surface of the target viscera or scattered on the pelvic floor
   Target: Supplies smooth muscles and glands of the viscera of pelvis, hindgut, and erectile tissue

The overall distribution of parasympathetic innervations are illustrated in Figure 4.6.

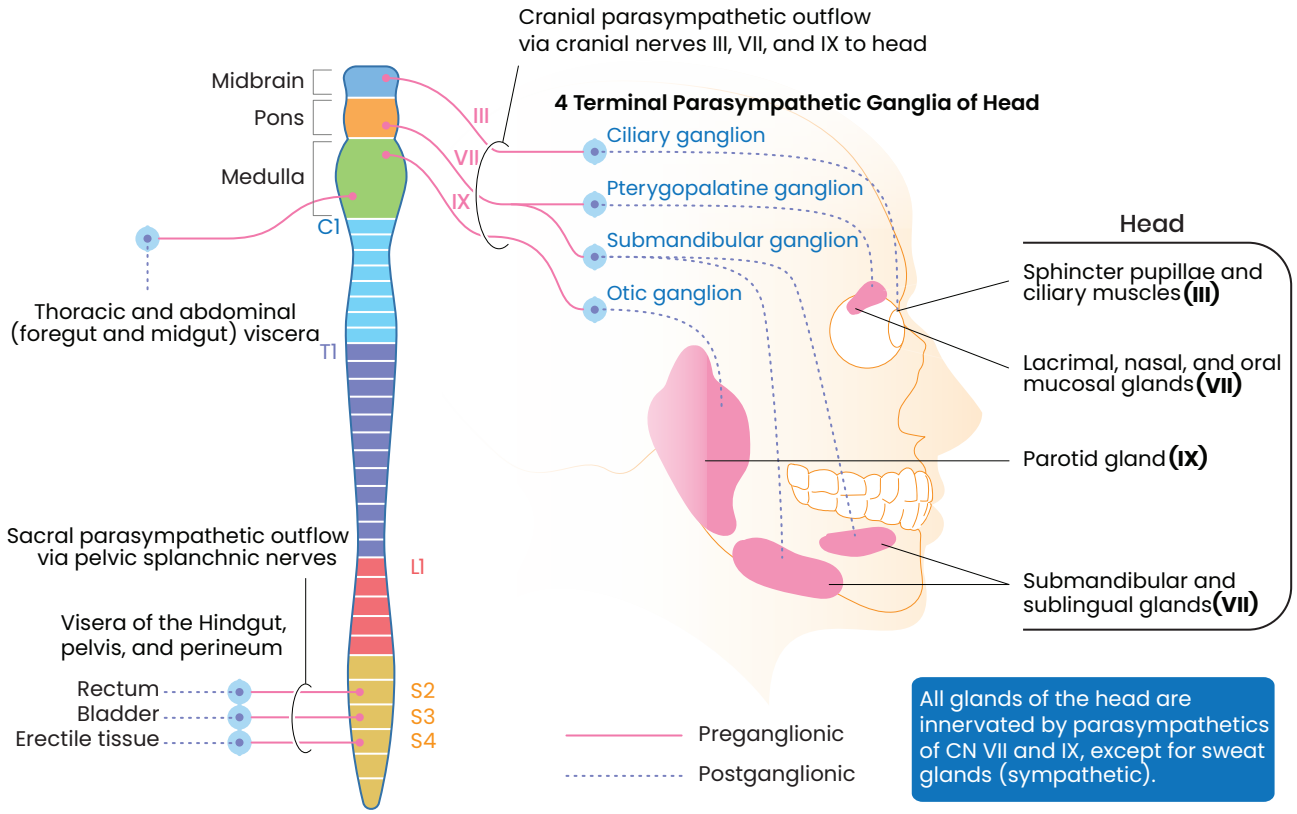


FIGURE 4.6 Parasympathetic Nervous System