2 Anatomy of the Sympathetic and Parasympathetic Nervous System

Colin Phillips and Katherine Ower

Introduction

The autonomic nervous system is composed of both the sympathetic and parasympathetic nervous systems. This system is immensely important in the general function and homeostasis of the body.

Sympathetic Nervous System

The sympathetic fibres originate from the spinal cord at T1 to either L2 or L3. However, these fibres travel in a chain that extends from the base of the skull to the coccyx. These branches are divided into either preganglionic or postganglionic neurons. For each preganglionic neuron, there is a cell body in the intermediolateral horn. The preganglionic neurons travel through the white ramus to a ganglion in the sympathetic chain. There are three possible courses from this ganglion: to synapse with a postganglionic neuron, to travel up or down the chain to a different ganglion, or to travel along the chain and outwards through a sympathetic nerve to a peripheral ganglion [1]. As sympathetic nerves leave a ganglion they rejoin with spinal nerves via a grey ramus, and provide sympathetic innervation to that respective area.

The one exception to this system is the sympathetic control of the adrenal gland. Here, preganglionic fibers travel directly to the target organ without synapsing first.

In contrast to the parasympathetic system, the sympathetic system also synapses with postganglionic fibers not at the target organ but rather in the sympathetic chain or ganglion [1]. The other differences between these systems can be seen in Table 2.1. Transmission of impulses along the sympathetic nervous system are designated as adrenergic. The primary neurotransmitter at the terminal junction of sympathetic postganglionic fibers is norepinephrine. Norepinephrine is synthesized and stored near the postganglionic terminal. The preganglionic neurons secrete acetylcholine [2]. One important exception to this organization is sweat glands, where the postganglionic fibers release acetycholine [1]. The other primary neurotransmitter in the adrenergic system is epinephrine. Both epinephrine and norepinephrine are secreted by adrenal medulla and interact with both alpha and beta receptors throughout the body [2], Table 2.1.

Stellate Ganglion

The stellate ganglion is an important target in chronic pain management. The inferior cervical plexus and the first thoracic ganglion combine

C. Phillips · K. Ower (✉)
Department of Anesthesia and Perioperative Medicine, Western University, London, ON, Canada
e-mail: Katherine.Ower@lhsc.on.ca

A. Abd-Elsayed (ed.), *Pain*, https://doi.org/10.1007/978-3-319-99124-5_2

Table 2.1 Comparison of Sympathetic to Parasympathetic (Figs. 2.1 and 2.2)

Characteristic	Sympathetic	Parasympathetic
Preganglionic Neuron Location	Lateral Horn of T1 – L2/3	Brainstem for cranial nerves III, VII, IX, and X as well as S2–4 lateral grey matter
Location of Ganglia	Terminal ganglia located at target organ	Sympathetic trunk and prevertebral ganglia located in anterior space of spinal cord
Type of transmission	Adrenergic	Cholinergic
Preganglionic neurotransmitter	Acetylcholine	Acetylcholine
Postganglionic neurotransmitter	Norepinephrine (NE)	Acetylcholine (ACh)
Receptors involved	α_1 - sweat gland secretion, ureter contraction α_2 - vasoconstriction β_1 - increased contractility and rate of heart β_2 - bronchodilation	M_2 – decreased heart rate and contraction M_3 – bronchoconstriction, vasodilation Nicotinic receptor – postsynaptic junction
Neurotransmitter metabolism and degradation	Norepinephrine is synthesized in both the adrenal medulla and the postganglionic neurons Epinephrine is synthetized in the adrenal medulla. Dopamine is converted to NE, which is in turn converted to Epinephrine NE is removed from the synaptic cleft by reuptake and diffusion NE is metabolized by catechol-O-methyltransferase (COMT)	Formed in presynaptic terminal by choline acetyltransferase from choline and acetyl coenzyme A ACh is hydrolyzed by acetylcholinesterase at the synaptic cleft
Common Agonists	Epinephrine acts at all four receptors NE has highest affinity for α_1 and β_1 Phenylephrine is a direct acting α_1 Ephedrine is indirect as it promotes release of NE Isoproterenol is a strong β agonist, with high β_1 selectivity Clonidine – a centrally acting α_2 agonist SNRI's – inhibit reuptake, increased NE activity Cocaine – inhibits reuptake of NE	Acetacholine, carbachol, methacholine, muscarine, pilocarpine are muscarinic agonists Nicotine and acetacholine are agonists at the nicotinic receptor Anticholinesterase – neostigmine increases presence of ACh at ganglion
Common Antagonists	Phentolamine – competitive antagonist at α_1 and α_2 Selective β_1 - examples are atenolol and bisoprolol Non-selective β - propranolol and labetolol	Atropine, scopolamine, and glycopyrrolate – common muscarinic antagonist

to form the ganglion [3]. It provides sympathetic stimulation to the upper extremity, as well as the head and neck. In general, sympathetic coverage of the head comes from the upper thoracic segments. They form three ganglia called the superior, middle, and inferior cervical ganglia [3].

Abdominal Sympathetic Chain

The celiac plexus provides innervation to the pancreas, stomach, liver and biliary system, spleen, and upper half of the duodenum. The celiac plexus has sympathetic input from the greater, lesser, and least splanchnic nerve as well

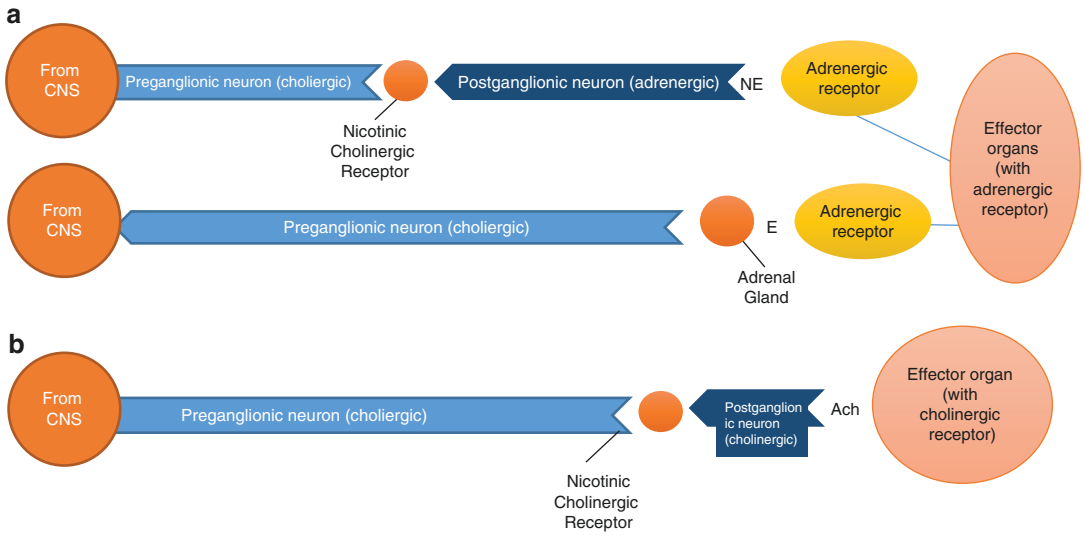

Fig. 2.1 Sympathetic and parasympathetic neuron synapse. (**a**) Sympathetic nervous system. (**b**) Parasympathetic nervous system. E Epinephrine, NE norepinephrine, Ach acetylcholine

as parasympathetic contribution from the vagus nerve [4]. It is located in the retroperitoneal space at the level L1 vertebrae, anterior to the abdominal aorta [4].

The greater, lesser, and least splanchnic nerves provide innervation to the abdominal organs, providing sympathetic innervation to the area and carrying sensory innervation from the organs [4]. The greater splanchnic nerve originates from T5–9, lesser from T10–11, and least from T12 [4].

Lumbar Sympathetic Chain

The function of the lumbar sympathetic chain is to provide tone to vasculature in the lower extremities as well as sympathetic output to the kidney, ureter, and genitals [4]. There are five paired lumbar sympathetic ganglia. The ganglia lie at the anterior aspect of the vertebral body. The first and second ganglia are often fused together, making it common a target for lumbar sympathetic blockade [4].

Hypogastric Plexus and Ganglion Impar

The hypogastric plexus is a continuation of the lumbar sympathetic chain. It is made up of both postganglionic fibers from this chain as well as parasympathetic fibers from the sacral plexus [2].

As the sympathetic chain continues through the pelvis, the two sides converge on the anterior aspect of the coccyx [2]. This ganglion is known as the ganglion impar. This ganglion can be targeted anterior to the sacrococcygeal junction. The most common indication for this block is coccydynia.

Parasympathetic Nervous System

The parasympathetic system arises from cranial nerves III, VII, IX and X as well as the second to fourth sacral segments [1]. Cranial nerve X, the vagus nerve, carries the majority of parasympathetic information. The four cranial nerves synapse at one of the parasympathetic ganglia.

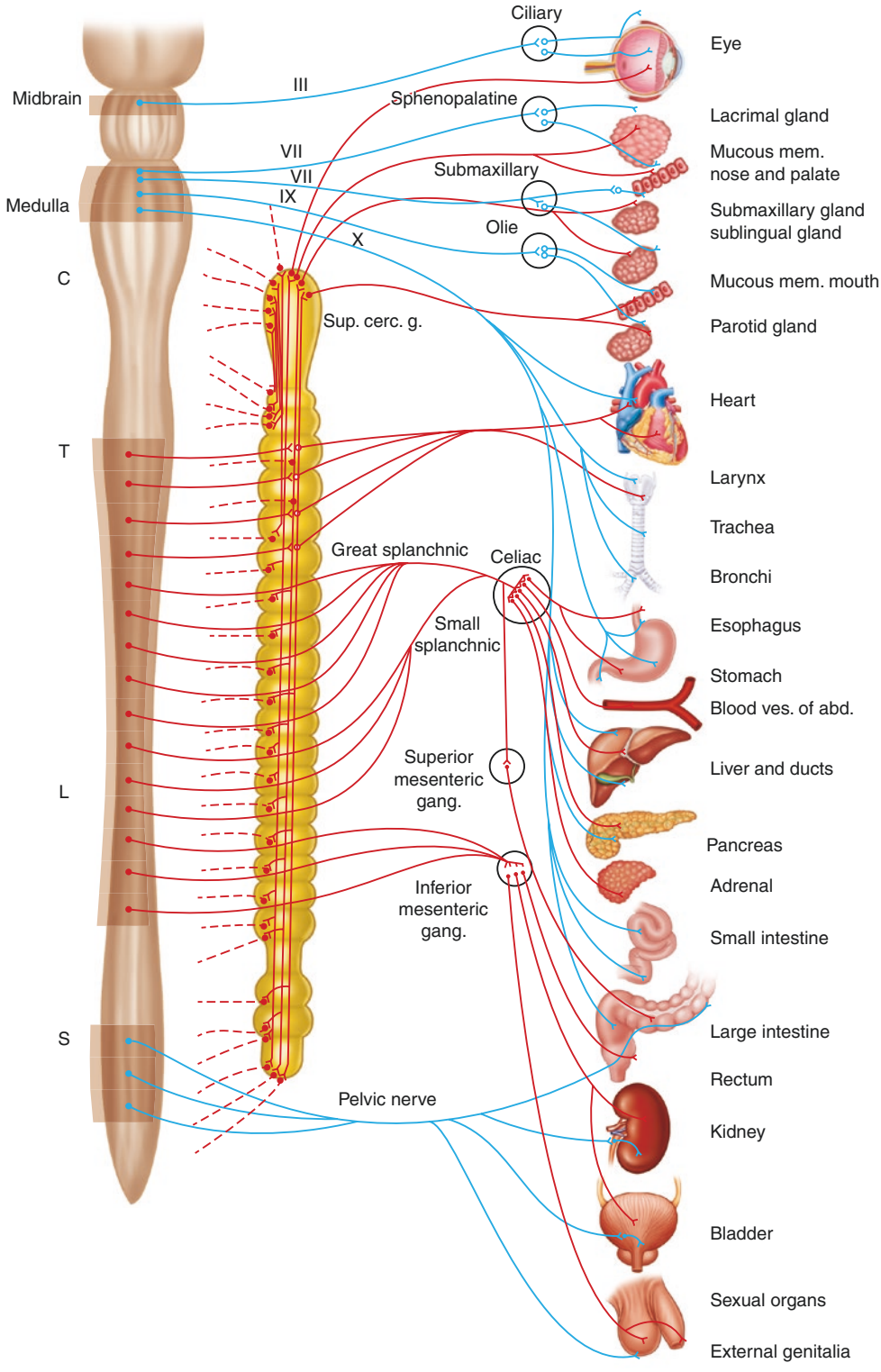

Fig. 2.2 Sympathetic and parasympathetic nervous systems

Unlike the sympathetic system, the parasympathetic preganglionic nerves travel to the organ being innervated where they synapse with postganglionic neurons.

In terms of neurotransmitters and function, the parasympathetic system is termed cholinergic. As with the sympathetic, acetylcholine is the primary neurotransmitter at the preganglionic neuron. However, acetylcholine is also the principle neurotransmitter at the postganglionic terminal. Acetylcholine interacts with both nicotinic and muscarinic receptors. It is synthesized and stored primarily in the presynaptic nerve terminal by the action of choline acetyltransferase [1], Table 2.1.

Head Parasympathetic Ganglia

There are four parasympathetic ganglia of the head and neck. These are the ciliary ganglion, pterygopalatine ganglion, submandibular ganglion, and the otic ganglion. Presynaptic parasympathetic fibers synapse in the ganglia and then travel to the target organ. Sympathetic nerves cross the ganglia without synapsing. The postsynaptic parasympathetic fibers then travel with the trigeminal nerve.

The ciliary ganglion innervates both the iris and ciliary muscle. The otic ganglion, which carries the glossopharyngeal nerve, provides innervation to mucous, salivary, and lacrimal glands [1]. Postganglionic fibers from the pterygopalantine ganglion supply glands in the mouth, nose, and tear gland. The submandibular ganglion provides innervation to the submandibular and sublingual glands.

Sacral Parasympathetic

The preganglionic fibers join other nerves to form the sacral plexus. The pelvic splanchnic nerves leave the plexus, and go on to innervate the distal colon, rectum, bladder, and external genitalia [4]. The function of this system is to provide peristalsis to the colon, contraction of the detrusor muscle in the bladder and relaxation of the sphincter between the urethra and bladder. To the genitals, it increases blood flow and causes smooth muscle relaxation.

High Yield Points

- The autonomic system is composed of both the sympathetic and parasympathetic systems.
- The sympathetic system originates from T1 to L2 in the spinal cord.
- The parasympathetic system originates from cranial nerves III, VII, IX, and X as well as sacral levels S2–4.
- The sympathetic chain synapses closer to the spinal cord, where as the parasympathetic synapses at the target organ. The exception to this is the adrenal gland, where the sympathetic system synapses at the gland.
- Acetylcholine is the preganglionic neurotransmitter for both systems.
- Norepinephrine is the postganglionic neurotransmitter for the sympathetic system, and acetylcholine works as the postganglionic neurotransmitter for the parasympathetic.
  - The notable exception to this is the sweat glands, where acetylcholine is the neurotransmitter.

Questions

1. Regarding the course of the sympathetic fibres, when leaving a ganglion in the sympathetic chain they may do all except:
   A. Synapse with a postganglionic neuron
   B. Travel directly to an organ to provide sympathetic innervation
   C. Travel along the chain and outwards through a sympathetic nerve to a peripheral ganglion
   D. Travel up or down the chain to a different ganglion
   Answer: B

2. Parasympathetic ganglia of the head and neck include all of the following except:
   A. The ciliary ganglion
   B. The otic ganglion
   C. The submandibular ganglion
   D. The stellate ganglion
   Answer: D
3. The celiac plexus does not innervate:
   A. The liver
   B. The kidneys
   C. The pancreas
   D. The stomach
   Answer: B

References

1. Hall JE, Guyton AC. Guyton and Hall textbook of medical physiology. Philadelphia: Saunders/Elsevier; 2016. pg 773, 774, 775, 776, 777.
2. Miller RD. Miller's anesthesia. New York: Elsevier/Churchill; 2005. pg 347, 348, 350, 1910.
3. Benzon H. Essentials of pain medicine and regional anesthesia. Toronto: Elsevier Canada; 1999. pg 441.
4. Waldman SD. Pain management. Philadelphia: Saunders; 2011. pg 1265, 1314, 1350.