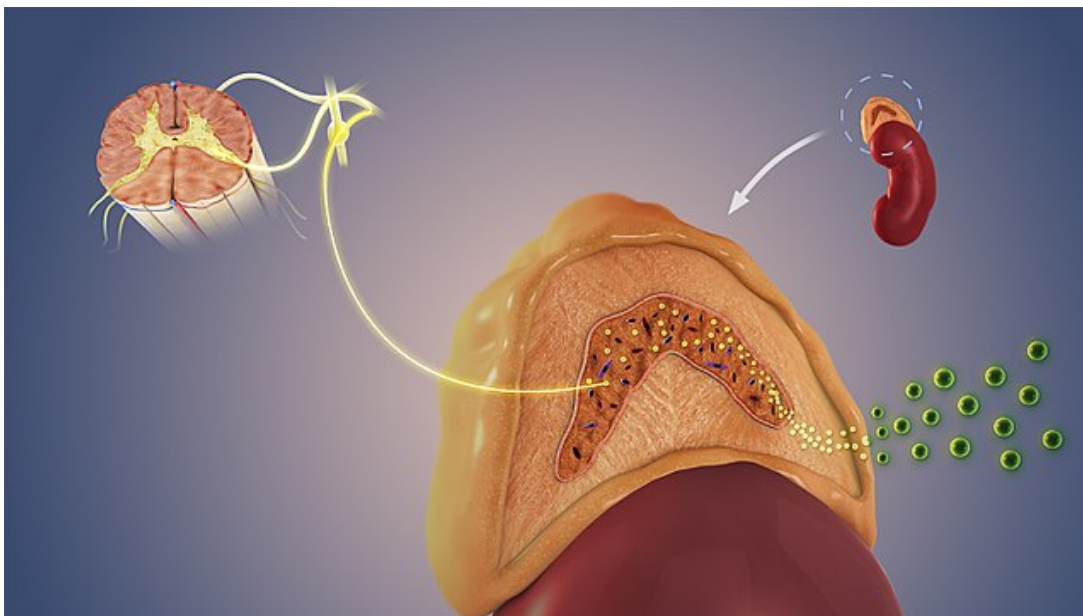


# Structure, Functions, and Diseases of the Autonomic Nervous System (ANS)

[See online here](#)

The nervous system helps organisms regulate and adapt to the changing conditions of the environment and the internal body. It communicates, controls, and innervates all the organs of the body. The nervous system can be subdivided into an anatomic (CNS and PNS) part and a functional (SNS and ANS/VNS) one. They are intrinsically tied to each other. The following article will provide a detailed insight into the structure, functionality, and pathology of the vegetative/autonomic nervous system (VNS or ANS).



## Functional Organization of the Vegetative/Autonomic Nervous System

The **vegetative or autonomic nervous system** (from Greek: *autos* = self; *nomos* = law) uses both sensory and efferent neurons, which especially control the function of the internal organs.

The characteristic feature of the autonomic system is that its efferent nerves emerge as myelinated fibers from the brain and spinal cord, are interrupted in their course by a synapse in a peripheral ganglion, and are then relayed for distribution as fine, non-myelinated fibers. In this respect, they differ from the cerebrospinal efferent nerves, which pass without interruption to their terminations.

The autonomic nervous system allows the higher brain centers (the cerebral cortex and the limbic system) to subconsciously control organs of the autonomic nervous system. It

controls functions such as sexual arousal, urination, digestion, and cardiorespiratory functions.

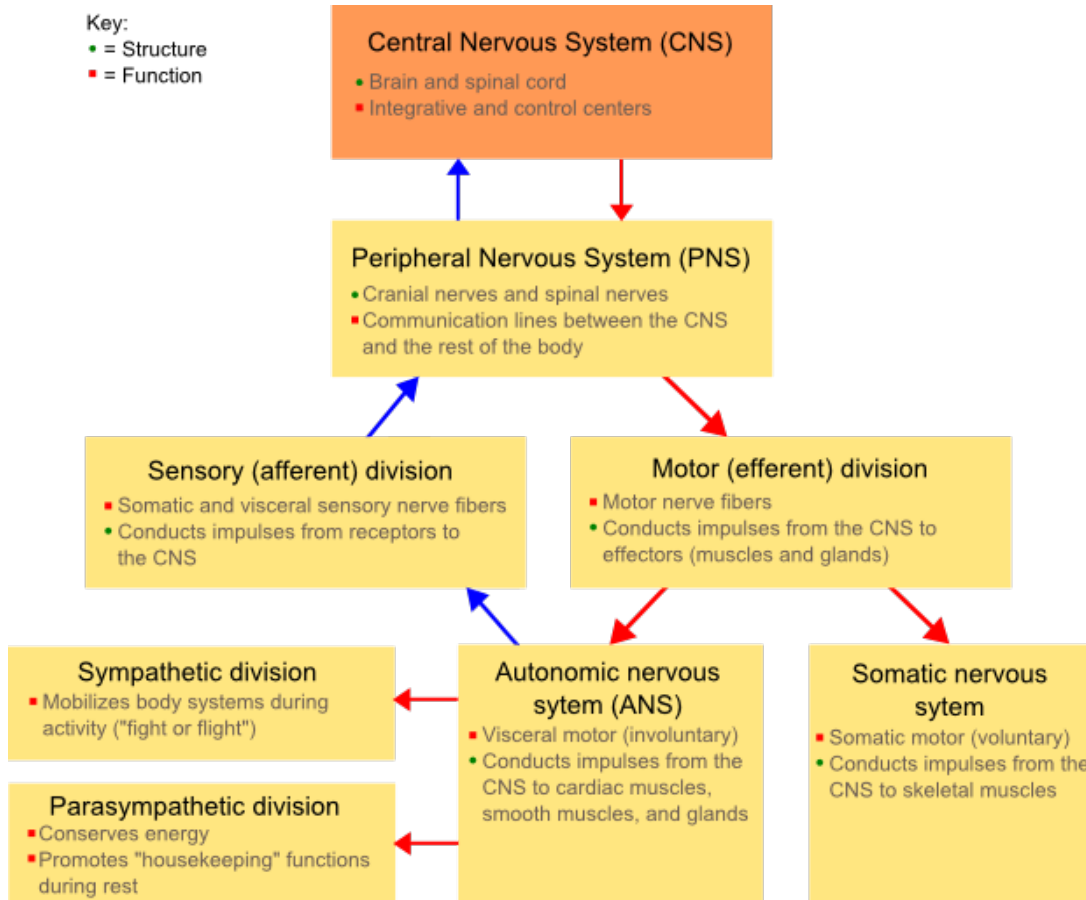


Image: Diagram showing the divisions of the nervous system. By Fuzzform. License: [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)

### Autonomic nervous system divisions

The autonomic nervous system has 2 divisions based on anatomical, functional, and to a considerable extent, pharmacological grounds: the sympathetic and parasympathetic divisions. The 2 divisions have antagonistic effects on the internal organs they innervate.

Anatomically, the sympathetic nervous system has its motor cell stations in the lateral grey column of the thoracic and upper 2 lumbar segments of the spinal cord. The parasympathetic system is less neatly defined anatomically since it is divided into a cranial outflow, which passes along the cranial nerves 3, 7, 9, and 10, and a sacral outflow, with cell stations in the 2nd, 3rd, and sometimes 4th sacral segments of the cord.

### Sensory neurons

The main input of the ANS particularly comes from **autonomic sensory (viscerosensory) neurons**, which are usually associated with **interoceptors** and act as sensory receptors in the blood vessels, the visceral organs, and the muscles. These neurons, which have the task to transduce information to the CNS, are usually located in the stomach and the lungs.

Unlike the signals that are triggered by a nice-smelling odor or a delicious-looking meal, the inner sensory signals are normally not experienced consciously, although the activation of the interoceptors can indeed advance into consciousness. Here, 2 typical

examples would be the pain caused by damaged intestines or angina pectoris (chest pain) caused by inadequate perfusion of the myocardium.

## Efferent neurons

On the other hand, efferent neurons forward the nerve impulses from the CNS to the target tissue (smooth muscle, heart muscle, or glands) and regulate visceral activities by an increase (**excitation**) or decrease (**inhibiting**).

Nerves of the **sympathetic** and **parasympathetic** nervous systems are responsible for these oppositional effects.

**Sympathetic neurons** accelerate the heartbeat, support the processes or effort of the body, and enable a 'fight-or-flight' reaction. This allows an improvement in performance and consequently, is stimulated in states of excitement, activity, and stress.

**Parasympathetic neurons, in contrast**, decelerate the heartbeat and induce a 'rest-and-digest' reaction. These neurons are responsible for relaxation, recreation, and inducing the regeneration of vital energy reserves.

Efferent responses are not controlled consciously, thus the activity of the ANS is unintentional. So-called 'lie-detector tests' are based on several autonomous reactions, since the pulse cannot be manipulated intentionally to half of the standard value. However, some people can alter their autonomic activities by applying adequate relaxing techniques.

Unlike the transmission of the impulse via the somatic motor neurons to the skeletal muscles, transmission to the visceral effectors involves 2 neurons.

## Structure of the ANS/VNS

The 1st of the 2 motor neurons in every motoric signaling pathway is called a **preganglionic neuron**. Its soma is located in the brain or the spinal cord and its axon, on the other hand, leaves the CNS as a part of a cranial nerve or a spinal nerve.

Generally, the preganglionic neuron connects with an **autonomic ganglion**, where it forms a synapse with the second neuron of the signaling pathway, the **postganglionic neuron**. The soma and the dendrites of the postganglionic neurons are located in an autonomic ganglion, where they form synapses with 1 or more preganglionic neurons.

The ANS transduces nerve impulses from the preganglionic neurons to the autonomic neurons, where the signals are forwarded to the postganglionic neurons and then transmitted to the target tissue.

The following example deserves mention:

**Spinal cord (CNS) → preganglionic neuron → autonomic ganglion → postganglionic neuron → heart (target tissue/effector)**

## Preganglionic neurons

### Thoracolumbar part

The sympathetic part of the ANS is also called the **thoracolumbar part** since the somas of the preganglionic neurons are located in the lateral horn of the 12 thoracic segments,

as well as the 1st 2 or 3 lumbar segments of the spinal cord.

### **Craniosacral part**

On the other hand, the parasympathetic part of the ANS is also referred to as the **craniosacral part** because the somas of the parasympathetic, preganglionic neurons are located in the nuclei of 4 cranial nerves in the area of the brain stem, as well as in the lateral horns of the second to the fourth sacral segment of the spinal cord.

## **Autonomic ganglia**

Autonomic ganglia are divided into 3 groups:

- Sympathetic chain ganglia
- Sympathetic prevertebral ganglia
- Parasympathetic ganglia

Sympathetic ganglia are located where the synapses between preganglionic and postganglionic sympathetic neurons interact.

### **Sympathetic chain ganglia**

Ganglia of the sympathetic trunk (**paravertebral ganglia**) are arranged in a vertical column on each side of the spine and reach from the base of the skull down to the coccygeal bone. For the most part, organs above the diaphragm are innervated by the postganglionic axons of the ganglia of the sympathetic trunk.

### **Sympathetic prevertebral ganglia**

Sympathetic prevertebral ganglia are located on the ventral side of the spine close to the large abdominal arteries. On the other hand, postganglionic axons of prevertebral ganglia innervate organs inferior to the diaphragm. The 3 largest **prevertebral ganglia** are:

- Coeliac ganglion (located right underneath the diaphragm)
- Superior mesenteric ganglion (located in the epigastric region)
- Inferior mesenteric ganglion (located in the umbilical region)

The branches of the sympathetic ganglionic chain have somatic and visceral distribution.

### **Somatic distribution**

Each spinal nerve receives 1 or more grey rami from a sympathetic ganglion which distributes postganglionic non-medullated sympathetic fibers to the segmental skin area supplied by the spinal nerve. These fibers are vasoconstrictive to the skin arterioles, pseudo motor to sweat glands, and pilomotor to the cutaneous hairs.

### **Visceral distribution**

Postganglionic fibers to the head and neck and to the thoracic viscera arise from the ganglion cells of the sympathetic chain. Those to the head ascend along the internal carotid and vertebral arteries, whereas those to the thoracic organs are distributed by the cardiac, pulmonary, and esophageal plexuses.

The abdominal and pelvic viscera are supplied by the postganglionic fibers which have their cell stations in more peripherally-placed prevertebral ganglia—the celiac, hypogastric, and pelvic plexuses—which receive their preganglionic fibers from the splanchnic nerves.

# Parasympathetic Ganglia

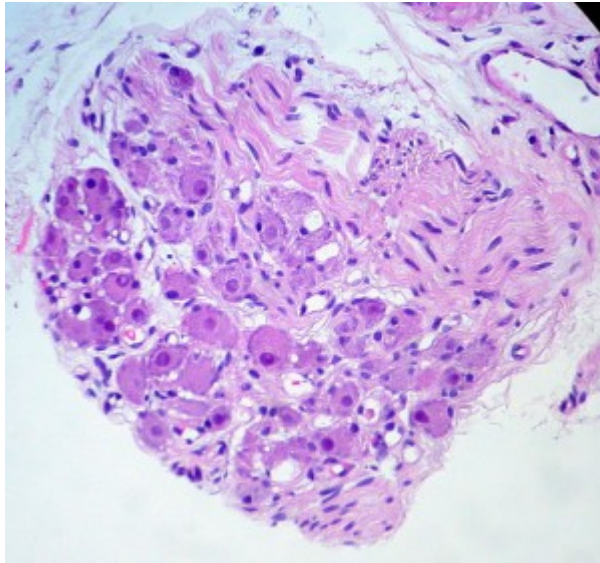


Image: Parasympathetic Ganglion, by Ed Uthman. License: [CC BY 2.0](#)

Preganglionic axons of the parasympathetic nervous system form synapses with postganglionic neurons in **terminal** or **intramural ganglia**. For the most part, the ganglia are located near to or inside the wall of an organ.

Axons of **preganglionic parasympathetic neurons** are usually longer than most of the axons of preganglionic sympathetic neurons since they reach from the CNS all the way to an intramural ganglion of the innervated organ.

## Afferent parasympathetic fibers

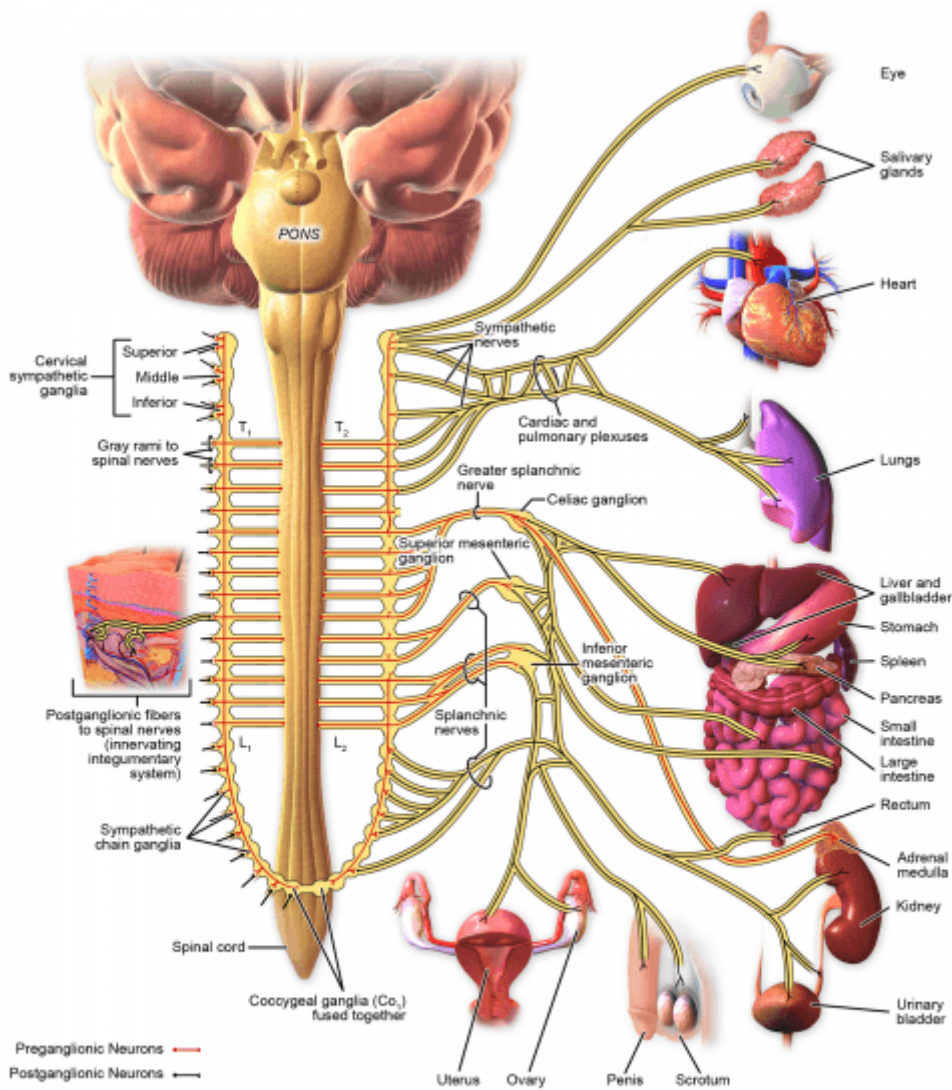
Visceral afferent fibers from the heart, lungs, and the alimentary tract are conveyed in the vagus nerve. Sacral afferents are conveyed in the pelvic splanchnic nerves and are responsible for visceral pain experienced in the bladder, prostate, rectum, and uterus.

Although afferent fibers are conveyed in both sympathetic and parasympathetic nerves, they are completely independent of the autonomic system. They do not relay in the autonomic ganglia and have their cell stations, just like somatic sensory fibers, in the dorsal ganglia of the spinal and cranial nerves. They simply use the autonomic nerves as a convenient anatomical conveyor system from the periphery to the brain.

## Postganglionic neurons

Axons of preganglionic sympathetic neurons can be connected to postganglionic neurons by the following 3 possibilities after they have headed to the ganglia of the sympathetic trunk:

1. An axon can form a synapse with a postganglionic neuron directly in the first reached ganglion.
2. An axon can ascend or descend to a higher or lower located ganglion before it is wired up with the postganglionic neuron, which runs vertically next to the sympathetic trunk.
3. An axon can run through the sympathetic ganglion without forming a synapse and end in a prevertebral ganglion to be switched over to the postganglionic neuron.



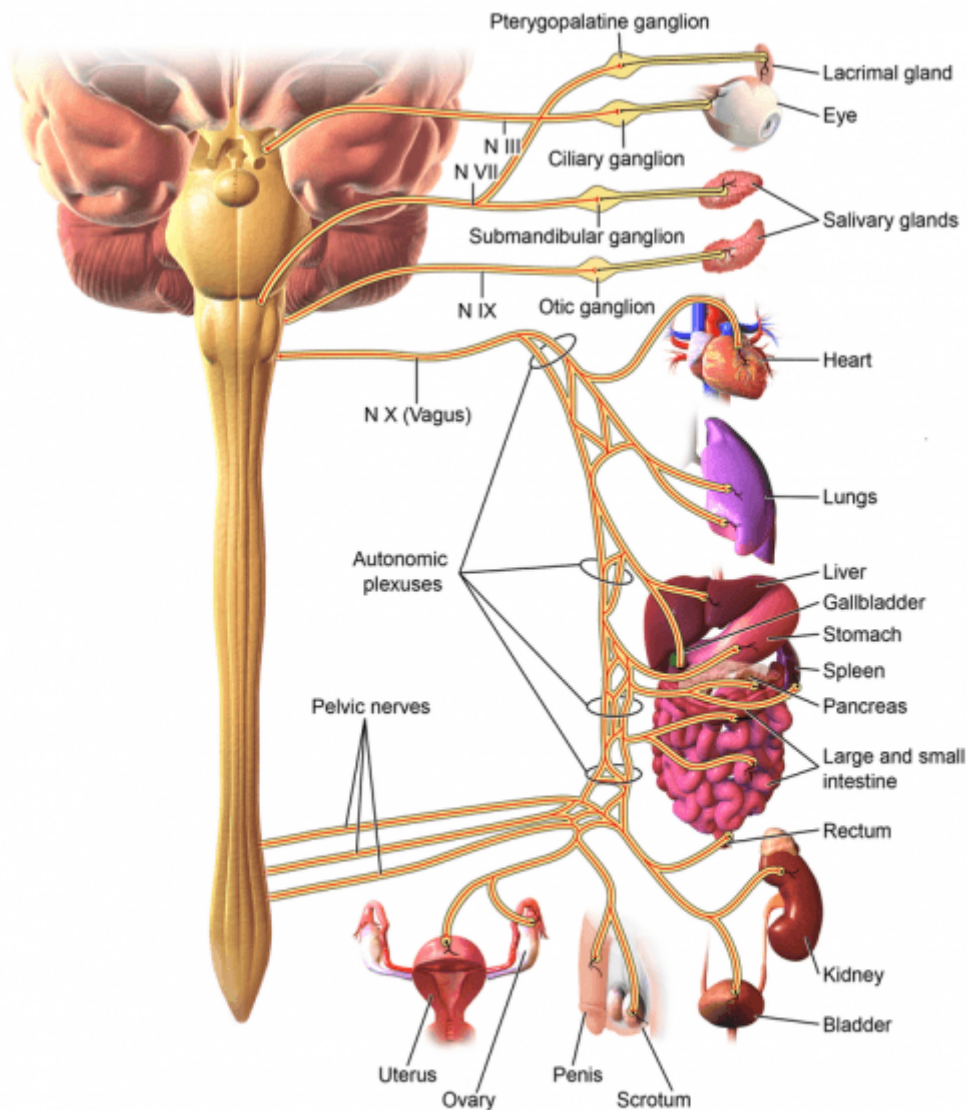
## Sympathetic Innervation

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A single preganglionic sympathetic fiber has many branches, which is the reason why it can be connected with more than 20 or more postganglionic neurons over synapses. The postganglionic axons typically end in different target tissues.

In these ganglia, presynaptic neurons only transmit to 4–5 postsynaptic neurons. They all individually provide a visceral target tissue and, as a consequence, this target tissue can be controlled separately by parasympathetic fibers.





## Parasympathetic Innervation

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### Autonomic plexuses

Axons and sympathetic and parasympathetic neurons form networks that are called **autonomic plexuses**. They run along large arteries and can be found in the thorax, the abdomen, and the pelvis. The large **cardiac plexus** in the thorax is in charge of the innervation of the heart and the **pulmonary plexus** for the bronchial tree.

The largest autonomic plexus is the **celiac (solar) plexus**, which passes onto the liver, gallbladder, stomach, pancreas, spleen, kidneys, adrenal cortex, testicles, and the ovaries.

### Neurotransmitter and Receptors of the ANS/VNS

Neurotransmitters are assigned to receptors - integral membrane proteins that are located in the plasma membrane of the postsynaptic neuron or a cell of the target tissue.

We differentiate between cholinergic and adrenergic neurons.

## Cholinergic neurons and receptors

The ANS includes the following cholinergic neurons:

- All sympathetic and parasympathetic preganglionic neurons
- Sympathetic postganglionic neurons for most of the sweat glands
- All postganglionic parasympathetic neurons

**Cholinergic neurons** release the neurotransmitter acetylcholine (ACh) which is stored in synaptic vesicles and liberated by exocytosis. After that, it diffuses through the synaptic cleft and binds to specific cholinergic receptors.

Cholinergic receptors are further subdivided into the nicotinic and muscarinic receptors that both bind to ACh.

**Nicotinic receptors** are embedded in the sympathetic and parasympathetic postganglionic neurons, as well as in the neuromuscular junction. They bear this term because nicotine simulates the action of ACh after binding to the receptors. In non-smokers, this substance is not traceable since nicotine is not a physiologically present substance in the human organism.

However, in the plasma membrane of all target tissues (the smooth muscle, myocardium, and the glands), the **muscarinic receptors** are present, which are supplied by the parasympathetic postganglionic axons. An inhibition occurs in several receptors, whereas in others, an excitation occurs. Similarly, sweat glands have muscarinic receptors which result in increased sweating.

**Note:** ACh is able to activate both types of cholinergic receptors, whereas nicotine is not able to activate muscarinic receptors; muscarine is not able to activate nicotinic receptors.

ACh is quickly deactivated by the enzyme acetylcholine esterase and thus, the effects triggered by cholinergic neurons are short.

## Adrenergic neurons and receptors

Noradrenaline (NA) is released in the ANS by adrenergic neurons. A great number of postganglionic sympathetic neurons are adrenergic. The NA is stored, just like ACh, in the synaptic vesicles, and released by exocytosis, which diffuses through the synaptic cleft and binds to specific adrenergic receptors of the postsynaptic membrane. The consequence is excitation or inhibition of the effector cell.

NA, as well as adrenaline, binds to the adrenergic receptors. The NA can be released as a neurotransmitter by sympathetic postganglionic neurons or as a hormone by the adrenal medulla, into the blood. Adrenaline is solely released as a hormone.

Also, the adrenergic receptors can again be subdivided into 2 subtypes which are innervated by most of the postganglionic sympathetic neurons. They are called alpha ( $\alpha$ )-receptors and beta ( $\beta$ )-receptors, which are further subdivided according to their specific answers and the corresponding binding properties ( $\alpha 1$ ,  $\alpha 2$ ,  $\beta 1$ ,  $\beta 2$ , etc.).

Broadly speaking, an activation of the  $\alpha 1$ - and  $\beta 1$ -receptors induces an excitation, whereas  $\alpha 2$ - and  $\beta 2$ -receptors yield an inhibition of the target tissue.

**Note:** NA stimulates  $\alpha$ -receptors stronger than the  $\beta$ -receptors. There is no noticeable



difference in the stimulation of  $\alpha$ - and  $\beta$ -receptors with ADR. NA remains longer in the synaptic cleft than the ACh. Consequently, the effects triggered by the adrenergic neurons last longer than the actions caused by cholinergic neurons.

## Autonomic reflexes

Answers that are triggered by the nerve impulses in an autonomic reflex arc are called **autonomic reflexes**. They play a key role in the following processes:

- Blood pressure (i.e. by adjusting the heart rate)
- Digestion (adjustment of motility and muscle tone in the GI tract)
- Defecation
- Urination (regulating the opening and closing of the sphincter)

The main control and integration center of the ANS is the hypothalamus, which receives sensory information about visceral functions (smell, taste, temperature etc.). Signals of the limbic system, which cohere with emotions, influence this process as well. The signals coming from the hypothalamus affect the autonomous centers in the brain stem, as well as in the spinal cord (medulla spinalis).

An autonomic reflex arc consists of the following components:

### Receptor

- The distal end of a sensory neuron is the receptor of an autonomic reflex arc, which reacts to a stimulus and triggers a nerve impulse. Usually, autonomic sensory receptors are associated with interoceptors.

### Sensory neurons

- The sensory neuron forwards nerve impulses to the CNS.

### Integration center

- The main integration centers for the autonomic reflexes are located in the hypothalamus and the brain stem. Some autonomic reflexes are situated in the integration centers of the spinal cord, which are mostly responsible for urination and defecation.
- Connectivity: interneurons of the CNS forward signals from the sensory neurons to the motor neurons.

### Motor neurons

- Signals triggered by the integration centers leave the CNS, via motor neurons, towards the target tissue. Two motor neurons connect the CNS in an autonomic reflex arc with the effector. The impulse is transduced by the preganglionic neuron to an autonomic ganglion from where it is forwarded through the postganglionic neuron to the target tissue.

### Target tissue (effector)

- The effectors of the autonomic reflex are the smooth muscles, the heart muscle, or the glands.

# Diseases of the ANS/VNS

In contrast to the somatic nervous system, the tissues that are innervated by the ANS also keep running while damaged. The heart, for example, keeps beating if it is isolated from its vegetative nerve fibers. Smooth muscle cells of the gastrointestinal tract contract independently and rhythmically, and the glands produce several substances without being controlled via the ANS. For this reason, most autonomous responses cannot be deliberately changed or suppressed by a significant rate.

Contrary to the somatic nervous system, the tissues which are innervated by the ANS also work after damage to the neural nourishment. The heart, for example, keeps beating if it is disrupted from its vegetative nerve fibers. Smooth muscle cells of the gastrointestinal (GI) tract contract independently and rhythmically and the glands produce several substances without the control of the ANS. This is why most autonomic answers cannot be changed or suppressed intentionally to a greater extent.

However, the autonomic/vegetative nervous system can be affected by a pathological impairment.

## Horner's Syndrome

Horner's Syndrome describes the damaged sympathetic nerves of one side of the face, which affects the sympathetic output of the superior cervical ganglion. This can be caused by an injury, a disease, or a hereditary mutation. A commonly examined scenario is where Horner's syndrome can present in a **Pancoast lung tumor**—its metastatic spread can invade the sympathetic chain and cause this syndrome.

Horner's syndrome is characterized by the following symptoms:

- **Ptosis** (drooping of the upper eyelid)
- **Miosis** (constricted pupil)
- **Enophthalmos** (posterior displacement of the eyeball)

## Further diseases of the autonomic nervous system

- Raynaud's phenomenon
- Autonomic dysreflexia
- Autonomic neuropathy
- Dysautonomia
- Hyperhidrosis
- Megacolon
- Sudeck's disease
- Vagotomy

## Autonomic nervous system dysfunction

ANS dysfunction (also known as dysautonomia) leads to non-functional organs of the ANS. Some of the causes of this dysfunction include autonomic neuropathy, HIV/AIDS, multiple sclerosis, paraneoplastic syndromes, and Parkinson's disease. Patients present with features of unopposed efferent neuronal function which include anhydrosis, anxiety, constipation, orthostatic hypotension, tachycardia, vertigo, and bowel incontinence, difficulty in swallowing, exercise intolerance, and chronic fatigue.

Treatment of ANS dysfunction entails symptomatic relief using a wide array of drugs such

as proton pump inhibitors (PPIs). H2 receptor antagonists can be used to reverse hyperacidity and reflux while anticholinergic agents such as scopolamine reverse the effects of disorders such as hyperhidrosis and tachycardia.

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