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ARTICLE : REVIEW

The autonomic nervous system

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Brigid was born on Hayling Island, near Portsmouth on the south coast of England. She studied medicine at the University of Edinburgh and remained in Edinburgh for two years as a junior doctor. She is currently working at the Palmerston North Hospital as a paediatric registrar while trying to decide between career paths in emergency medicine or obstetrics & gynaecology. In the meantime, she is enjoying the increased availability of outdoor activities and has taken up white water kayaking, mountain biking, surfing, tramping and rescuing penguins.

Table 1. Functions of the parasympathetic nervous system
Constriction of the pupil (miosis)
Lacrimation
Salivation
Slowing of the heart (bradycardia)
Production of bronchial secretions
Production of digestive juices from stomach, pancreas and gallbladder
Peristalsis
Sphincter relaxation
Urination and defecation
Penile erection

THE PARASYMPATHETIC NERVOUS SYSTEM

Physiologically, the functions of the parasympathetic nervous system can be thought of as "rest and digest" (see Table 1). These include salivation, production of digestive juices, peristalsis, urination and defecation. Throughout the parasympathetic nervous system, the neurotransmitter is acetylcholine. Drugs such as atropine block the effects of acetylcholine



ABSTRACT

This is a short accessible review of the autonomic nervous system for medical students. The sympathetic and parasympathetic systems are different anatomically and physiologically. Parasympathetic nerves are all either cranial nerves (notably the vagus nerve) or sacral nerves (from S2, 3, 4). The sympathetic nervous system emerges only from the spinal cord between T1 and L2. Any sympathetic supply above this must travel upwards from T1. For the organism as a whole, the most important parasympathetic nerve is the vagus nerve. In a spinal injury, the vagus nerve is spared, whereas the extent to which the sympathetic innervation is lost depends on the site of injury.

INTRODUCTION

The autonomic nervous system is a part of the nervous system which functions "automatically" without a conscious control, to regulate physiological processes in the body.

Functionally it is divided into two: the sympathetic nervous system and the parasympathetic nervous system. Although these are often mentioned as a pair and appear together on diagrams, they are quite different functionally, anatomically and physiologically. In general, these two components of the autonomic nervous system act in opposition to one another.

Autonomic nerves may carry sensory (afferent) signals to the brain and spinal cord, or efferent signals from the brain to the target organs. Central control of the autonomic nervous system comes mostly from the hypothalamus, with some input from the limbic system and the reticular activating system.

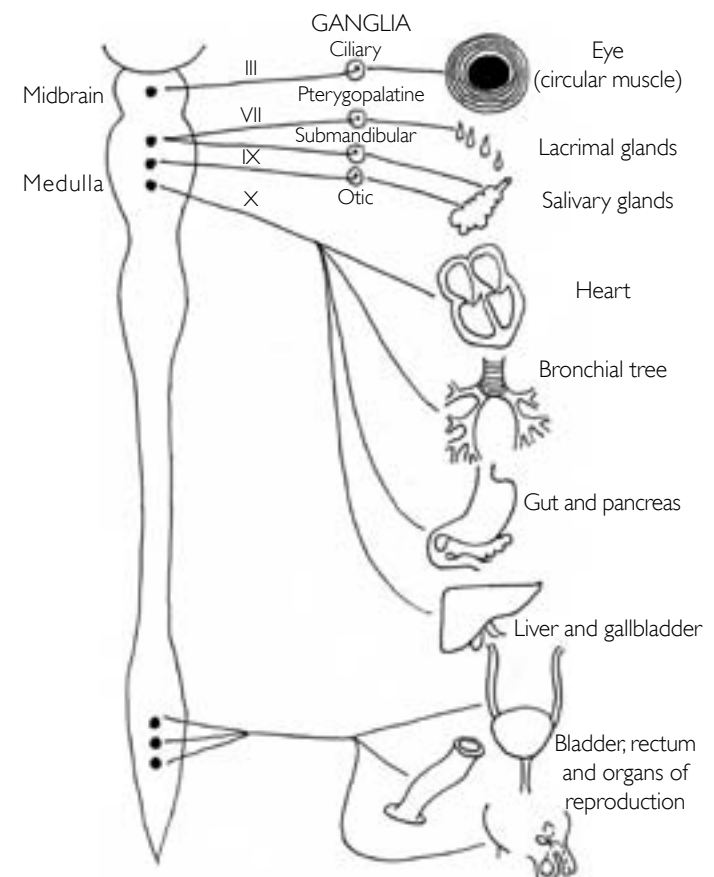


Figure 1. The parasympathetic nervous system

and therefore counter many of the effects of the parasympathetic nervous system (see Figure 3).

Anatomically, the parasympathetic nervous system consists mostly of fibres which travel in cranial nerves III, VII, IX, and X. (Additionally, a small amount of parasympathetic supply comes from the sacral nerve roots, S2, 3 and 4 (see Figure 1).

For the organism as a whole, the most important of these is the *vagus nerve* (Lt: "wandering"), which supplies parasympathetic signals to almost all the organs of the thorax and abdomen (those derived from foregut and midgut). The functions of the *vagus* are many and complex; only parasympathetic functions are described here.

The *vagus nerve* arises from the medulla oblongata, and leaves the skull via the jugular foramen. In the neck, it travels in a neurovascular bundle which includes the internal jugular vein and the common carotid artery. In the mediastinum, the *vagus nerves* lie on either side of the oesophagus, and cross the diaphragm with the oesophagus. Below the diaphragm the *vagus nerves* contribute to a plexus around the coeliac arterial trunk, known as the *coeliac plexus* (formerly called the solar plexus) which also includes sympathetic fibres. The plexus has branches which pass throughout the abdomen and therefore it is impossible to follow the *vagus nerve* as a single structure, although its fibres extend to almost all the viscera.

As a result of its wide distribution, many different stimuli (such as stretching the peritoneum) can stimulate the *vagus nerve* to produce bradycardia. This effect can be used therapeutically in the treatment of supraventricular tachycardia: massaging the carotid sinus (which is innervated by the *vagus nerve*) can slow the heart by vagal stimulation.

Since the *vagus nerve* is a cranial nerve, it is spared in lesions of the spinal cord. A high spinal cord injury, e.g. at C5, may render the patient quadriplegic, but the processes of digestion still continue because the function of the *vagus* is unaffected. However, the sacral component of the parasympathetic nervous system is lost, resulting in loss of voluntary continence and sexual function.

The other cranial nerves which contain parasympathetic fibres are as follows:

- The *oculomotor nerve* (cranial nerve three) contains both motor and parasympathetic fibres. The motor fibres supply the muscles of the orbit. The parasympathetic action of cranial nerve iii is on both the iris muscles of the eye (constricting the pupil) and the ciliary muscle, which causes thickening of the lens for close focusing (accommodation).
- The *oculomotor nerve* emerges from the midbrain, and has a comparatively long course before it enters the orbit via the superior orbital fissure. In conditions of raised intracranial pressure (such as trauma or intracranial bleeding), the innermost part of the temporal lobe (the uncus) may be squeezed downwards by pressure from above (uncal herniation). This causes stretching of the *oculomotor nerve*. The first sign of this is a dilated pupil which fails to respond to light (known colloquially as a "blown pupil"); later, complete paralysis of the nerve occurs. A blown pupil occurs on the same side as the lesion. It is a sign of severe intracranial pathology, usually requiring immediate surgery.
- The *facial nerve* (cranial nerve seven) contains, motor, sensory and parasympathetic fibres. The motor fibres supply the muscles of facial expression. The sensory fibres convey taste sensation from the anterior two thirds of the tongue. The parasympathetic fibres innervate the sublingual and submandibular salivary glands (but not the parotid gland), and the lacrimal gland of the orbit.
- The *glossopharyngeal nerve* (cranial nerve nine) is a predominantly sensory nerve whose parasympathetic fibres supply the parotid salivary gland. The ninth nerve also conveys sensation from the throat and the posterior third of the tongue. The sensory component of the gag reflex is mediated via the ninth nerve. It also conveys taste sensation from the posterior third of the tongue.
- The *pelvic splanchnic nerves* (sometimes called the *nervi erigentes*) emerge from the sacral nerve roots S2, 3 and 4. They supply parasympathetic

fibres to hindgut-derived structures, which includes the distal third of the colon, the rectum and the anus. They are responsible for voluntary relaxation of the urinary and anal sphincters, and hence for continence. They also supply the genitals and are responsible for penile erection.

Table 2. Functions of the sympathetic nervous system

Increased heart rate (tachycardia)
Vasoconstriction of skin and viscera
Sweating
Bronchodilation
Dilation of the pupil (mydriasis)
Inhibition of production of digestive juices
Inhibition of peristalsis
Relaxation of the uterus

THE SYMPATHETIC NERVOUS SYSTEM

Physiologically, the functions of the sympathetic nervous system are concerned with readying the body to deal with threat or danger: the "fight or flight" response (see Table 2). Blood is diverted away from non-vital areas and directed to the heart, brain and muscles, while heart rate and breathing are increased to meet extra demands for blood and oxygen. The sympathetic nervous system is also responsible for the transmission of visceral pain from organs such as the gut, bladder and uterus.

Many functions of the sympathetic nervous system oppose those of the parasympathetic nervous system, although it is important to note that not all organs receive innervation from both components of the autonomic nervous system. For example, most large arteries are richly innervated by the sympathetic nervous system but are sparsely innervated by the parasympathetic system.

The sympathetic nervous system innervates the adrenal glands. The adrenal medulla can be thought of as a specialised synapse, which releases its transmitter directly into the bloodstream. The transmitters involved are adrenaline and noradrenaline. The effects of the sympathetic nervous system are therefore mediated both by direct neural connections and by endocrine effects of adrenaline and noradrenaline in the circulation.

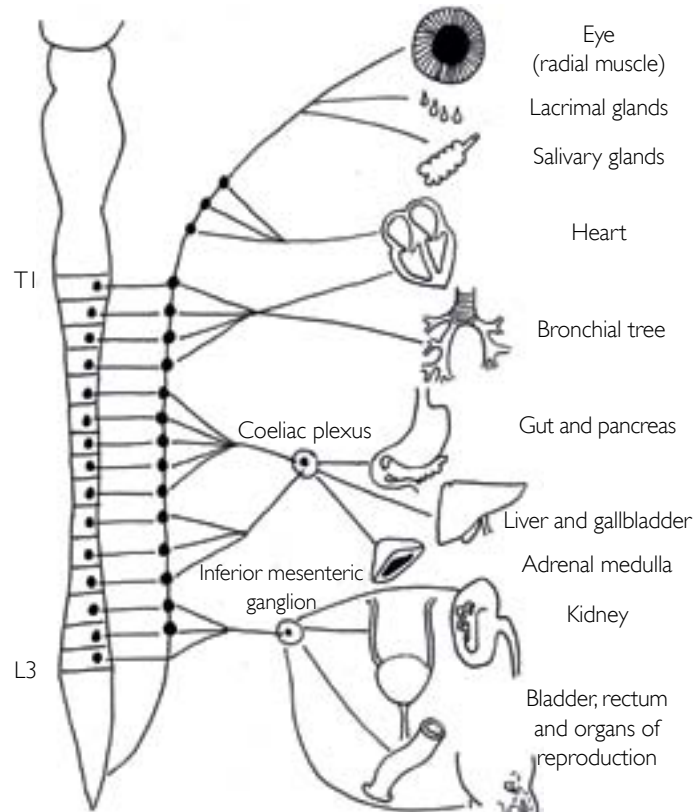


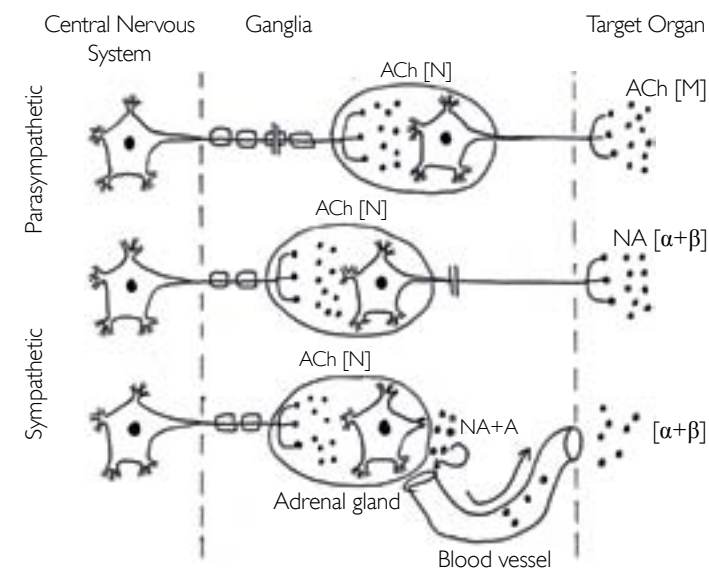
Figure 2. The sympathetic nervous system

A *phaeochromocytoma* is a rare tumour of the adrenal medulla which releases pathological quantities of adrenaline and noradrenaline into the circulation.

The neurotransmitter between the sympathetic nervous system and the target organs is noradrenaline (except in sweat glands where it is acetylcholine). Noradrenaline receptors are categorised as α or β . α receptors tend to be found in blood vessels, where they promote vasoconstriction. β_1 receptors are found in the heart, where they stimulate rate and force of contraction. β_2 receptors are found in the smooth muscle of the bronchial tree and the uterus, where they cause relaxation.

Fibres from the sympathetic nervous system arise only from the spinal cord, between T1 and L2. Most sympathetic fibres travel only a short distance, before synapsing in a chain of ganglia, the sympathetic trunk, which lies on either side of the vertebral bodies. Thereafter, the fibres pass to the target organs (see Figures 2 and 3).

In order for sympathetic supply to reach the arm and the head, sympathetic fibres must travel upwards from T1. Lesions of the T1 nerve root, or the sympathetic trunk above T1, will remove all sympathetic innervation of the head and arm on that side. The effects of this are most pronounced in the head, and are known as *Horner's syndrome* (see Table 3).



Ach	Acetylcholine	[N]	Nicotinic acetylcholine receptor
NA	Noradrenaline	[M]	Muscarinic acetylcholine receptor
A	Adrenaline	[α+β]	Alpha and beta adrenoceptors

Figure 3. Autonomic ganglia

Horner described three specific findings: a constricted pupil (miosis), a drooping upper eyelid (ptosis, because levator palpebrae superioris which opens the eyelid is partly innervated by the sympathetic nervous system), and unilateral absence of sweating (anhidrosis). A fourth sign not described by Horner is unilateral congestion of the nasal mucosa, which can be thought of as "stuffynosis".

The upper sympathetic trunk passes over the dome of the pleura. A tumour at the apex of the lung (known as a *Pancoast tumour*) may erode the sympathetic trunk at this point, causing Horner's syndrome, which may

Table 3. Features of Horner's syndrome

Constriction of the pupil (miosis)
Drooping of the upper eyelid (ptosis)
Absence of sweating (anhidrosis)
(Unilateral nasal congestion: "stuffynosis")
All of these signs are present on the same side as the lesion.

First described by Johann Friedrich Horner, Swiss ophthalmologist, in 1869.

be the presenting feature of the tumour. Horner's syndrome may also result from damage to the sympathetic system at other sites such as the brain stem, the cervical cord, or the internal carotid artery.

Alternatively, some patients who suffer from excessive sweating of the hands (hyperhidrosis) may have the upper sympathetic trunk surgically divided via the pleural space. This procedure, a thoracic sympathectomy, can be performed using keyhole surgery, having deliberately collapsed the lung first. Dividing the trunk around T2 can reduce sweating in the hands without necessarily causing Horner's syndrome.

Above T1, the sympathetic trunk continues as three more ganglia, the superior, middle and inferior cervical ganglia. The inferior cervical ganglion is sometimes continuous with the T1 ganglion and this is known as the *stellate* (Lt: "star-shaped") *ganglion*.

Fibres from the superior cervical ganglion enter the skull with the internal carotid artery and form a plexus, the internal carotid plexus, whose branches accompany several cranial nerves to supply the structures of the head.

Below L2, the sympathetic chain continues downward in a series of ganglia which terminates at the coccyx.

Because it arises only from the spinal cord, the sympathetic nervous system is affected by lesions of the spinal cord. A cord lesion above T1 will result in complete loss of sympathetic function for the whole body. This can make the patient's heart rate and blood pressure unstable (the heart receives its own sympathetic supply from T1, 2 and 3). A cord lesion lower down, e.g. at T8, will be less severe in its effects, but sympathetic function will still not be normal, since the adrenal glands themselves receive sympathetic innervation from T10-12.

CONCLUSION

We hope that this introduction will provide the reader with a good working understanding of the autonomic nervous system. However, for the sake of simplicity many anatomical and physiological details have been omitted. We recommend that the interested reader consult a textbook of neuroanatomy if further detail is required.

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