THE AUTONOMIC NERVOUS SYSTEM

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The nervous system is divided into the somatic nervous system which controls organs under voluntary control (mainly muscles) and the Autonomic Nervous System (ANS) which regulates individual organ function and homeostasis, and for the most part is not subject to voluntary control. It is also known as the visceral or automatic system.

The ANS is predominantly an efferent system transmitting impulses from the Central Nervous System (CNS) to peripheral organ systems. Its effects include control of heart rate and force of contraction, constriction and dilatation of blood vessels, contraction and relaxation of smooth muscle in various organs, visual accommodation, pupillary size and secretions from exocrine and endocrine glands. Autonomic nerves constitute all of the efferent fibres which leave the CNS, except for those which innervate skeletal muscle. There are some afferent autonomic fibres (i.e. transmit information from the periphery to the CNS) which are concerned with the mediation of visceral sensation and the regulation of vasomotor and respiratory reflexes, for example the baroreceptors and chemoreceptors in the carotid sinus and aortic arch which are important in the control of heart rate, blood pressure and respiratory activity. These afferent fibres are usually carried to the CNS by major autonomic nerves such as the vagus, splanchnic or pelvic nerves, although afferent pain fibres from blood vessels may be carried by somatic nerves.

The ANS is primarily involved in reflex arcs, involving an autonomic or somatic afferent limb, and then autonomic and somatic efferent limbs. For instance, afferent fibres may convey stimuli from pain receptors, or mechanoreceptors and chemoreceptors in the heart, lungs, gastrointestinal tract etc.

There may then be a reflex response to this involving autonomic efferent fibres causing contraction of smooth muscle in certain organs (e.g. blood vessels, eyes, lungs, bladder, gastrointestinal tract) and influencing the function of the heart and glands. The efferent limbs of these reflexes may also involve the somatic nervous system (e.g. coughing and vomiting). Simple reflexes are completed entirely within the organ concerned, whereas more complex reflexes are controlled by the higher autonomic centres in the CNS, principally the hypothalamus.

The ANS is divided into two separate divisions called the Parasympathetic and Sympathetic Systems, on the basis of anatomical and functional differences. Both of these systems consist of myelinated preganglionic fibres which make synaptic connections with unmyelinated postganglionic fibres, and it is these which then innervate the effector organ. These synapses usually occur in clusters called ganglia. Most organs are innervated by fibres from both divisions of the ANS, and the influence is usually opposing (e.g.the vagus slows the heart, whilst the sympathetic nerves increase its rate and contractility), although it may be parallel (e.g. the salivary glands). The responses of major effector organs to autonomic nerve impulses are summarised in Table 1.

Organ	Sympathetic stimulation	Parasympathetic stimulation
Heart	↑ heart rate β_1 (and β_2) ↑ force of contraction β_1 (and β_2) ↑ conduction velocity	↓ heart rate ↓ force of contraction ↓ conduction velocity
Arteries	Constriction (α_1) Dilatation (β_2)	Dilatation
Veins	Constriction (α_1) Dilatation (β_2)	
Lung	Bronchial muscle relaxation (β_2)	Bronchial muscle contraction ↑ bronchial gland secretions
Gastrointestinal tract	↓ motility (β_2) Contraction of sphincters (α)	↑ motility Relaxation of sphincters
Liver	Glycogenolysis (β_2 and α) Gluconeogenesis (β_2 and α) Lipolysis (β_2 and α)	glycogen synthesis
Kidney	Renin secretion (β_2)	
Bladder	Detrusor relaxation (β_2) Contraction of sphincter (α)	Detrusor contraction Relaxation of sphincter
Uterus	Contraction of pregnant uterus (α) Relaxation of pregnant and non-pregnant uterus (β_2)	
Eye	Dilates pupil (α)	Constricts pupil ↑ lacrimal gland secretions
Submandibular and parotid glands	Viscous salivary secretions (α)	Watery salivary secretions

PARASYMPATHETIC NERVOUS SYSTEM

The preganglionic outflow of the parasympathetic nervous system arises from the cell bodies of the motor nuclei of the cranial nerves III, VII, IX and X in the brain stem and from the second, third and fourth sacral segments of the spinal cord. It is therefore also known as the cranio-sacral outflow.

Preganglionic fibres run almost to the organ which is innervated, and synapse in ganglia close to or within that organ, giving rise to postganglionic fibres which then innervate the relevant tissue. The ganglion cells may be either well organised (e.g. myenteric plexus of the intestine) or diffuse (e.g. bladder, blood vessels).

The cranial nerves III, VII and IX affect the pupil and salivary gland secretion, whilst the vagus nerve (X) carries fibres to the heart, lungs, stomach, upper intestine and ureter. The sacral fibres form pelvic plexuses which innervate the distal colon, rectum, bladder and reproductive organs.

In physiological terms, the parasympathetic system is concerned with conservation and restoration of energy, as it causes a reduction in heart rate and blood pressure, and facilitates digestion and absorption of nutrients, and consequently the excretion of waste products.

The chemical transmitter at both pre and postganglionic synapses in the parasympathetic system is Acetylcholine (Ach). Ach is also the neurotransmitter at sympathetic preganglionic synapses, some sympathetic postganglionic synapses, the neuromuscular junction (somatic nervous system), and at some sites in the CNS. Nerve fibres that release Ach from their endings are described as

cholinergic fibres.

The synthesis of Ach occurs in the cytoplasm of nerve endings and is stored in vesicles in the presynaptic terminal. The arrival of a presynaptic action potential causes an influx of calcium ions and the release of the contents of several hundred vesicles into the synaptic cleft. The Ach then binds to specific receptors on the postsynaptic membrane and increases the membrane permeability to sodium, potassium and calcium ions, which results in an excitatory post-synaptic potential. The action of Ach is terminated by hydrolysis with the enzyme Acetyl Cholinesterase.

The specific Ach receptors have been subdivided pharmacologically by the actions of the alkaloids muscarine and nicotine. The actions of Ach at the preganglionic synapses in both the parasympathetic and sympathetic systems is mimicked by nicotine, and all autonomic ganglia are therefore termed nicotinic. Nicotinic transmission also occurs at the neuromuscular junction, in the CNS, the adrenal medulla and at some sympathetic postganglionic sites (see later). However, the actions of Ach at the parasympathetic postganglionic nerve ending is mimicked by muscarine. Muscarinic transmission also occurs at certain sites in the CNS.

SYMPATHETIC NERVOUS SYSTEM

The cell bodies of the sympathetic preganglionic fibres are in the lateral horns of the spinal segments T1-L2, the so called thoraco-lumbar outflow. The preganglionic fibres travel a short distance in the mixed spinal nerve, and then branch off as white rami (myelinated) to enter the sympathetic ganglia. These are mainly arranged in two paravertebral chains which lie anterolateral to the vertebral bodies and extend from the cervical to the sacral region. They are called the sympathetic ganglionic chains. The short preganglionic fibres which enter the chain make a synapse with a postsynaptic fibre either at the same dermatomal level, or at a higher or lower level, and then the longer postganglionic fibres usually return to the adjacent spinal nerve via grey rami (unmyelinated) and are conveyed to the effector organ.

Some preganglianic fibres do not synapse in the sympathetic chains but terminate in separate cervical or abdominal ganglia, or travel in the greater splanchnic nerve and directly synapse with chromaffin cells in the adrenal medulla. As discussed above, Ach is the neurotransmitter via a nicotinic receptor at the preganglionic synapse. The adrenal medulla is innervated by preganglionic fibres and therefore adrenaline is released from the gland by stimulation of nicotinic Ach receptors.

At most postganglionic sympathetic endings, the chemical transmitter is noradrenaline, which is present in the presynaptic terminal as well as in the adrenal medulla. In sweat glands, however, postganglionic sympathetic fibres release Ach and this transmission is nicotinic.

In contrast to the parasympathetic system, the sympathetic system enables the body to be prepared for fear, flight or fight. Sympathetic responses include an increase in heart rate, blood pressure and cardiac output, a diversion of blood flow from the skin and splanchnic vessels to those supplying skeletal muscle, increased pupil size, bronchiolar dilation, contraction of sphincters and metabolic changes such as the mobilisation of fat and glycogen.

Adrenaline and noradrenaline are both catecholamines, and are both synthesized from the essential amino acid phenylalanine by a series of steps, which includes the production of dopamine. The terminal branches of the sympathetic postganglionic fibres have varicosities or swellings, giving them the appearance of a string of beads. These swellings form the synaptic contact with the effector organ, and are also the site of synthesis and storage of noradrenaline. On the arrival of a nerve impulse, noradrenaline is released from granules in the presynaptic terminal into the synaptic cleft. The action of noradrenaline is terminated by diffusion from the site of action, re-uptake back into the presynaptic nerve ending where it is inactivated by the enzyme Monoamine Oxidase in mitochondria or metabolism locally by the enzyme Catechol-O-Methyl-Transferase.

The synthesis and storage of catecholamines in the adrenal medulla is similar to that of sympathetic postganglionic nerve endings, but due to the presence of an additional enzyme the majority of noradrenaline is converted to adrenaline. The adrenal medulla

responds to nervous impulses in the sympathetic cholinergic preganglionic fibres by transforming the neural impulses into hormonal secretion. In situations involving physical or psychological stress, much larger quantities are released.

The actions of catecholamines are mediated by specific postsynaptic cell surface receptors. Pharmacological subdivision of these receptors into two groups (α and β) was first suggested by Ahlquist in 1948, based upon the effects of adrenaline at peripheral sympathetic sites. These have since been further subdivided on functional and anatomical grounds. Thus β_1 adrenoceptor mediated effects in the heart (increased force and rate of contraction) have been differentiated from those producing smooth muscle relaxation in the bronchi and blood vessels (β_2 effects). Similarly, α–adrenoceptor mediated effects such as vasoconstriction have been termed, α_1 effects, to differentiate them from the feedback inhibition by noradrenaline on its own release from presynaptic terminals, which is mediated by α_2 adrenoceptors on the presynaptic membrane.

However, further research now shows that the classification is not as simple as this. For instance, many organs have both β_1 and β_2 adrenoceptors. (e.g. in the heart, there is one β_2 adrenoceptor to every three β_1 adrenoceptors). The receptors also show differing responses to adrenaline and noradrenaline. At β_1 adrenoceptors in the heart, adrenaline and noradrenaline appear to have an equal effect, whereas at β_2 adrenoceptors in smooth muscle are more sensitive to circulating adrenaline than noradrenaline.