FUNCTIONS OF THE AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system (Figure 3–1) is composed of the sympathetic and parasympathetic divisions. It functions to innervate

1. smooth muscle,
2. cardiac muscle, and
3. exocrine glands.

It also regulates

1. heart rate,
2. blood pressure,
3. sweat, salivary, and gastric secretions,
4. pupil diameter and eye accommodation,
5. gastrointestinal motility, and
6. diameter of the bronchioles.

DIVISIONS OF THE AUTONOMIC NERVOUS SYSTEM

Common Characteristics of Sympathetic and Parasympathetic Divisions

Each parasympathetic and sympathetic nerve

• originates in the central nervous system (CNS),
• has its activity controlled and integrated by the brain, and
• contains a preganglionic neuron, whose cell of origin lies within the CNS, and a postganglionic neuron, whose cell of origin lies within a
ACh at Ganglia  NE at Neuromusc. Junction*  
[Alpha & Beta Receptor]*  

Neurotransmitters and Receptors  

Blood Pressure  
Heart Rate  
Sweat  

Inervates Heart, Blood Vessels, Glands, Other Visceral Organs, and Smooth Muscles  

Pupil Diameter  
Accommodation of Eye  

Gastric Secretions  

Sweat Secretion  
Bronchodilation  
Decr GI Motility  
Incr Heart Rate  

Autonomic Nervous System  

Parasympathetic Division  

Physiological Functions  

ACh at Ganglia  
[Nicotinic Receptor]  

Neurotransmitters and Receptors  

ACh at Neuromusc Junction  
[Muscarinic Receptor]  

Physiological Functions  

Eye Accommodation  
Incr GI Motility  

Incr Saliva  
Decr Heart Rate  

* A few sympathetic nerves, notably those innervating sweat glands, release ACh. In this case the receptors stimulated are muscarinic.

Figure 3–1 Overview of the functions of the sympathetic and parasympathetic divisions of the autonomic nervous system. (Drawing by Ted Johnson.)  
ACh = acetylcholine; Decr = decrease; E = epinephrine; GI = gastrointestinal; Incr = increase; NE = norepinephrine.
ganglion outside the CNS. The pre- and postganglionic neurons synapse at a ganglion.

**Parasympathetic Division**

1. Most preganglionic fibers originate in the midbrain or medulla oblongata of the brain.
2. Ganglia are found close to, or within, innervated organs.
3. A few preganglionic nerves leave the CNS in the sacral portion of the spinal cord. These fibers also synapse with postganglionic nerves close to, or within, the innervated organs.
4. The parasympathetic nervous system carries on many of the mundane day-to-day functions:
   (a) Flow of saliva
   (b) Peristalsis
   (c) Constriction of pupils
   (d) Accommodation for near vision

**Sympathetic Division**

1. Sympathetic preganglionic fibers begin in the intermediolateral columns of the spinal cord and extend from the first thoracic to the second or third lumbar segments.
2. Once outside the spinal cord, preganglionic fibers synapse with postganglionic nerves at ganglia located in three areas of the body:
   (a) Paravertebral ganglia, which lie on each side of the vertebral column
   (b) Prevertebral ganglia (ie, celiac, superior mesenteric, inferior mesenteric, and aorticorenal ganglia) in the abdominal cavity
   (c) Terminal ganglia near the urinary bladder and rectum
3. Stimulation of the sympathetic nervous system prepares the body to meet stress in the following ways:
   (a) Increasing heart rate
   (b) Elevating cardiac output
   (c) Stimulating intermediary metabolism
   (d) Dilating bronchioles
   (e) Redistributing blood from the GI tract to the skeletal muscles
NEUROTRANSMITTERS

Chemical Transmission of Impulses

Ganglia

Acetylcholine is the neurotransmitter at all autonomic ganglia. Released by preganglionic nerve endings, acetylcholine stimulates nicotinic receptors on the postganglionic neurons (Figure 3–2).

Parasympathetic Nerve Endings

Acetylcholine is also the neurotransmitter at all parasympathetic nerve endings. Following its release, acetylcholine stimulates muscarinic receptors on the innervated tissue.

Figure 3–2 Chemical transmission of nerve impulses. ACh = Acetylcholine; NE = norepinephrine; E = Epinephrine; N = nicotinic receptors; M = Muscarinic receptors; \( \alpha_1 \) = alpha receptors; \( \beta_1 \) or \( \beta_2 \) = beta receptors. (After Johnson GE, Osis M, Hannah KJ. Pharmacology and the nursing practice. 4th ed. Toronto: WB Saunders, 1998:258–260.)
Sympathetic Nerve Endings

Norepinephrine (noradrenaline) is the neurotransmitter released from most sympathetic postganglionic neurons. Once released, it stimulates alpha1 receptors on blood vessels to cause vasoconstriction, or beta1 receptors in the heart to increase both heart rate and force of contraction. Acetylcholine is the neurotransmitter released by a few sympathetic postganglionic nerves (eg, sympathetic innervation of the sweat glands), where it stimulates muscarinic receptors.

Adrenal Medulla

Epinephrine (adrenaline) is an emergency hormone released by the adrenal medullae. It increases heart rate by stimulating cardiac beta1 receptors and dilates the bronchioles by stimulating beta2 receptors. Adrenaline redistributes blood in the body, shunting it from the peritoneal area to the skeletal muscles. It does this by stimulating alpha1 receptors on visceral vessels and beta2 receptors on vessels in skeletal muscle.

Synthesis and Inactivation of Neurotransmitters

Acetylcholine

Synthesized within nerves from acetylcoenzyme A and choline by the enzyme choline acetylase (Figure 3–3), acetylcholine is stored in vesicles within the nerve until released. The enzyme acetylcholine esterase, also formed within the nerve, rapidly inactivates acetylcholine (Figure 3–4).

Norepinephrine and Epinephrine

The synthesis of norepinephrine and epinephrine is presented in Figure 3–5. The rate-limiting step in the synthesis of norepinephrine and epinephrine is the conversion of tyrosine to dopa (dihydroxyphenylalanine), the precursor of dopamine. Epinephrine, norepinephrine, and dopamine are often called catecholamines. In the noradrenergic neurons, the end product is norepinephrine. In the adrenal medulla, the synthesis is carried one step further. An enzyme found in the adrenal medulla, phenylethanolamine-N-methyltransferase, converts norepinephrine to epinephrine. The human adrenal medulla contains approximately four times as much epinephrine as norepinephrine. The absence of phenylethanolamine-N-methyltransferase in noradrenergic neurons accounts for the absence of significant amounts of epinephrine in noradrenergic neurons.

The final step in the synthesis of norepinephrine, the conversion of dopamine to norepinephrine, takes place within intraneuronal storage vesicles. Norepinephrine is released from noradrenergic nerve endings by
Figure 3-3  Synthesis of acetylcholine. After Johnson GE, Osis M, Hannah KJ. Pharmacology and the nursing practice. 4th ed. Toronto: WB Saunders, 1998:258–260.

action potentials through exocytosis. The norepinephrine contents of entire vesicles are emptied into the synaptic region, where they may interact with adrenergic receptors.

Norepinephrine is removed from the area of the synapse and receptors by

- reuptake into the secreting neuron. Neuronal reuptake is the most important mechanism for terminating the action of released norepinephrine. Following neuronal reuptake, norepinephrine is either stored in vesicles or inactivated by mitochondrial monoamine oxidase (MAO);
- diffusion from the synapse into the circulation and ultimate enzymatic destruction in the liver by MAO or catechol-O-methyltransferase (COMT); and

• active transport of the catecholamine into effector cells (extraneuronal uptake), followed by enzymatic inactivation by COMT. Figure 3–6 summarizes these processes.

AUTONOMIC RECEPTORS

Cholinergic Receptors

Nicotinic Receptors (so-called because the effects of nicotine in ganglia and on skeletal muscle mimic the actions of acetylcholine)

Found in all autonomic ganglia. Nicotinic receptors are also found on skeletal muscle. However, nicotinic receptors in ganglia are not identical to those on skeletal muscle. Nicotinic receptors in ganglia can be blocked competitively by ganglionic blockers. Ganglionic blockers do not block nicotinic receptors on skeletal muscle; rather, these receptors are blocked by neuromuscular blockers (eg, tubocurarine).

Muscarinic Receptors (so-called because the effects of muscarine on receptors innervated by parasympathetic postganglionic nerves and sympathetic cholinergic nerves mimic the actions of acetylcholine on these receptors)

Found in smooth muscle, cardiac muscle, and exocrine glands innervated by parasympathetic nerves. They are involved in the constriction of bronchioles, slowing of heart rate, increase in GI motility, and secretion of salivary, gastric, and bronchiolar glands. They are also found in sweat glands innervated by the sympathetic nervous system. Muscarinic receptors are also located in the brain. Several subtypes of muscarinic receptors have been detected:

• M₁ receptors are found in various secretory glands.
• M₂ receptors predominate in the myocardium and also appear to be found in smooth muscle.
• M₃ and M₄ receptors are located in smooth muscle and secretory glands. All subtypes are found in the CNS.

Adrenergic Receptors

Alpha₁ Postsynaptic

Found on smooth muscle innervated by sympathetic nerves. Important functions include vasoconstriction of precapillary resistance vessels (arterioles) and capacitance vessels (veins).
Alpha₂ Presynaptic

Found on adrenergic nerve terminals. They are responsible for reducing the release of norepinephrine from sympathetic nerves.

Beta₁ Postsynaptic

Found on postsynaptic effector cells, especially in the heart. They are responsible for the sympathetically mediated increase in heart rate and force of contraction. They are also found on fat cells where they are responsible for the sympathetically mediated increase in lipolysis. Beta₁ receptors also mediate the release of renin.

Beta₂ Postsynaptic

Found on bronchioles, where they mediate sympathetic bronchodilation. They are located on precapillary resistance vessels (arterioles) in skeletal muscle where they mediate vasodilation. Beta₂ receptors relax the bladder and decrease intestinal motility.