The Autonomic Nervous System

The autonomic nervous system is the portion of the nervous system that controls the visceral functions of the body. This system acts rapidly to control arterial pressure, gastrointestinal motility and secretion, urinary bladder emptying, sweating, body temperature, and many other activities.

General Organization of the Autonomic Nervous System

The central portions of the autonomic nervous sys- tem are located in the hypothalamus, brain stem, and spinal cord. Higher brain centers, such as the limbic cortex and portions of the cerebral cortex, can influence the activity of the autonomic nervous system by sending signals to the hypothalamus and lower brain areas. The autonomic nervous system also often operates through visceral reflexes. That is, subconscious sensory signals from a visceral organ can enter the autonomic ganglia, the brain stem, or the hypothalamus and then return subconscious reflex responses directly back to the visceral organ to control its activities. The efferent autonomic signals are transmitted to the various organs of the body through two major sub- divisions called the sympathetic nervous system and the parasympathetic nervous system. The autonomic nervous system is a motor system for the visceral organs, blood vessels, and secretory glands. The cell body of the preganglionic neuron is located in either the brain stem or the spinal cord. The axon of this visceral motor neuron projects as a thinly myelinated preganglionic fiber to an autonomic ganglion. The postganglionic neuron has its cell body in the ganglia and sends an unmyelinated axon, the postganglionic fiber, to visceral effector cells. In general, sympathetic ganglia are located close to the central nervous system, whereas parasympathetic ganglia are located close to the effector tissues. Sympathetic pathways have short preganglionic fibers and long postganglionic fibers, whereas parasympathetic pathways have long preganglionic fibers and short post- ganglionic fibers.

Physiologic Anatomy of the Sympathetic Nervous System In the sympathetic division of the autonomic nervous system, visceral motor neurons are located in the intermediolateral horn of the spinal cord from level T-1 to L-2. The axons of these motor neurons leave the spinal cord via the ventral root. From here, the axon can take one of three paths:

1. It can enter the sympathetic chain via the white ramus and terminate at its level of origin.

2. It can enter the sympathetic chain via the white ramus and ascend or descend before terminating in the sympathetic chain at a different level.

3. It can enter the sympathetic chain through the white ramus and exit without synapsing via a splanchnic nerve and terminate in a prevertebral ganglion.

The postganglionic neuron originates in one of the sympathetic chain ganglia or prevertebral ganglia. From either source, the postganglionic fibers travel to their destinations.

Preganglionic Sympathetic Nerve Fibers Pass All the Way to the Adrenal Medulla without Synapsing. Preganglionic sympathetic nerve fibers that innervate the adrenal medulla originate in the intermediolateral horn of the spinal cord and pass through the sympathetic chains and splanchnic nerves to reach the adrenal medulla, where they end directly on modified neuronal cells that secrete epinephrine and norepinephrine into the bloodstream. Embryologically, the secretory cells of the adrenal medulla are derived from nervous tissue and are analogous to postganglionic neurons.

Physiologic Anatomy of the Parasympathetic Nervous System In the parasympathetic division of the autonomic nervous system, visceral motor neurons are located in discrete brain stem nuclei or in sacral spinal cord segments 2 to 4. The axons of these motor neurons leave the brain stem via cranial nerves III, VII, IX, and X or leave the sacral spinal cord via the pelvic nerves. Parasympathetic fibers in the third cranial nerve travel to the pupillary sphincters and ciliary muscles of the eye. Fibers from the seventh cranial nerve travel to the lacrimal, nasal, and submandibular glands; and fibers from the ninth cranial nerve travel to the parotid gland. About 75% of all parasympathetic nerve fibers are located in the tenth cranial nerve, the vagus nerve. The vagus nerve supplies parasympathetic input to the heart, lungs, esophagus, stomach, small intestine, proximal half of the colon, liver, gallbladder, pancreas, and upper portions of the ureters. The sacral parasympathetic fibers distribute their fibers to the descending colon, rectum, bladder, and lower portions of the ureters and external genitalia.

Basic Characteristics of Sympathetic and Parasympathetic Function

The two primary neurotransmitter substances of the autonomic nervous system are acetylcholine and nor- epinephrine. Autonomic neurons that secrete acetylcholine are said to be cholinergic; those that secrete norepinephrine are said to be adrenergic. All preganglionic neurons in both the sympathetic and parasympathetic divisions of the autonomic nervous system are cholinergic. Acetylcholine and acetylcholine-like sub- stances therefore excite both the sympathetic and para- sympathetic postganglionic neurons. Virtually all postganglionic neurons of the parasympathetic nervous system secrete acetylcholine and are cholinergic. Most postganglionic sympathetic neurons secrete norepinephrine and are adrenergic. A few post- ganglionic sympathetic nerve fibers, however, are cholin- ergic. These fibers innervate sweat glands, piloerector muscles, and some blood vessels.

Synthesis and Secretion of Acetylcholine and Norepinephrine by Postganglionic Nerve Endings Acetylcholine is synthesized in the terminal endings of cholinergic nerve fibers through the combination of acetyl-coenzyme A (CoA) with choline. Once released by the cholinergic nerve endings, acetylcholine is rap- idly degraded by the enzyme acetylcholinesterase. Norepinephrine and epinephrine are synthesized from the amino acid tyrosine. Tyrosine is converted to DOPA, which is then converted to dopamine; dopa- mine is subsequently converted to norepinephrine. In the adrenal medulla, this reaction proceeds one step further to transform 80% of the norepinephrine to epinephrine. The action of norepinephrine is terminated by reuptake into the adrenergic nerve endings or by diffusion from the nerve endings into the surrounding fluids.

Receptors on Effector Organs (p. 732)

Cholinergic Receptors Are Subdivided into Muscarinic And Nicotinic Receptors. Muscarinic receptors are found on all effector cells stimulated by the postganglionic neurons of the parasympathetic nervous system as well as those stimulated by the postganglionic cholinergic neu- rons of the sympathetic nervous system. Nicotinic receptors are found in the synapses between the pre- ganglionic and postganglionic neurons of both the sympathetic and parasympathetic nervous systems as well as in the skeletal muscle neuromuscular junction.

Adrenergic Receptors Are Subdivided into Alpha (a) and Beta (b) Receptors. Norepinephrine and epinephrine have somewhat different affinities for the a- and b-adrenergic receptors. Norepinephrine excites mainly a-receptors, although it excites b-receptors to a lesser extent. Epinephrine excites both types of receptor approximately equally. The relative effects of norepinephrine and epinephrine on

various effector organs are deter- mined by the types of receptor located on these organs. The stimulation of a-receptors results in vasoconstriction, dilation of the iris, contraction of the intestinal and bladder sphincters, and contraction of the pilomotor muscles. The b-receptor is subdivided into b1-, b2-, and b3 receptor subtypes. Stimulation of b1-receptors causes an increase in heart rate and strength of contraction. Stimulation of b2-receptors causes skeletal muscle vaso- dilation, bronchodilation, uterine relaxation, calorigenesis, and glycogenolysis. Stimulation of b3-receptors induces lipolysis in adipose tissue and the conversion of energy in lipids into heat (thermogenesis).

Excitatory and Inhibitory Actions of Sympathetic and Parasympathetic Stimulation (p. 733) Sympathetic stimulation causes excitatory effects in some organs but inhibitory effects in others. Likewise, parasympathetic stimulation causes excitation in some organs but inhibition in others. Occasionally, the two divisions of the autonomic nervous system act reciprocally in an organ, with one system causing an increase in activity and the other system causing a decrease in activity. Most organs, however, are dominantly con- trolled by one of the two systems.

Effects of Sympathetic and Parasympathetic Stimulation on Specific Organs (p. 735)

Eyes. Two functions of the eyes are controlled by the autonomic nervous system: pupillary opening and focusing of the lens. Sympathetic stimulation contracts the radial dilator muscle of the iris, resulting in pupil- lary dilation, whereas parasympathetic stimulation con- tracts the sphincter muscle of the iris, resulting in pupillary constriction. Focusing of the lens is controlled almost entirely by the parasympathetic nervous system. Parasympathetic excitation contracts the ciliary muscle, which releases the tension on the suspensory ligament of the lens and allows it to become more convex. This change allows the eye to focus on close objects.

Glands of the Body. The nasal, lacrimal, salivary, and gastrointestinal glands are strongly stimulated by the parasympathetic nervous system, resulting in copious quantities of watery secretion. Sympathetic stimu- lation causes vasoconstriction of blood vessels that supply the glands and in this way often reduces the rate of secretion from these glands. Sympathetic stimulation has a direct effect on glandular cells by causing forma- tion of a concentrated secretion that contains extra enzymes and mucus. The sweat glands secrete large quantities of sweat when the sympathetic nerves are stimulated. Parasympathetic stimulation has no effect on sweat gland secretion. The sympathetic fibers to most sweat glands are cholinergic; almost all other sympathetic fibers are adrenergic. The apocrine glands in the axillae secrete a thick, odoriferous secretion as a result of sympathetic stimulation. These glands do not respond to parasympathetic stimulation. The apocrine glands are controlled by adrenergic fibers rather than by cholinergic fibers.

Intramural Nerve Plexus of the Gastrointestinal System. Sympathetic and parasympathetic stimulation can affect gastrointestinal activity mainly by increasing or decreasing activity on the intestinal enteric nervous system. In general, parasympathetic stimulation increases the overall degree of activity of the gastrointestinal tract. Normal function of the gastrointestinal tract is not particularly dependent on sympathetic stimulation. Strong sympathetic stimulation, however, inhibits peristalsis and increases the tone of the various sphincters in the gastrointestinal tract.

Heart. Sympathetic stimulation increases the rate and strength of heart contractions. Parasympathetic stimulation causes the opposite effect.

Systemic Blood Vessels. Sympathetic stimulation causes vasoconstriction of many of the blood vessels of the body, especially the abdominal viscera and the skin on the limbs. **Arterial Pressure.** The arterial pressure is determined by two factors: propulsion of blood by the heart and resistance to the flow of this blood through the blood vessels. Sympathetic stimulation increases both propul- sion by the heart and resistance to flow, which results in an increase in arterial pressure. Parasympathetic stim- ulation decreases the pumping ability of the heart but has little effect on peripheral vascular resistance. This change results in a slight fall in arterial pressure. **Other Body Functions.** Most of the endodermal structures, such as the ducts of the liver, gallbladder, ureter, urinary bladder, and bronchi, are inhibited by sympathetic stimulation but excited by parasympathetic stimulation. Sympathetic stimulation also has multiple metabolic effects such as release of glucose from the liver, increase in blood glucose concentration, increase in glycogenolysis in both liver and muscle, increase in skeletal muscle strength, increase in basal metabolic rate, and increase in mental activity. The sympathetics and parasympathetics are involved in execution of the male and female sexual acts, as explained in Chapters 80 and 81.

Function of the Adrenal Medullae (p. 736) Stimulation of the sympathetic nerves to the adrenal medulla causes large quantities of epinephrine and nor- epinephrine to be released into the circulating blood. About 80% of the secretion from the adrenal medulla is epinephrine, and about 20% is norepinephrine. The effect of the epinephrine and norepinephrine released from the adrenal medulla lasts 5 to 10 times longer than when they are released by sympathetic neurons because these hormones are slowly removed from the blood. The circulating norepinephrine causes vasoconstriction, increased heart rate and contractility, inhibition of the gastrointestinal tract, and dilated pupils. The circulating epinephrine, because of its ability to strongly stimulate the b-receptors, has a greater effect on cardiac performance than does norepinephrine. Epinephrine causes only weak constriction of the blood vessels in muscles, resulting in a slight increase in arterial pres- sure but a dramatic increase in cardiac output. Epinephrine and norepinephrine are always released by the adrenal medulla at the same time that organs are directly stimulated by generalized sympathetic activa- tion. This dual mechanism of sympathetic stimulation provides a safety factor to ensure optimal performance when it is needed.

Sympathetic and Parasympathetic "Tone" (p. 737) The basal rate of activity of the autonomic nervous sys- tem is known as sympathetic and parasympathetic tone. Sympathetic tone and parasympathetic tone allow a single division of the autonomic nervous system to increase or decrease the activity of a visceral organ or to constrict or dilate a vascular bed. Normally, sympathetic tone constricts systemic arterioles to about one half of their maximum diameter, whereas parasympathetic tone maintains normal gastrointestinal motility.

Discrete or Mass Discharges of the Autonomic Nervous System (p. 738) In some instances, the sympathetic nervous system becomes very active and causes a widespread reaction throughout the body called the alarm or stress response. At other times, sympathetic activation occurs in isolated areas of the body; for example, local vasodilation and sweating occur in response to a local increase in temperature. The parasympathetic nervous system is usually responsible for highly specific changes in visceral func- tion, such as changes in salivary and gastric secretion or in bladder and rectal emptying. Also, parasympathetic cardiovascular reflexes usually act only on the heart to increase or decrease its rate of beating and have little effect on vascular resistance. Widespread activation of the sympathetic nervous system can be brought about by fear, rage, or severe pain. The alarm or stress response that results is often called the fight or flight reaction. Widespread sympathetic activation causes increases in arterial pressure, muscle blood flow, metabolic rate, blood glucose con- centration, glycogenolysis, and mental

alertness and decreases in blood flow to the gastrointestinal tract and kidneys and a shorter coagulation time. These effects allow an individual to perform far more strenuous activity than would otherwise be possible.

Medullary, Pontine, Mesencephalic and Higher Areas of the Brain Control Autonomic Activity (p. 739)
Many neuronal areas in the brain stem reticular substance and along the course of the tractus solitarius of the medulla, pons, and mesencephalon, as well as in many special nuclei control autonomic functions such as arterial pressure, heart rate, glandular secretion in the gastrointestinal tract, gastrointestinal peristalsis, and degree of contraction of the urinary bladder. Signals from the hypothalamus and even from the cerebrum influence the activities of almost all the brain stem autonomic control centers. For instance, stimulation in appropriate areas mainly of the posterior hypo- thalamus can activate the medullary cardiovascular control centers strongly enough to increase arterial pressure to more than twice normal. Likewise, other hypo- thalamic centers control body temperature, increase or decrease salivation and gastrointestinal activity, and cause bladder emptying. To some extent therefore, the autonomic centers in the brain stem act as relay stations for control activities initiated at higher levels of the brain, especially in the hypothalamus.