

CHAPTER SCOPE

This is the third of the four-chapter unit on the nervous system and is entirely devoted to the subconscious or involuntary control over *smooth muscle*, *cardiac muscle*, or *glands*. Neurons of the autonomic nervous system (ANS) are always **motor** (efferent) and are classified as either **sympathetic** or **parasympathetic**. There are a variety of neurotransmitters released by autonomic neurons. The action of these neurons is largely dependent upon the neurotransmitter chemical that is released from the presynaptic axon terminal and upon which specific type of receptor type that is waiting on the postsynaptic membrane to receive these neurotransmitters.

There are two major types of autonomic neuron receptors — those that are **adrenergic**, receiving norepinephrine, epinephrine, and related neurotransmitter substances; and those that are **cholinergic**, receiving acetylcholine (ACh). Interestingly, because the receptor types can vary from neuron to neuron, the same neurotransmitter may cause one *response* at one neuron that will be completely different from the response to the same neurotransmitter at another neuron. Sometimes *antagonistic*, sometimes *complementary*, and sometimes *cooperative*, typical autonomic neuron responses are described in this chapter. Since these neurons are all motor, many of their action potentials originate, and are controlled by higher brain centers such as the **hypothalamus**, **limbic system**, **cerebellum**, and **cerebrum**.

If time is taken in this chapter to understand well the structure and function of the **autonomic nervous system**, the effort will be quickly rewarded in a better understanding of the chapters that follow — endocrine (chapter 11), cardiovascular (chapters 13, 14), respiratory (chapter 15), renal (chapter 16), and reproduction (chapter 20).

I. NEURAL CONTROL OF INVOLUNTARY EFFECTORS

The autonomic nervous system helps to regulate the activities of cardiac muscle, smooth muscle, and glands. In this regulation, impulses are conducted from the CNS by an axon that synapses with a second autonomic neuron. It is the axon of this second neuron in the pathway that innervates the involuntary effectors.

A. Multiple Choice

- ___ 1. Which of the following is *not* an effector (target) of autonomic nervous system (ANS) motor neurons?
a. cardiac muscle
b. exocrine glands
c. skeletal muscle
d. endocrine glands
e. smooth muscle
- ___ 2. Somatic motor neurons have cell bodies located _____ the CNS that send axons to _____; usually under _____ control.
a. outside; skeletal muscle; involuntary
b. inside; the viscera; voluntary
c. outside; the viscera; involuntary
d. inside; skeletal muscle; voluntary
e. outside; the viscera; voluntary
- ___ 3. Which of the following statements does *not* describe *denervation hypersensitivity*?
a. autonomic target tissues become more sensitive than normal to stimulating agents
b. skeletal muscle effectors enter a state of flaccid paralysis and atrophy
c. can result from severing (cutting) autonomic motor neurons
d. an example is restoring the secretion of acid from the stomach following vagotomy (severing the Vagus nerve)

B. True or False/Edit

- ___ 4. Autonomic motor nerves innervate organs whose functions are *not* usually under voluntary control.
- ___ 5. The word *viscera* refers to the organs located within the body cavities.
- ___ 6. Unlike somatic motor neurons, autonomic motor neurons always involve two neurons in the efferent pathway.
- ___ 7. A *ganglion* is defined as a collection of cell bodies inside the CNS (brain and spinal cord).

- ___ 8. Ganglia are an integral part of the somatic motor pathway.
- ___ 9. Cardiac muscle (the heart) and many smooth muscles can contract rhythmically even in the absence of autonomic nerve stimulation.
- ___ 10. Unlike somatic motor neurons that always cause stimulation of skeletal muscle effectors, some autonomic nerves release neurotransmitter substances that inhibit the activity of their effectors.

II. DIVISIONS OF THE AUTONOMIC NERVOUS SYSTEM

Preganglionic neurons of the sympathetic division of the autonomic system originate in the thoracic and lumbar levels of the spinal cord and send axons to sympathetic ganglia, which parallel the spinal cord. Preganglionic neurons of the parasympathetic division, by contrast, originate in the brain and in the sacral level of the spinal cord, and send axons to ganglia located in or near the effector organs.

A. Multiple Choice

- ___ 11. Which statement regarding autonomic sympathetic neurons is *false*?
 - a. They are usually activated as a single unit (mass activation).
 - b. They emerge from the brain and sacral regions.
 - c. They form white and gray rami communicantes fibers.
 - d. They may have ganglia located along the spinal cord.
- ___ 12. Which of the following ganglia is *not* a collateral (prevertebral) ganglion?
 - a. celiac
 - b. superior mesenteric
 - c. inferior mesenteric
 - d. cervical
- ___ 13. Which system is *not* served by postganglionic fibers that arise from the *collateral* (prevertebral) ganglia?
 - a. respiratory
 - b. digestive
 - c. urinary
 - d. reproductive
 - e. All of these systems are served by these postganglionic fibers.
- ___ 14. Which of the following statements about parasympathetic neurons is *false*?
 - a. Like sympathetics, they travel within spinal nerves.
 - b. They synapse in terminal ganglia, either next to or within the organs innervated.
 - c. They originate in the brain or sacral spinal cord regions (the craniosacral division).
 - d. Postganglionic fibers are usually shorter than those of sympathetic neurons.
 - e. They send preganglionic fibers to the visceral organs, such as the heart, lungs, esophagus, intestine, among others.

B. True or False/Edit

- ___ 15. Both sympathetic and parasympathetic neurons have preganglionic cell bodies located inside the CNS and postganglionic cell bodies located outside the CNS.
- ___ 16. Preganglionic sympathetic neurons are myelinated, and thus, called *white* rami communicantes, while postganglionic sympathetic fibers are unmyelinated, and therefore, known as the *gray* rami communicantes.
- ___ 17. The convergence of impulses from the spinal cord to the ganglia and the divergence of impulses within the ganglia usually result in the mass activation of almost all postganglionic fibers as a unit.
- ___ 18. The cortex of the adrenal gland is a modified sympathetic ganglion.
- ___ 19. Neurons whose cell bodies originate in the medulla oblongata and whose axons serve as cranial nerves would be classified as parasympathetic.
- ___ 20. Sympathetic neurons show great divergence from preganglionic to postganglionic fibers, whereas parasympathetic neurons diverge only a little.

III. FUNCTIONS OF THE AUTONOMIC NERVOUS SYSTEM

The sympathetic division of the autonomic system activates the body to “fight or flight,” largely through the release of norepinephrine from postganglionic fibers and the secretion of epinephrine from the adrenal medulla. The parasympathetic division often produces antagonistic effects through the release of acetylcholine from its postganglionic fibers. The actions of the two divisions must be balanced in order to maintain homeostasis.

A. Multiple Choice

- ___ 21. Which neuron does *not* release **acetylcholine** (ACh) as a neurotransmitter?
- preganglionic sympathetic fibers
 - postganglionic sympathetic fibers
 - preganglionic parasympathetic fibers
 - postganglionic parasympathetic fibers
- ___ 22. *Catecholamines* are substances derived from the amino acid, tyrosine, and include all of the following *except*
- acetylcholine (ACh).
 - epinephrine.
 - dopamine.
 - norepinephrine.
- ___ 23. Which of the following is *not* a β -adrenergic response?
- slowing down (relaxation) of the digestive tract muscular motility, such as peristalsis
 - opening of the airways or bronchioles in the lung
 - increasing the force and rate of the heart beat
 - dilating the smooth muscle of the skin and splanchnic blood vessels
 - relaxing the smooth muscle wall of the urinary bladder
- ___ 24. The drug that aids the suffering of asthmatics by serving as a β_2 agonist to dilate the airways of the lung, is
- terbutaline.
 - atenolol.
 - phenylephrine.
 - clonidine.
- ___ 25. Which statement about *muscarinic* receptors is *false*?
- They are not found in autonomic ganglia or at the neuromuscular junctions of skeletal muscle fibers.
 - They are stimulated by extracts from poisonous mushrooms.
 - They are subtypes of adrenergic receptors.
 - They are not affected by the drug, curare that specifically blocks nicotinic receptors.
 - They can be found on the target organs of specific postganglionic parasympathetic fibers.
- ___ 26. Which of the following molecules is *not* a proposed neurotransmitter of the select group of “nonadrenergic noncholinergic” postganglionic autonomic axons?
- adenosine triphosphate (ATP)
 - gamma aminobutyric acid (GABA)
 - vasoactive intestinal peptide (VIP)
 - nitric oxide (NO)
 - All of these are candidate neurotransmitters.
- ___ 27. The separate effects of sympathetic and parasympathetic innervation of the pacemaker region of the heart can best be described as
- antagonistic.
 - complementary.
 - cooperative (synergistic).
- ___ 28. The effects of sympathetic and parasympathetic innervation on the urinary and reproductive systems are
- antagonistic.
 - complementary.
 - cooperative (synergistic).

- ___ 29. The effects of sympathetic and parasympathetic stimulation on the salivary gland secretion are
- antagonistic.
 - complementary.
 - cooperative (synergistic).
- ___ 30. Which of the following target tissues is (are) innervated *only* by the sympathetic neurons?
- adrenal medulla
 - arrector pili muscle
 - sweat glands
 - most blood vessels
 - All of these are only innervated by sympathetic neurons.
- ___ 31. That brain stem region that directly controls many activities of the autonomic nervous system (ANS), is the
- medulla oblongata.
 - pituitary gland.
 - cerebellum.
 - hypothalamus.
 - basal ganglia.
- ___ 32. Which system does *not* have its control center in the *medulla*?
- cardiovascular system
 - pulmonary system
 - urinary system
 - reproductive system
 - immune system
- ___ 33. The *hypothalamus* does *not* contain the control center for the homeostatic regulation of
- body temperature.
 - various emotional states.
 - hunger.
 - breathing.
 - thirst.

B. True or False/Edit

- ___ 34. The term “fight or flight” is used to describe the mass activation of the parasympathetic system that prepares the body for intense physical activity in emergency situations.
- ___ 35. Cocaine is considered a sympathomimetic drug – a drug that mimics or promotes the effects of sympathetic nerve activity through the action of norepinephrine.
- ___ 36. Sympathetic and parasympathetic neurons usually release different neurotransmitters from their respective postganglionic neuron axons.
- ___ 37. Those sympathetic postganglionic neurons activating blood vessels in skeletal muscle and in sweat glands are unique in their release of acetylcholine (ACh) instead of norepinephrine (NE).
- ___ 38. Adrenergic stimulation by epinephrine, usually secreted by the adrenal medulla, and by norepinephrine, secreted from sympathetic nerve endings, can produce both excitatory and inhibitory effects.
- ___ 39. The autonomic neurons are unique in that they form synapses *en passant* (“synapses in passing”) as neurotransmitters are released from numerous swellings or varicosities as they pass through their target organs.
- ___ 40. The two major subtypes of alpha-receptors produce their effects by stimulating increases in the production of the second messenger, cyclic AMP (cAMP), within the target cell cytoplasm.
- ___ 41. The response of a target cell when norepinephrine binds to α_1 receptors results in a rise in intracellular calcium (Ca^{2+}) concentration that serves as a “second messenger” molecule.
- ___ 42. The physiology of α_2 -adrenergic receptors is complex because these receptors are mainly located on the presynaptic axon terminals (decreasing NE release), yet are found on the postsynaptic membrane of vascular smooth muscle cells, resulting in complicated influence on blood pressure.
- ___ 43. When epinephrine and norepinephrine bind to adrenergic receptors in the ANS a group of membrane-associated G-proteins dissociate into subunits, and thereby activate their respective target cells.
- ___ 44. Stimulation of alpha-adrenergic receptors located on smooth muscle fibers in the walls of blood vessels almost always results in muscle contraction and vasoconstriction.

- ___ 45. The activation of all somatic motor neurons or preganglionic autonomic neurons results in cholinergic effects that can be both excitatory and inhibitory.
- ___ 46. Both nicotinic and muscarinic receptors bind with and respond to the neurotransmitter, acetylcholine (ACh).
- ___ 47. Cholinergic receptors of the *muscarinic* type are ligand-gated ion channels — that is, binding by ACh causes the faster entry of Na⁺ that always results in depolarization and excitation of the target cell.
- ___ 48. Five different subtypes of *muscarinic* ACh receptors (designated with the letter “M,” followed by a number in subscript) have been identified.
- ___ 49. The responses of muscarinic receptors on target cells that are activated by the binding of ACh is mediated by second messenger systems, and is therefore not mediated by ligand-gated ion channels.
- ___ 50. **Nitric oxide** (NO) is one of many nonadrenergic, noncholinergic paracrine regulator molecules that produce relaxation of smooth muscles in many organs and in blood vessels.
- ___ 51. Parasympathetic neuron stimulation of the pacemaker region of the heart increases the heart rate.
- ___ 52. In the digestive system, activation of parasympathetic neurons increases intestinal movements and stimulates intestinal secretions.
- ___ 53. Increased sympathetic neuron activity to smooth muscle fibers around blood vessels of the skin (cutaneous) causes vasoconstriction, whereas cutaneous vasodilation results when sympathetic nerve activity is decreased.
- ___ 54. Cooling of the body can be accomplished by sweat glands along the trunk that secrete both a watery sweat that evaporates and a chemical called *bradykinin*, that dilates surface blood vessels to help radiate heat.
- ___ 55. The Vagus nerve (cranial nerve X) is a mixed nerve, containing both sensory and motor neuron fibers.
- ___ 56. *Thermoregulation*, the regulation of heat gain or loss by the body, is accomplished without the direct involvement of the parasympathetic nervous system.
- ___ 57. Blushing, pallor, fainting, breaking out in a cold sweat, a racing heartbeat, and “butterflies in the stomach”, are only some of the many visceral reactions that accompany emotional activation of the hypothalamus.

C. Label the Figure — Autonomic Nervous System Neurotransmitters

Neurons of the autonomic nervous system are always motor (efferent); releasing either the neurotransmitter acetylcholine (ACh) or norepinephrine (NE). Those autonomic synapses with receptors for acetylcholine are called *cholinergic* and those with receptors for norepinephrine are called *adrenergic*. Study figure 9.1 and locate the nine blank spaces at the autonomic synapses. Write either *ACh* or *NE* in the spaces provided. When finished, check your work with figure 9.7 in the text.

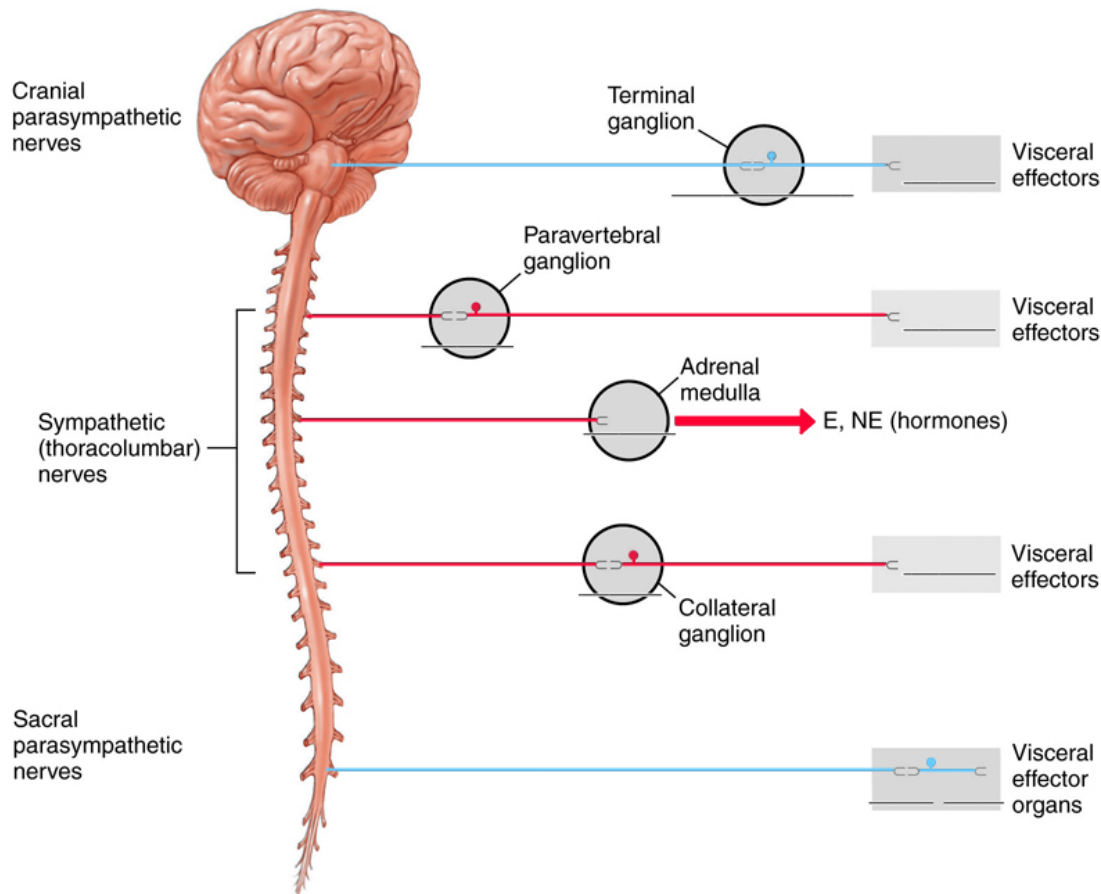


Figure 9.1

CHAPTER REVIEW

A. Completion

58. Autonomic neuron axons are always motor or _____, originating in the _____ or _____ as preganglionic neurons. Postganglionic neurons originate from collections of _____ outside the CNS, known as _____.
59. The three target or _____ cells at the end of autonomic neurons are _____, _____, and _____.
60. Severing or cutting autonomic neurons results in an increase in responsiveness at the target cell. This characteristic of autonomic neurons is called _____. Preganglionic sympathetic neurons emerge from the _____ and _____ levels of the spinal cord, whereas preganglionic parasympathetic fibers originate in the _____ and _____ levels of the spinal cord.
61. Cell bodies of postganglionic sympathetic neurons are located in ganglia called the sympathetic or _____ ganglia; the _____ ganglia (which include the celiac and mesenteric) innervate organs of the digestive, _____, and _____ systems. Modified sympathetic ganglion cells are located directly in the medulla of the _____ gland.
62. Many cranial nerves are _____ (pre-/post-) ganglionic _____ (sympathetic/parasympathetic) neurons with _____ (long/short) postganglionic neurons because the ganglia are located close to or _____ the target cells.
63. “Fight or flight” results from the release of the neurotransmitter _____ from postganglionic _____ (sympathetic/parasympathetic) neurons—effects called _____.

64. All preganglionic fibers and all postganglionic fibers that carry information themed as “repast and repose” are _____ (sympathetic/parasympathetic), release only the neurotransmitter _____; and their effects are called _____. **Hint:** Sympathetic fibers that innervate _____ and those that innervate _____ in skeletal muscles are *cholinergic*!
65. Norepinephrine binds to two groups of receptor proteins, known as _____ and _____, with two subtypes for each (1 and 2), which produce _____ (adrenergic/cholinergic) effects in various organs of the body.
66. In organs stimulated by both sympathetic and parasympathetic neurons (_____ innervation), the actions between these two types of neurons will be _____, _____, or _____.
67. The two most important regions of the brain directly responsible for the control of autonomic nervous system activity are the _____ located in the brain stem and the higher brain region called the _____.

B. Crossword Puzzle—The Autonomic Nervous System

Across

1. Autonomic nervous system action on salivary glands
3. One origin for preganglionic neurons of the sympathetic division
6. Related to the female gonad
7. Key economic indicator
8. Change in the autonomic effector that may occur when disconnected from its innervation
11. Most common (85%) catecholamine released from the adrenal medulla during sympathetic stimulation
13. Specialized receptors on the postsynaptic membrane that recognize ACh
16. Long cranial nerve (X)
19. Alcohol form of a steroid molecule
20. Double chain of sympathetic ganglia outside the spinal cord
22. Autonomic effectors include smooth muscle, cardiac muscle, and _____
23. Division of the autonomic nervous system including spinal nerves that exit the brain and lower spinal cord (lumbar)
26. Emergency distress signal
27. If not the beginning
28. Subconscious or involuntary division of the nervous system
30. Spinal cord origin of preganglionic sympathetic neurons
32. Adrenergic effects include heart stimulation and _____ of the bronchi
33. Actions taken involving the law
34. One type of muscle innervated by autonomic neurons
35. Autonomic neurons originating from ganglia located outside the central nervous system (CNS)
37. Drug that inhibits the effects of parasympathetic nerve stimulation (anticholinergic)
38. Cats love to play with balls of this material (not yarn)

39. Drug that acts as a beta-blocker on both the heart and the bronchioles of the lung
41. Preganglionic neurons of the parasympathetic division of the autonomic nervous system (ANS) originate here
42. Specialized receptors on the postsynaptic membrane that recognize catecholamines (for example, epinephrine)
43. Common time piece

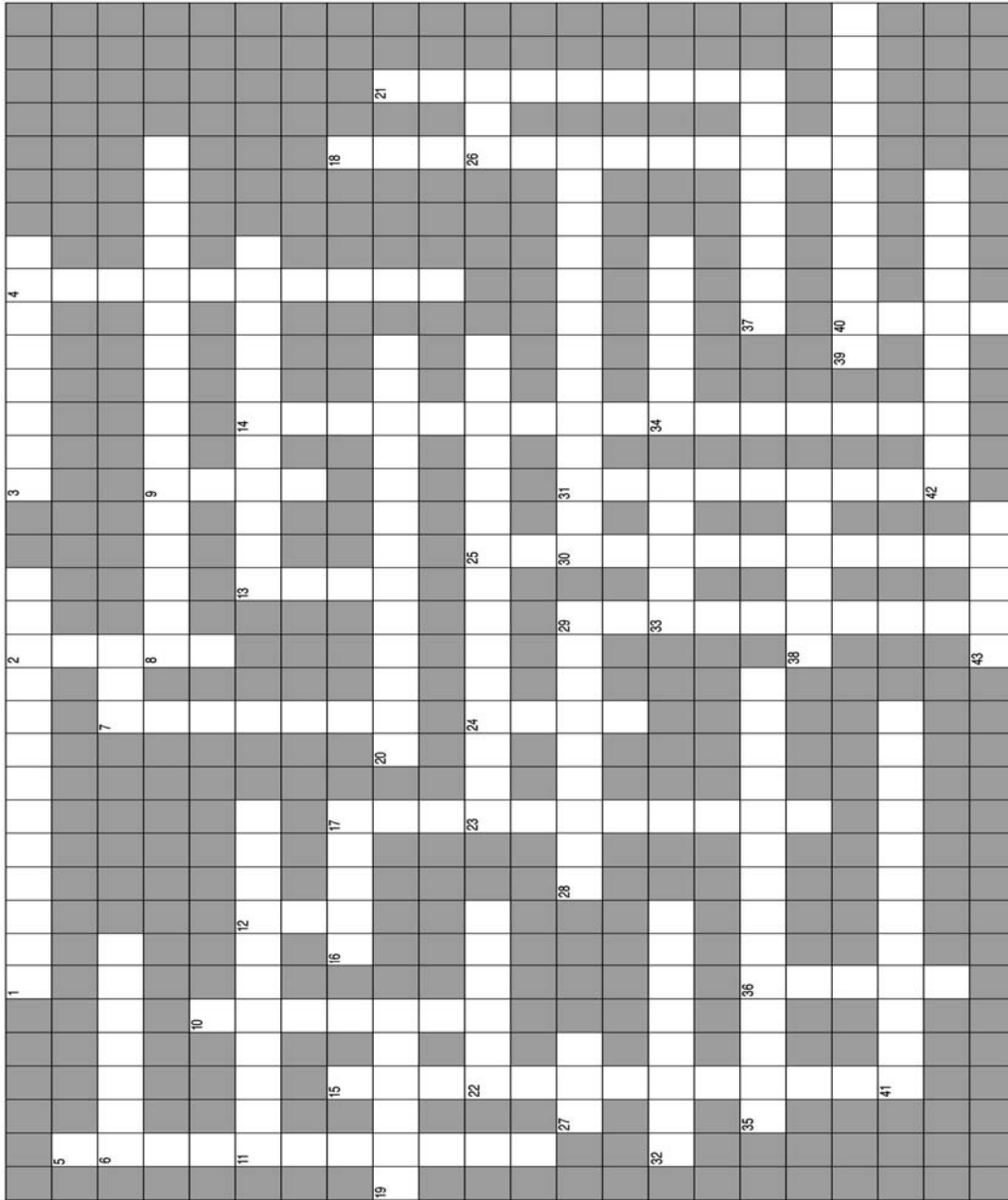
Down

2. Adrenergic receptor proteins are grouped as either _____ or beta
4. Autonomic nerves can have either excitatory or _____ effects on their target organs
5. Action of the autonomic nervous system on the regulation of the reproductive and urinary systems
7. Collections of neuron cell bodies located outside the CNS
9. Word vital to all “real” shoppers
10. Autonomic portion of the adrenal glands—activated during “fight-or-flight”
12. Nucleic acid used in the synthesis of proteins
13. Deoxyribonucleic acid (DNA) is commonly called the genetic _____
14. Any chemical synthesized by and released from presynaptic neurons
15. Autonomic neurons originating from the brain or spinal cord
17. “Fight-or-flight” division of the autonomic nervous system
18. Adrenergic effects include heart stimulation and blood vessel _____
21. Drug that promotes cholinergic effects of parasympathetic nerve stimulation
24. Smallest unit of matter
25. Action of the autonomic nervous system on the heart and pupils
29. Include the celiac, superior, and inferior mesenteric ganglia

31. Area of the brain stem most in control of autonomic system activity is the medulla

36. Excessive secretion of growth hormone (GH) can result in a pituitary _____

40. Fishing outing requires a rod 'n' _____



C. Essay

Essay Tutorial

This essay tutorial will answer the first essay question found in the “**Review Activities**” section of your *Human Physiology* textbook. Please read question 1 located in the “**Test Your Understanding of Concepts and Principles**” section at the end of chapter 9 and let me guide you through one possible answer. Watch for key terms in boldface type, helpful tips and general suggestions on writing the essay or short-answer questions. Enjoy!

68. Compare the sympathetic and parasympathetic systems in terms of the **location** of their **ganglia** and the **distribution** of their **nerves**.

Answer. This question can easily be answered by creating a numbered outline within a “mini-table” such as that which follows:

Sympathetic	Parasympathetic
1. Ganglia — double (left and right) chain close to and parallel to the vertebrae (<i>paravertebral</i>); or farther out from the spinal cord in <i>collateral</i> ganglia (celiac, superior, and inferior mesenteric ganglia); and the direct “hotline” to the <i>adrenal medulla</i> .	1. Terminal ganglia are located on or close to the target cells.
2. Nerve distribution — preganglionic nerves exit the thoracic and lumbar areas of the spinal cord with branches from the head down to the lower abdomen.	2. Preganglionic nerve exits the brain or sacral region of the spinal cord. Many cranial nerves such as III, VII, IX, and X (vagus nerve); may innervate the same or different cells.

Do you notice how organized your answers can be? Students who spend the time and effort constructing tables like this one will be rewarded with quick “table-at-a-glance” learning tools before exam time — and professors will enjoy the easier grading as a bonus! Keep up the good work! Now try a couple more if time permits.

69. Explain how sympathetic innervation of the adrenal medulla follows a “hotline” pathway from the brain, directing the “fight-or-flight” response to emergency situations.
70. Define the terms **adrenergic** and **cholinergic**; and describe the anatomical distribution of these autonomic effects.
71. Name the two most important areas of the brain controlling autonomic activity (involuntary); and describe the various physiologic systems that are controlled by these two regions.

Answers — Chapter 9

- I. Neural Control of Involuntary Effectors
- A. 1. c, 2. d, 3. b
- B. 4. T, 5. T, 6. T, 7. —Replace “inside” with “outside,” 8. F—Replace “somatic” with “autonomic,” 9. T, 10. T
- II. Divisions of the Autonomic Nervous System
- A. 11. b, 12. d, 13. a, 14. a
- B. 15. T, 16. T, 17. F—Switch “convergence” with “divergence,” 18. F—Replace “cortex” with “medulla,” 19. T, 20. T
- III. Functions of the Autonomic Nervous System
- A. 21. b, 22. a, 23. d, 24. a, 25. c, 26. b, 27. a, 28. c, 29. b, 30. e, 31. a, 32. e, 33. d
- B. 34. F—Replace “parasympathetic” with “sympathetic,” 35. T, 36. T, 37. T, 38. T, 39. T, 40. F—Replace “alpha” with “beta,” 41. T, 42. T, 43. T, 44. T, 45. F—They are excitatory only, 46. T, 47. F—Replace “muscarinic” with “nicotinic,” 48. T, 49. T, 50. T, 51. F—Replace “increases” with “decreases,” 52. T, 53. T, 54. T, 55. T, 56. T, 57. F—Replace “hypothalamus” with “limbic system”

C. Autonomic Nervous System

Neurotransmitters; See figure 9.7 in the text.

Chapter Review

- A. 58. efferent, brain, spinal cord; cell bodies, ganglia, 59. effector, smooth muscle, cardiac muscle, glands, 60. denervation hypersensitivity; thoracic, lumbar, brain, sacral, 61. paravertebral, collateral, urinary, reproductive; adrenal, 62. pre-, parasympathetic, short, within, 63. norepinephrine (NE), sympathetic, adrenergic, 64. parasympathetic, ACh, cholinergic; sweat glands, blood vessels, 65. alpha, beta, adrenergic, 66. dual, antagonistic, complementary, cooperative, 67. medulla oblongata, hypothalamus

