Chapter 45

Hormones and the Endocrine System

Key Concepts

45.1 Hormones and other chemical signals bind to target receptors, triggering specific response pathways

45.2 Negative feedback and antagonistic hormone pairs are common features of the endocrine system

45.3 The endocrine and nervous systems act individually and together to regulate an animal's physiology

45.4 Endocrine glands respond to diverse stimuli in regulating metabolism, homeostasis, development, and behavior

Framework

This chapter introduces the intricate system of chemical control and communication within animals. Endocrine cells or neurosecretory cells produce hormones that regulate the activity of other cells and organs. Steroid hormones bind with receptors within their target cells and influence gene expression. The signal transduction pathways of most polypeptide and amine hormones involve binding with cell surface receptors and triggering metabolic reactions in target cells.

The hypothalamus and pituitary gland play coordinating roles by integrating the nervous and endocrine systems and producing many tropic hormones that control the synthesis and secretion of hormones in other endocrine glands and organs.

Chapter Review

An animal hormone is a chemical signal released into the extracellular fluid and usually transported through the circulatory system that elicits a specific response from target cells. Coordination and communication among the specialized parts of complex animals are achieved by the endocrine system, which produces hormones that regulate many biological processes, and the nervous system, which conveys high-speed messages along neurons that regulate other neurons, muscle cells, and endocrine cells.

45.1 Hormones and other chemical signals bind to target receptors, triggering specific response pathways

Types of Secreted Chemical Signals

Chemical signals bind to specific receptor proteins on or in target cells. Endocrine cells secrete endocrine signals, or hormones, that travel through the bloodstream. Endocrine glands are ductless secretory organs composed of groups of endocrine cells. Hormones regulate growth, development, and reproduction, and maintain homeostasis.

Local regulators are chemical signals that reach their target cells by diffusion. Paracrine signals act on neighboring cells; autocrine signals act on the secreting cell itself.

Neurotransmitters are secreted by neurons at synapses with other neurons and muscles. Neurosecretory cells are specialized brain neurons that secrete chemical signals called neurohormones, which travel through the bloodstream to target cells.

Pheromones are chemical signals released into the environment that communicate between different individuals.

Chemical Nature of Hormones

Three groups of hormones include polypeptides (peptides and proteins), amines, and steroid hormones. Polypeptides and many amines are water-soluble; steroids are lipid-soluble.

Hormone Receptor Localization

Research in the 1960s showed that the steroid hormones progesterone and estradiol accumulate within the nuclei of cells in female reproductive organs but not in other cells. Receptors for steroid and lipid-soluble hormones have been identified inside cells. Water-soluble hormones bind to cell membranes. Other research showed that microinjection of the water-soluble hormone melanocyte-stimulating hormone into frog skin cells produced no response, while injection into the interstitial space caused a response, indicating that the receptor for MSH is located on the cell surface.
**Cellular Response Pathways** Water-soluble hormones are released by exocytosis, travel through the bloodstream, and bind to cell-surface receptors, triggering a cytoplasmic response or change in gene expression. Lipid-soluble hormones travel in the bloodstream bound to transport proteins, enter target cells, and bind to a receptor in the cytoplasm or nucleus, triggering changes in gene transcription.

Binding of water-soluble hormones to plasma membrane receptors initiates **signal transduction**, which converts extracellular signals to specific intracellular responses. For instance, the binding of epinephrine, released in response to stress by the adrenal gland, to G-protein coupled receptors on liver cells initiates a signal transduction pathway that results in the release of glucose into the bloodstream.

Steroid hormones bind to cytoplasmic receptors, and the hormone-receptor complex then moves into the nucleus, where it stimulates transcription of specific genes. Thyroxine, vitamin D, and other non-steroid lipid-soluble hormones bind with receptors inside the nucleus.

### INTERACTIVE QUESTION 45.1

Label the parts of these diagrams, indicating which represents a water-soluble hormone and which a lipid-soluble hormone.

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**Multiple Effects of Hormones** A given signal can have different effects on different target cells and can produce different effects in different species. These differences may result from the types of receptors (for example, the α-type and β-type epinephrine receptors), the specific signal transduction pathways present, or the particular transcription factors that are activated.

**Signaling by Local Regulators** Cytokines are polypeptide regulators involved in immune responses. **Growth factors** are polypeptides that are required in the extracellular environment for many types of cells to divide and develop.

- **Nitric oxide (NO)** is a gas that can serve as a neurotransmitter and as a local regulator that produces vasodilation, increasing blood flow.
- **Prostaglandins (PGs)** are modified fatty acids that have a wide range of effects on nearby target cells. Prostaglandins help to induce labor. Aspirin and ibuprofen inhibit the synthesis of prostaglandins and thus reduce their fever- and inflammation-inducing and pain-intensifying actions.

#### 45.2 Negative feedback and antagonistic hormone pairs are common features of the endocrine system

**Simple Hormone Pathways** In many hormone pathways, endocrine cells secrete a hormone in response to a stimulus; the hormone travels to target cells, where signal transduction produces a response that reduces the stimulus; and the pathway shuts off. This type of control, called **negative feedback**, is typical of pathways involved in maintaining homeostasis. In many instances, a pair of pathways, each counteracting the other, provides the control system.

**Insulin and Glucagon: Control of Blood Glucose** Two antagonistic hormones regulate glucose concentration in the blood, and negative feedback controls these pathways. **Insulin** is released in response to a rise in blood glucose above the set point and triggers the uptake of glucose from the blood. **Glucagon**, released in response to a drop in blood glucose concentration, stimulates the release of glucose into the blood. Scattered within the exocrine tissue of the **pancreas** are clusters of endocrine cells known as the **islets of Langerhans**. Within each islet are **alpha cells** that secrete glucagon and **beta cells** that secrete insulin.

Insulin lowers blood glucose levels by promoting the movement of glucose from the blood into body cells, by slowing the breakdown of glycogen in the liver, and by inhibiting the conversion of amino acids and glycerol (from fats) to sugar. Glucagon raises glucose concentrations by stimulating target cells in the liver to increase glycogen hydrolysis, convert amino acids and glycerol to glucose, and release glucose to the blood.
In diabetes mellitus, the absence of insulin in the bloodstream or the loss of response to insulin in target tissues reduces glucose uptake by cells. Glucose accumulates in the blood and is excreted in the urine, with an accompanying loss of water. The body must use fats for fuel, and acids from fat breakdown may lower blood pH.

Type 1 diabetes mellitus, also known as insulin-dependent diabetes, is an autoimmune disorder in which pancreatic cells are destroyed. This type of diabetes is treated by regular injections of genetically engineered human insulin. More than 90% of diabetics have type 2 diabetes, or non-insulin-dependent diabetes, characterized by reduced responsiveness of target cells to insulin. Exercise and dietary control are often sufficient to manage this disease, although it is becoming a growing public health problem.

45.3 The endocrine and nervous systems act individually and together to regulate an animal’s physiology

Coordination of Endocrine and Nervous Systems in Invertebrates In invertebrates, reproduction and development are usually controlled by an integration of the endocrine and nervous systems.

Hormones control molting and metamorphosis in insects. Prothoracicotrophic hormone (PTTH), produced by neurosecretory cells in the brain, stimulates the prothoracic glands to secrete ecdysone. Ecdysone triggers molts and metamorphosis. Juvenile hormone promotes retention of larval characteristics during molting. When its level is high, ecdysone-induced molting produces larger larval stages; only after the juvenile hormone level has decreased does molting result in a pupa.

Coordination of Endocrine and Nervous Systems in Vertebrates The hypothalamus, situated in the lower brain, plays a key role in integrating the endocrine and nervous systems. In response to nerve signals it receives from throughout the body, the hypothalamus sends endocrine signals to the pituitary gland located at its base.

The pituitary gland has two discrete parts that develop separately and have different functions. The posterior pituitary, or neurohypophysis, is an extension of the hypothalamus that grows downward during embryonic development. It stores and secretes two hormones that are produced by the hypothalamus. The anterior pituitary, or adenohypophysis, develops from the roof of the embryonic mouth. The hypothalamus regulates secretion of hormones by the anterior pituitary.

Posterior Pituitary Hormones The posterior pituitary stores and releases two neurohormones that are produced by and delivered from neurosecretory cells of the hypothalamus. Oxytocin induces uterine contractions during birth and milk ejection during nursing. Both of these actions are under positive feedback. Antidiuretic hormone (ADH), or vasopressin, functions in osmoregulation. It increases water retention by the kidneys and thus decreases urine volume.
INTERACTIVE QUESTION 45.3

Explain the difference between negative and positive feedback in the control of hormonal pathways.

Anterior Pituitary Hormones Some hypothalamic neurosecretory cells produce releasing hormones and inhibiting hormones that regulate the hormones of the anterior pituitary. For example, thyrotropin releasing hormone (TRH) stimulates the anterior pituitary to secrete thyrotropin, or thyroid stimulating hormone (TSH). These hypothalamic hormones are released into capillaries at the base of the hypothalamus and travel via a short portal vessel to capillary beds in the anterior pituitary.

In a hormone cascade pathway, the hypothalamus secretes a hormone that stimulates or inhibits release of an anterior pituitary hormone, which then acts on a target endocrine tissue, stimulating the release of a hormone that produces a response to the stimulus. For example, TRH delivered to the anterior pituitary stimulates the release of TSH, which stimulates the thyroid gland to release thyroid hormone.

Hormones that regulate endocrine glands or cells are called tropic hormones. In addition to TSH, the anterior pituitary produces three other tropic hormones. Follicle-stimulating hormone (FSH) and luteinizing hormone (LH), also called gonadotropins, stimulate gonad activity. Adrenocorticotropic hormone (ACTH) stimulates the adrenal cortex to produce and secrete its steroid hormones.

The hormone prolactin (PRL) is a protein with diverse effects in different vertebrate species, ranging from milk production and secretion in mammals, to delay of metamorphosis in amphibians, to osmoregulation in fishes.

Melanocyte-stimulating hormone (MSH) regulates the activity of pigment-containing cells in the skin of some vertebrates and appears to inhibit hunger in mammals.

Growth hormone (GH) has diverse metabolic non-tropic effects. Its main trophic action is signaling the release of insulin-like growth factors (IGFs) that are produced by the liver and stimulate bone and cartilage growth. Gigantism and acromegaly are human growth disorders caused by hypersecretion of GH. Pituitary dwarfism can now be treated with genetically engineered GH.

INTERACTIVE QUESTION 45.4

Fill in the following table to review the hormones stored and released by the posterior pituitary (a and b) and secreted by the anterior pituitary (c–h).

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Main Actions</th>
</tr>
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<tbody>
<tr>
<td>Oxytocin</td>
<td>a.</td>
</tr>
<tr>
<td>ADH</td>
<td>b.</td>
</tr>
<tr>
<td>TSH</td>
<td>c.</td>
</tr>
<tr>
<td>FSH and LH</td>
<td>d.</td>
</tr>
<tr>
<td>ACTH</td>
<td>e.</td>
</tr>
<tr>
<td>Prolactin</td>
<td>f.</td>
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<tr>
<td>MSH</td>
<td>g.</td>
</tr>
<tr>
<td>GH</td>
<td>h.</td>
</tr>
</tbody>
</table>

45.4 Endocrine glands respond to diverse stimuli in regulating metabolism, homeostasis, development, and behavior

Thyroid Hormones: Control of Metabolism and Development Thyroid hormone regulates development and contributes to homeostasis in mammals, helping to maintain normal blood pressure, heart rate, muscle tone, digestion, and reproductive functions. The thyroid gland produces two hormones, triiodothyronine (T3) and thyroxine (T4). A negative feedback loop controls secretion of thyroid hormones. High levels of T3 and T4 inhibit the secretion of TRH and TSH.

Excess thyroid hormone results in hyperthyroidism, with symptoms of weight loss, irritability, and high body temperature and blood pressure. Hypothyroidism can cause weight gain and lethargy in adults.

Thyroid hormones are critical to vertebrate development and maturation. In humans, an inherited deficiency called congenital hypothyroidism results in retarded skeletal and mental development.

INTERACTIVE QUESTION 45.5

Explain how a lack of iodine in the diet may result in goiter, an enlarged thyroid gland.
Parathyroid Hormone and Vitamin D: Control of Blood Calcium The four parathyroid glands secrete parathyroid hormone (PTH), which stimulates Ca\(^{2+}\) reabsorption in the kidney, and its release from bone to raise blood calcium levels. PTH also activates vitamin D, which then increases Ca\(^{2+}\) uptake from food in the intestines. If blood Ca\(^{2+}\) rises above the set point, the thyroid gland secretes calcitonin, a hormone that lowers calcium levels in the blood. In humans, calcitonin appears to be only required during the bone growth of childhood.

Adrenal Hormones: Response to Stress In mammals, the adrenal glands consist of two different glands: the outer adrenal cortex composed of endocrine cells and the central adrenal medulla derived from neural tissue.

The adrenal medulla produces epinephrine (adrenaline) and norepinephrine (noradrenaline)—both of which are catecholamines, a class of compounds synthesized from the amino acid tyrosine. Epinephrine and norepinephrine, released in response to positive or negative stress, increase the availability of energy sources by stimulating glycogen hydrolysis in skeletal muscle and the liver, glucose release from the liver, and fatty acid release from fat cells. These hormones increase metabolic rate and the rate and volume of the heartbeat, dilate bronchioles in the lungs, and influence the contraction or relaxation of smooth muscles to increase blood supply to the heart, brain, and skeletal muscles, while reducing the supply to other organs. Norepinephrine’s primary role is in sustaining blood pressure. Nerve signals from the hypothalamus stimulate the release of catecholamines from the adrenal medulla.

The adrenal cortex responds to endocrine signals released in response to stress. A releasing hormone from the hypothalamus causes the anterior pituitary to release ACTH. This tropic hormone stimulates the adrenal cortex to secrete corticosteroids, a group of steroid hormones.

Glucocorticoids promote synthesis of glucose from noncarbohydrates (such as muscle proteins) and thus increase energy supplies during stress. Cortisol has been used to treat inflammatory diseases such as arthritis, but its side effects can be dangerous.

Mineralocorticoids affect salt and water balance. Aldosterone, released in response to low blood volume or pressure, stimulates kidney cells to reabsorb sodium ions and water from the filtrate. ACTH secreted by the anterior pituitary in response to severe stress increases aldosterone secretion. Both glucocorticoids and mineralocorticoids appear to help maintain homeostasis during extended periods of stress.

A third group of corticosteroids produced by the adrenal cortex are sex hormones, in particular androgens, which appear to influence female sex drive.

INTERACTIVE QUESTION 45.6
Describe how the adrenal gland is signaled by the hypothalamus and responds to short-term and long-term stress.

a. Short-term stress:

b. Long-term stress:

Gonadal Sex Hormones The testes of males and ovaries of females produce steroids that affect growth, development, and reproductive cycles and behaviors. The three major categories of gonadal steroids—androgens, estrogens, and progesterins—are found in different proportions in males and females.

The testes primarily synthesize androgens, such as testosterone, which determine the gender of the developing embryo and stimulate development of the male reproductive system and secondary sex characteristics. Estrogens, in particular estradiol, regulate the maintenance of the female reproductive system and the development of secondary sex characteristics. In mammals, progesterone helps prepare and maintain the uterus for the growth of an embryo.

In a hormone cascade pathway, a hypothalamic releasing hormone, GnRH, controls secretion of FSH and LH, gonadotropins from the anterior pituitary gland, which then control the synthesis of estrogens and androgens.

Melatonin and Biorhythms The pineal gland, located near the center of the mammalian brain, secretes melatonin, which regulates functions related to light and changes in day length. The secretion of melatonin at night may target the suprachiasmatic nuclei (SCN), a biological clock for daily or seasonal activities such as reproduction.
Word Roots

adeno- = gland; -hypo = below (adenohypophysis: also called the anterior pituitary, a gland positioned at the base of the hypothalamus)

andro- = male; -gen = produce (androgen: the principal male steroid hormones, such as testosterone, which stimulate the development and maintenance of the male reproductive system and secondary sex characteristics)

anti- = against; -diure = urinate (antidiuretic hormone: a hormone that helps regulate water balance)

cata- = down; -chol = anger (catecholamines: a class of compounds, including epinephrine and norepinephrine, synthesized from the amino acid tyrosine)

-cortico = the shell; -tropic = to turn or change (adrenocorticotropic hormone: a hormone released from the anterior pituitary. It stimulates the production and secretion of steroid hormones by the adrenal cortex)

ecdys- = an escape (ecdysone: a steroid hormone that triggers molting in arthropods)

epi- = above, over (epinephrine: a hormone produced as a response to stress; also called adrenaline)

gluco- = sweet (glucagon: a peptide hormone secreted by pancreatic endocrine cells that raises blood glucose levels; an antagonistic hormone to insulin)

lut- = yellow (luteinizing hormone: a gonadotropin secreted by the anterior pituitary)

melan- = black (melatonin: a modified amino acid hormone secreted by the pineal gland)

neuro- = nerve (neurohypophysis: also called the posterior pituitary, it is an extension of the brain)

oxy- = sharp, acid (oxytocin: a hormone that induces contractions of the uterine muscles and causes the mammary glands to eject milk during nursing)

para- = beside, near (parathyroid glands: four endocrine glands, embedded in the surface of the thyroid gland, that secrete parathyroid hormone and raise blood calcium levels)

pro- = before; -lact = milk (prolactin: a hormone produced by the anterior pituitary gland, it stimulates milk synthesis in mammals)

tri- = three; -iodo = violet (triiodothyronine: one of two very similar hormones produced by the thyroid gland and derived from the amino acid tyrosine)

2. Explain how the action of secretin, which is released in response to a low pH in the intestine and stimulates the release of bicarbonate from the pancreas, illustrates a simple hormone pathway.

3. What is a hormone cascade pathway? Describe how the activation of the thyroid gland illustrates such a pathway.

Test Your Knowledge

MATCHING: Match the hormone and gland or organ that produces it to the descriptions. Choices may be used more than once, and not all choices are used.

<table>
<thead>
<tr>
<th>Hormones</th>
<th>Gland or Organ</th>
</tr>
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<tbody>
<tr>
<td>A. ACTH</td>
<td>a. adrenal cortex</td>
</tr>
<tr>
<td>B. androgens</td>
<td>b. adrenal medulla</td>
</tr>
<tr>
<td>C. ADH</td>
<td>c. hypothalamus</td>
</tr>
<tr>
<td>D. calcitonin</td>
<td>d. pancreas</td>
</tr>
<tr>
<td>E. epinephrine</td>
<td>e. parathyroid</td>
</tr>
<tr>
<td>F. glucagon</td>
<td>f. pineal</td>
</tr>
<tr>
<td>G. glucocorticoids</td>
<td>g. pituitary</td>
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<tr>
<td>H. insulin</td>
<td>h. testis</td>
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<tr>
<td>I. melatonin</td>
<td>i. thymus</td>
</tr>
<tr>
<td>J. oxytocin</td>
<td>j. thyroid</td>
</tr>
<tr>
<td>K. PTH</td>
<td></td>
</tr>
<tr>
<td>L. thyroxine</td>
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<table>
<thead>
<tr>
<th>Hormone</th>
<th>Gland</th>
<th>Hormone Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ACTH</td>
<td>adrenal cortex</td>
<td>1. involved in biological clock and seasonal activities</td>
</tr>
<tr>
<td>B. androgens</td>
<td>adrenal medulla</td>
<td>2. break down muscle protein for conversion to glucose</td>
</tr>
<tr>
<td>C. ADH</td>
<td>hypothalamus</td>
<td>3. increase blood sugar, glycogen breakdown in liver</td>
</tr>
<tr>
<td>D. calcitonin</td>
<td>pancreas</td>
<td>4. stimulate development of male reproductive system</td>
</tr>
<tr>
<td>E. epinephrine</td>
<td>parathyroid</td>
<td>5. stimulate adrenal cortex to synthesize corticosteroids</td>
</tr>
<tr>
<td>F. glucagon</td>
<td>pineal</td>
<td>6. increase available energy, heart rate, metabolism</td>
</tr>
<tr>
<td>G. glucocorticoids</td>
<td>pituitary</td>
<td>7. regulate metabolism, growth, and development</td>
</tr>
<tr>
<td>H. insulin</td>
<td>testis</td>
<td>8. lower blood calcium levels</td>
</tr>
<tr>
<td>I. melatonin</td>
<td>thymus</td>
<td>9. increase reabsorption of water by kidney</td>
</tr>
<tr>
<td>J. oxytocin</td>
<td>thyroid</td>
<td>10. stimulate contraction of uterus, milk secretion</td>
</tr>
</tbody>
</table>

Structure Your Knowledge

1. Briefly describe the two general mechanisms by which chemical signals trigger responses in target cells, depending on the location of the receptor.
MULTIPLE CHOICE: Choose the one best answer.

1. Which of the following is not an accurate statement about hormones?
   a. Not all hormones are secreted by endocrine glands.
   b. Most hormones move through the circulatory system to their destination.
   c. Target cells have specific protein receptors for hormones.
   d. Hormones are essential to homeostasis.
   e. Steroid hormones often function as neurotransmitters.

2. The best description of the difference between pheromones and hormones is that
   a. pheromones are small, volatile molecules, whereas hormones are steroids.
   b. pheromones are involved in reproduction, whereas hormones are not.
   c. pheromones are a form of neural communication; hormones are a form of chemical communication.
   d. pheromones are signals that function between organisms, whereas hormones communicate among the parts within an organism.
   e. pheromones are local regulators, whereas hormones travel greater distances.

3. Which one of the following hormones is incorrectly paired with its origin?
   a. releasing hormones—hypothalamus
   b. growth hormone—anterior pituitary
   c. progestins—ovary
   d. TSH—thyroid
   e. mineralocorticoids—adrenal cortex

4. Which of the following is an example of a positive feedback mechanism?
   a. the liver's production of insulin-like growth factors in response to growth hormone, which promote skeletal growth
   b. the ability of the neurotransmitter acetylcholine to cause skeletal muscle to contract, heart muscle to relax, and cells of the adrenal medulla to secrete epinephrine
   c. prostaglandins released from placental cells promoting muscle contraction during childbirth, with muscle contractions stimulating more prostaglandin release
   d. the action of secretin on the pancreas, stimulating the release of bicarbonate
   e. elevated levels of stress resulting in neural stimulation of the adrenal medulla and hormonal stimulation of the adrenal cortex

5. Ecdysone
   a. is a steroid hormone produced in insects that promotes retention of larval characteristics.
   b. is responsible for color changes in amphibians.
   c. is a hormone secreted from specialized neurons that triggers the formation of a pupa.
   d. is secreted by prothoracic glands in insects and triggers molts and development of adult characteristics.
   e. is involved in metamorphosis in amphibians.

6. Which of the following local regulators amplifies the sensation of pain?
   a. prostaglandins
   b. melanocyte-stimulating hormone
   c. growth factors
   d. cytokines
   e. nitric oxide

7. Atropine hormone is a hormone
   a. whose target tissue is another endocrine gland.
   b. that is produced by the hypothalamus but stored and released from the posterior pituitary.
   c. that acts by negative feedback to regulate its own level in the body.
   d. from the hypothalamus that regulates the synthesis and secretion of hormones of the posterior pituitary.
   e. that is released in response to nervous stimulation.

8. The anterior pituitary
   a. stores oxytocin and ADH produced by the hypothalamus.
   b. receives releasing and inhibiting hormones from the hypothalamus through portal vessels connecting capillary beds.
   c. produces several releasing and inhibiting hormones.
   d. is responsible for nervous and hormonal stimulation of the adrenal glands.
   e. produces only tropic hormones.

9. What is the best description of the mechanism of action of steroid hormones?
   a. transported by neurosecretory cells directly to target tissues
   b. form a hormone-receptor complex inside the cell that regulates gene expression
   c. amplified response using second messengers
   d. bind to membrane-bound receptors and initiate a signal transduction pathway
   e. secreted into the interstitial fluid and act as a local regulator
10. Which of the following hormones is not involved with increasing the blood glucose concentration?
   a. glucagon
   b. epinephrine
   c. glucocorticoids
   d. ACTH (adrenocorticotropic hormone)
   e. insulin

11. MSH (melanocyte-stimulating hormone) causes frog skin cells to darken when added to the interstitial fluid but has no effect on color when injected into the cells. Which of the following does this evidence support?
   a. MSH is a tropic hormone.
   b. MSH is a neurohormone.
   c. MSH is a steroid hormone.
   d. MSH binds to cell surface receptors.
   e. Both c and d are reasonable conclusions.

12. Which of the following is not true of norepinephrine?
   a. It is secreted by the adrenal medulla.
   b. It maintains blood pressure.
   c. Its release is stimulated by ACTH.
   d. It serves as a neurotransmitter.
   e. It is part of the flight-or-fight response to stress.

Choose from the following hormones to answer questions 13–15.
   a. ACTH
   b. parathyroid hormone
   c. epinephrine
   d. estrogen
   e. insulin

13. Which of the above is a tropic hormone?
14. Which hormone is a steroid hormone?
15. Which hormone is released in response to a nervous impulse?
16. A lack of iodine in the diet can lead to formation of a goiter because
   a. excess thyroxine production causes the thyroid gland to enlarge.
   b. with limited iodine available, triiodothyronine (T₃) rather than thyroxine (T₄) is produced.
   c. iodine is a key ingredient of the growth hormones that control growth of the thyroid.
   d. little thyroxine is produced, TRH and TSH production is not inhibited, and thyroid stimulation continues.
   e. the hypothalamus is stimulated to increase its production of TRH.