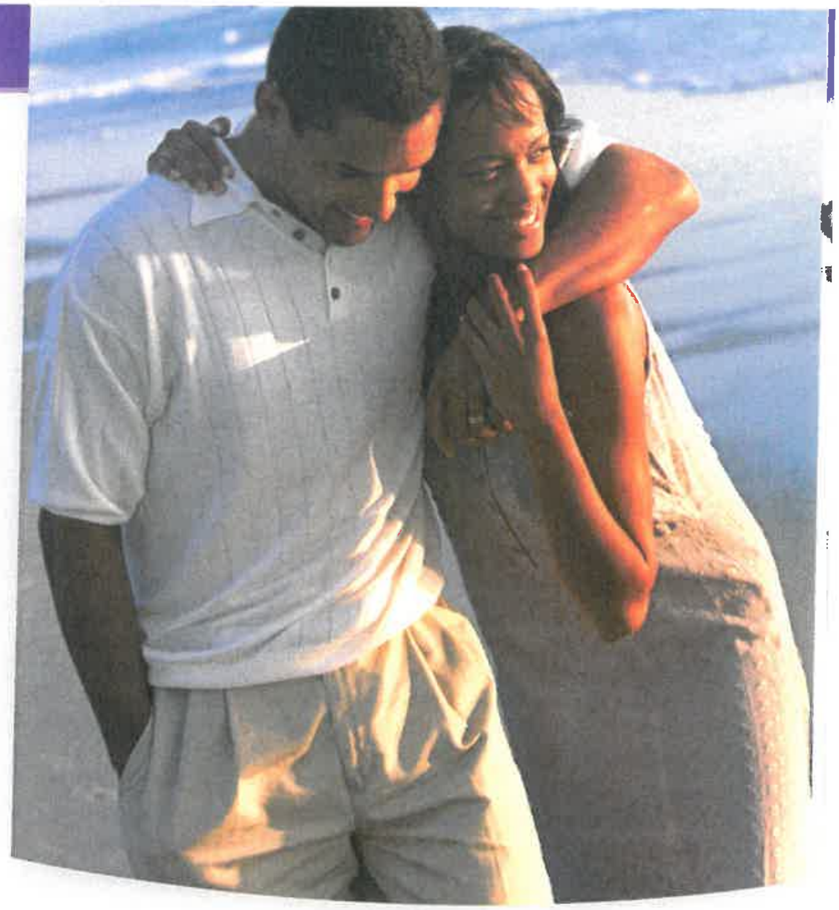
11

Endocrine System



The endocrine system produces hormones, which act within an individual. Humans may also produce pheromones, which affect other individuals and may play a role in mate selection, as they do in rodents and insects.

Smelly T-shirts. The endocrine system produces hormones, which are biochemicals that send messages in an individual. Less well understood are pheromones, which are chemical signals sent between individuals of a species. In insects and rodents, pheromones stimulate mating behavior. Experiments suggest that this may be the case with humans, too.

Mice and rats choose mates that are dissimilar to themselves with respect to a group of genes that provide immunity. Their sense of smell helps them discern appropriate mates. Biologists hypothesize that choosing mates based on scent may protect offspring in two ways—it prevents close relatives from mating, and it may team immune systems with different types of strengths.

Researchers have traced mouse social and mating behavior to receptors in the olfactory epithelium, in the nasal cavity. The receptors—called trace-amine-associated receptors—are attuned to molecules in mouse urine that direct social behavior. The genes that encode the receptors are also found in humans.

To test whether heterosexual humans use the sense of smell to respond to pheromones in mate selection as rodents do, researchers in Switzerland recruited forty-nine young women and forty-four young men. Each participant donated DNA, which was typed for genes that affect mating in rodents. The women used nasal spray for two weeks to clear their nasal passages. The men wore the same T-shirt on two consecutive days, using no deodorant or soap and avoiding contact with anything smelly that could linger. Each woman was then given three T-shirts from men genetically similar to her and three T-shirts from men genetically dissimilar to her, not knowing which shirts came from which men.

The women rated the shirts on intensity, pleasantness, and sexiness. Like the mice and rats, women preferred the sweaty T-shirts from the men least like them genetically.

Another, more specific experiment supported these findings. Women were given vials of fluid to sniff that either contained or did not contain a component of male sweat called androstadienone. Although they didn't know which samples they were sniffing, the women consistently reported mood elevation and sexual arousal when they smelled the sweat. In addition, their saliva had increased amounts of cortisol, a hormone that raises the blood sugar level, when they smelled androstadienone, suggesting that it might be a human pheromone. Despite the mounting scientific evidence for human pheromones, a definitive human pheromone has not yet been described.

Learning Outcomes

After studying this chapter, you should be able to do the following:

11.1 Introduction

1. Describe the secretions of the endocrine system. (p. 292)
2. Distinguish between paracrine and autocrine secretions. (p. 292)
3. Distinguish between endocrine and exocrine glands. (p. 292)

11.2 General Characteristics of the Endocrine System

4. Explain how the nervous and endocrine systems are alike and how they are different. (p. 292)
5. Describe the source of specificity of the endocrine system. (p. 293)
6. Name some functions of hormones. (p. 293)

11.3 Hormone Action

7. Explain how steroid and nonsteroid hormones affect target cells. (p. 294)

11.4 Control of Hormonal Secretions

8. Discuss how negative feedback mechanisms regulate hormonal secretions. (p. 296)
9. Explain how the nervous system controls secretion. (p. 297)

Learn **Practice** **Assess**

release hormones into the bloodstream, which carries these messenger molecules everywhere (fig. 11.1). However, the endocrine system is no less precise, because only target cells can respond to a hormone. A hormone's target cells have specific receptors that other cells do not have. These receptors are proteins or glycoproteins with binding sites for a specific hormone.

Endocrine glands and their hormones help regulate metabolic processes. They control the rates of certain chemical reactions, aid in the transport of substances across cell membranes, and help regulate water and electrolyte balances. They also play vital roles in reproduction, development, and growth.

Specialized small groups of cells produce some hormones. However, the major endocrine glands are the pituitary gland, thyroid gland, parathyroid glands, adrenal glands, pancreas, pineal gland, reproductive glands (testes and ovaries), kidneys, and thymus (fig. 11.2).

Practice

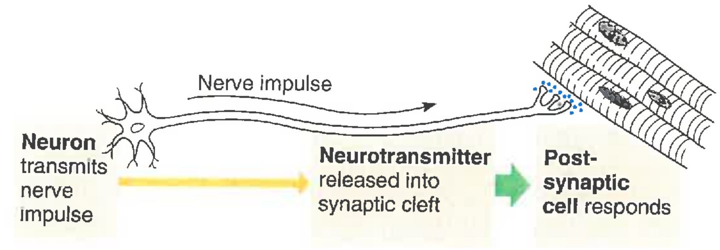
4. Explain how the nervous and endocrine systems are alike and how they differ.
5. What determines whether a cell is a target cell for a particular hormone?
6. State some functions of hormones.

11.3 HORMONE ACTION

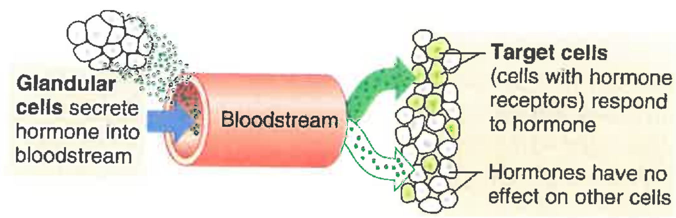
Most hormones are of two general types. They are either steroids (or steroidlike substances) synthesized from cholesterol, or they are amines, peptides, proteins, or glycoproteins synthesized from amino acids (table 11.2). Hormones can stimulate changes in target cells even in extremely low concentrations.

Table 11.2 Types of Hormones

Type of Compound	Formed From	Examples
Steroids	Cholesterol	Estrogen, testosterone, aldosterone, cortisol
Amines	Amino acids	Norepinephrine, epinephrine
Peptides	Amino acids	Antidiuretic hormone, oxytocin, thyrotropin-releasing hormone
Proteins	Amino acids	Parathyroid hormone, growth hormone, prolactin
Glycoproteins	Protein and carbohydrate	Follicle-stimulating hormone, luteinizing hormone, thyroid-stimulating hormone



(a)



(b)

Figure 11.1

Chemical communication takes place in both the nervous system and the endocrine system. In both cases, cells respond to chemicals released from other cells. **(a)** Neurons release neurotransmitters into a synapse, affecting postsynaptic cells. **(b)** Glands release hormones into the bloodstream. Blood carries hormone molecules throughout the body, but only target cells respond.

Q: *What do postsynaptic cells and target cells have in common that allow them to respond to secreted chemicals?*

Answers can be found in Appendix E on page 568.

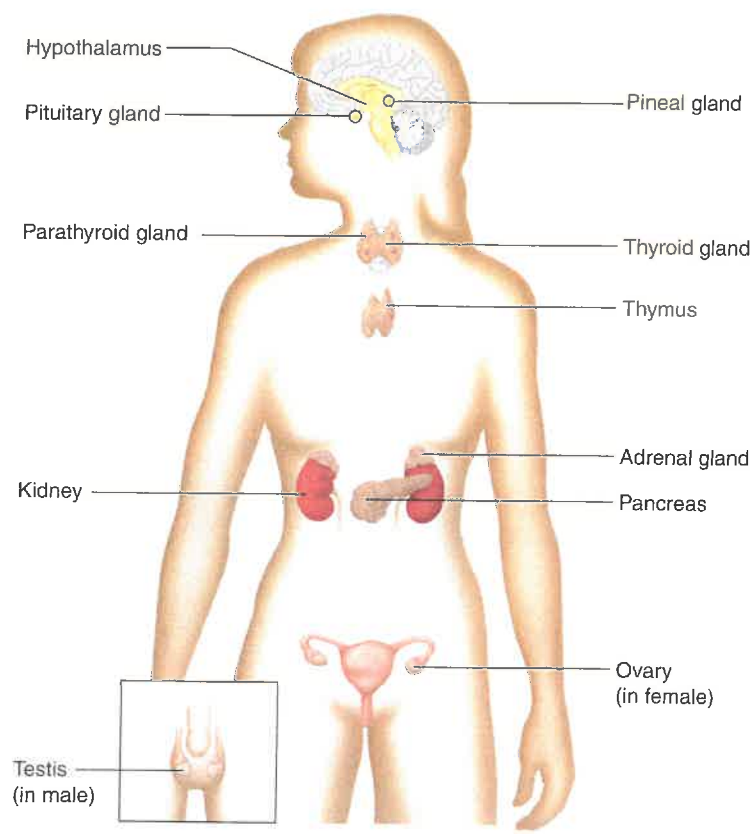


Figure 11.2

Locations of the major endocrine glands. The pituitary, thyroid, parathyroid, adrenal glands, and the pancreas are the main topics of this chapter. The functions of the other glands are described in more detail in subsequent chapters.

binding site and an *activity site*. A hormone molecule delivers its message to its target cell by uniting with the binding site of its receptor. This combination stimulates the receptor's activity site to interact with other membrane proteins. The hormone that triggers this cascade of biochemical activity is called a *first messenger*. The biochemicals in the cell that induce changes in response to the hormone's binding are called *second messengers*. The entire process of chemical communication, from outside cells to inside, is called **signal transduction.**

The second messenger associated with one group of hormones is *cyclic adenosine monophosphate*, also called **cyclic AMP (cAMP)** (sī′klik ay em pee). This mechanism works as follows (fig. 11.4):

1. A hormone binds to its receptor.
2. The resulting hormone-receptor complex activates a membrane protein called a *G protein*.
3. The G protein activates an enzyme called *adenylate cyclase*, which is a membrane protein.
4. In the cytoplasm, activated adenylate cyclase catalyzes the formation of cAMP from ATP.
5. cAMP activates another set of enzymes, called protein kinases, which transfer phosphate groups from ATP to their substrate molecules, which are specific proteins in the cell. This action, called phosphorylation, alters the shapes of these substrate molecules, thereby activating them.

The activated proteins then alter various cellular processes, bringing about the characteristic effect of the hormone.

The type of membrane receptors present and the kinds of protein substrate molecules in a cell determine the cell's response to a hormone. Such responses to second messenger activation include altering membrane permeabilities, activating enzymes, promoting synthesis of certain proteins, stimulating or inhibiting specific metabolic pathways, moving the cell, and initiating secretion of hormones or other substances.

Another enzyme (phosphodiesterase) quickly inactivates cAMP, so that its action is short-lived. For this reason, a continuing response of a target cell requires a continuing signal from hormone molecules binding the target cell's membrane receptors.

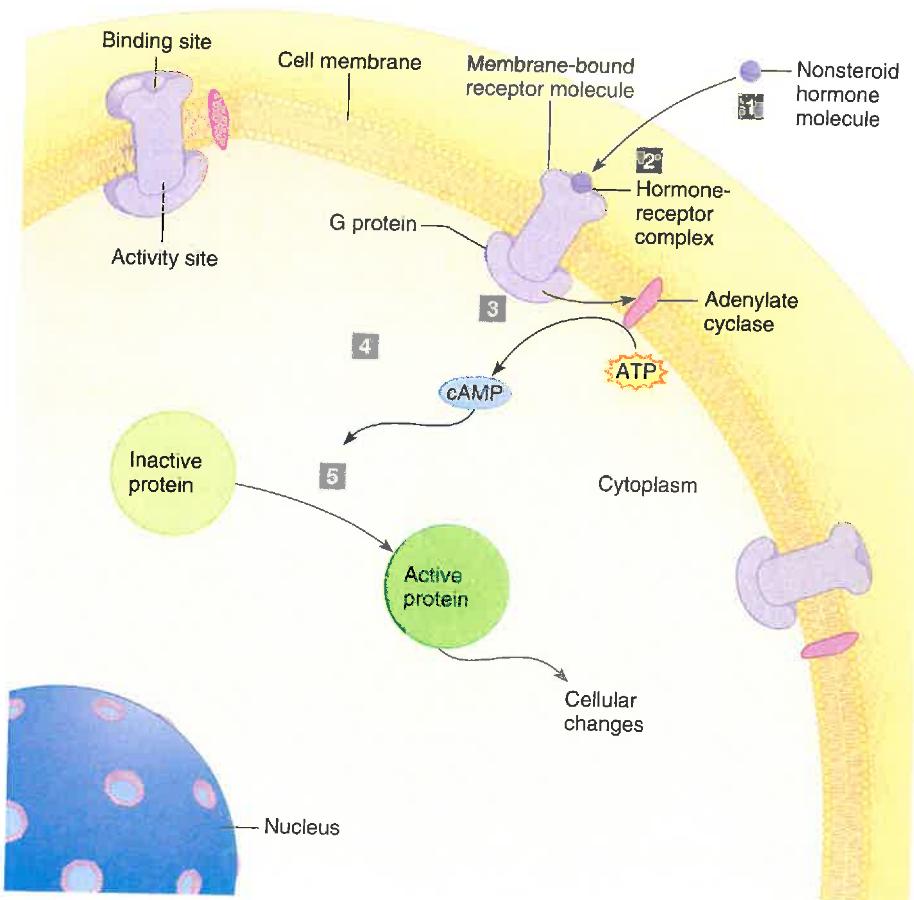


Figure 11.4 AP|R

Nonsteroid hormone action. **(1)** Body fluids carry nonsteroid hormone molecules to the target cell, where **(2)** they bind receptor molecules on the cell membrane. **(3)** This activates molecules of adenylate cyclase, which **(4)** catalyze conversion of ATP into cyclic adenosine monophosphate (cAMP). **(5)** The cAMP promotes a series of reactions leading to the cellular changes associated with the hormone's action.

about the internal environment from neural connections and cerebrospinal fluid (fig. 11.5*a*).

2. The nervous system stimulates some glands directly. The adrenal medulla, for example, secretes its hormones in response to sympathetic nerve impulses (fig. 11.5*b*).
3. Another group of glands responds directly to changes in the composition of the internal environment. For example, when the blood glucose level rises, the pancreas secretes insulin, and when the blood glucose level falls, it secretes glucagon, as discussed later in the chapter (fig. 11.5*c*).

In each of these cases, as hormone levels rise in the blood and the hormone exerts its effects, negative feedback inhibits the system, and hormone secretion decreases. Then, as hormone levels in the blood decrease and the hormone's effects are no longer taking place, inhibition of the system is lifted, and secretion of that hormone increases again. As a result of negative feedback, hormone levels in the bloodstream remain relatively stable, tending to fluctuate slightly above and below an average value (fig. 11.6).

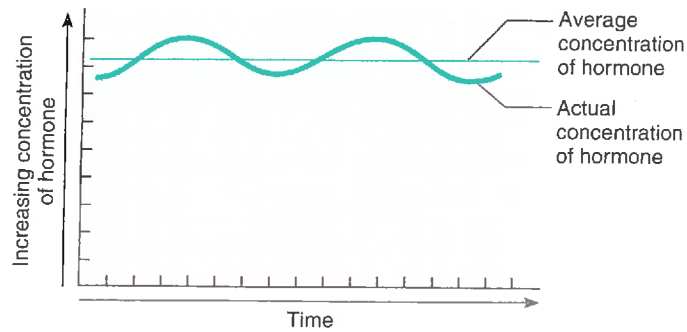


Figure 11.6

As a result of negative feedback, hormone concentrations remain relatively stable, although they may fluctuate slightly above and below average concentrations.

Practice

11. Explain three examples of control of hormonal secretion.
12. Describe a negative feedback system that controls hormone secretion.

11.5 PITUITARY GLAND

The **pituitary gland** (hypophysis) is located at the base of the brain, where a pituitary stalk (infundibulum) attaches it to the hypothalamus. The gland is about 1 centimeter in diameter and consists of an **anterior pituitary** (pĭ-tu′ĭ-tăr″e), or anterior lobe, and a **posterior pituitary,** or posterior lobe (fig. 11.7).

In the fetus, a narrow region develops between the anterior and posterior lobes of the pituitary gland. Called the *intermediate lobe* (pars intermedia), it produces melanocyte-stimulating hormone (MSH), which regulates the synthesis of melanin—the pigment in skin and in parts of the eyes and brain. This intermediate lobe is usually not present as a distinct structure in adults.

The brain controls most of the pituitary gland's activities. For example, the posterior pituitary releases hormones when nerve impulses from the hypothalamus signal the axon terminals of neurosecretory cells in the posterior pituitary (fig. 11.8). On the other hand, **releasing hormones** (or release-inhibiting hormones) from the hypothalamus control secretion from the anterior pituitary (fig. 11.8). These hormones travel in a capillary network associated with the hypothalamus. The capillaries merge to form the **hypophyseal portal veins,** which pass downward along the pituitary stalk and give rise to a capillary network in the anterior pituitary. Thus, the hypothalamus releases substances that the blood carries directly to the anterior pituitary.

Upon reaching the anterior pituitary, each of the hypothalamic hormones acts on a specific population of cells. Some of the resulting actions are inhibitory, but most stimulate the anterior pituitary to release hormones that stimulate secretions from peripheral endocrine glands. In many of these cases, important negative feedback regulates hormone levels in the bloodstream.

Practice

13. Where is the pituitary gland located?
14. Explain how the hypothalamus controls the secretory activity of the posterior and anterior lobes of the pituitary gland.

Anterior Pituitary Hormones

The anterior pituitary is enclosed in a capsule of dense, collagenous connective tissue and consists largely of epithelial tissue organized in blocks around many thin-walled blood vessels. So far researchers have identified five types of secretory cells in this epithelium. Four of these cell types each secrete a different hormone—growth hormone (GH), prolactin (PRL), thyroid-stimulating hormone (TSH), and adrenocorticotropic hormone (ACTH). The fifth type of cell secretes both follicle-stimulating hormone (FSH) and luteinizing hormone (LH). (In males, luteinizing hormone had been known as interstitial cell stimulating hormone, or ICSH.)

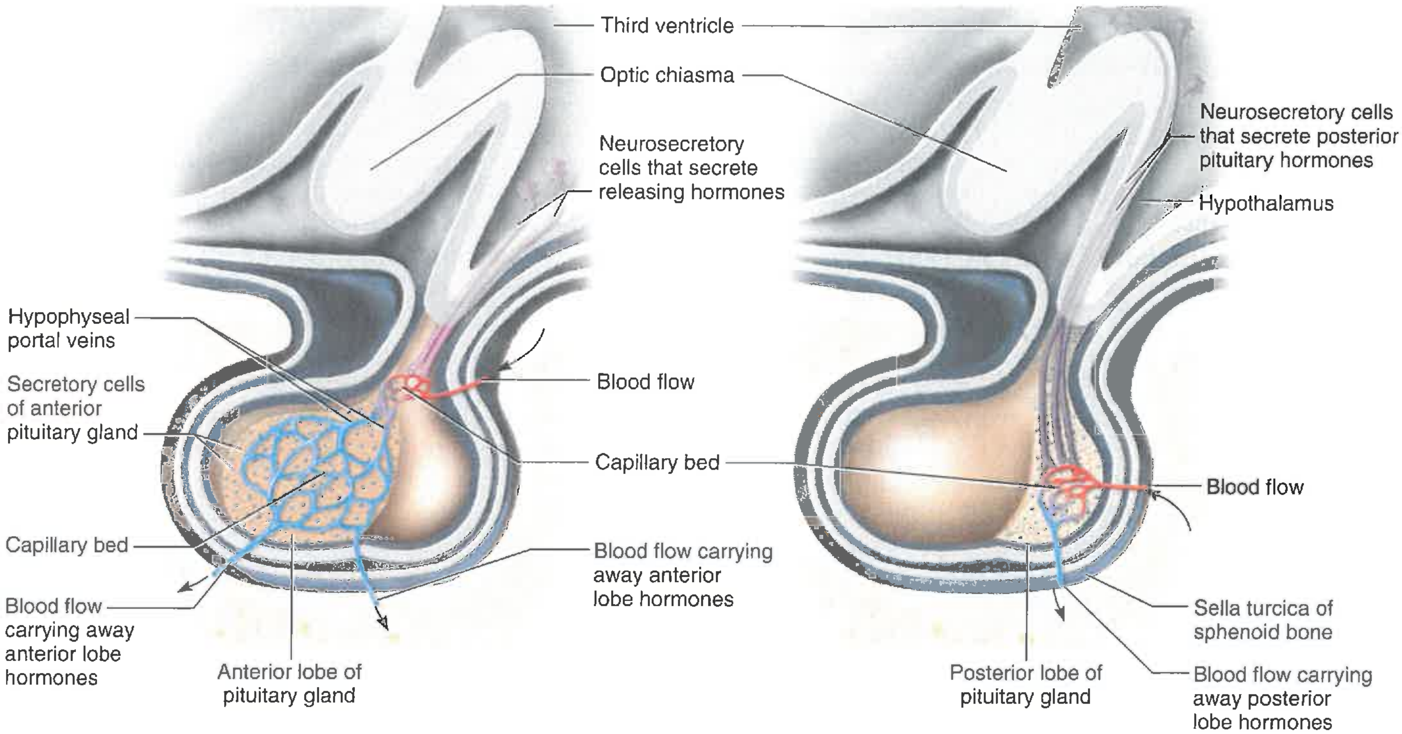


Figure 11.8 APR

Secretion of pituitary hormones. Releasing hormones from neurosecretory cells in the hypothalamus stimulate secretory cells of the anterior lobe of the pituitary gland to secrete hormones. Other neurosecretory cells in the hypothalamus release their hormones directly into capillaries of the posterior lobe of the pituitary gland.

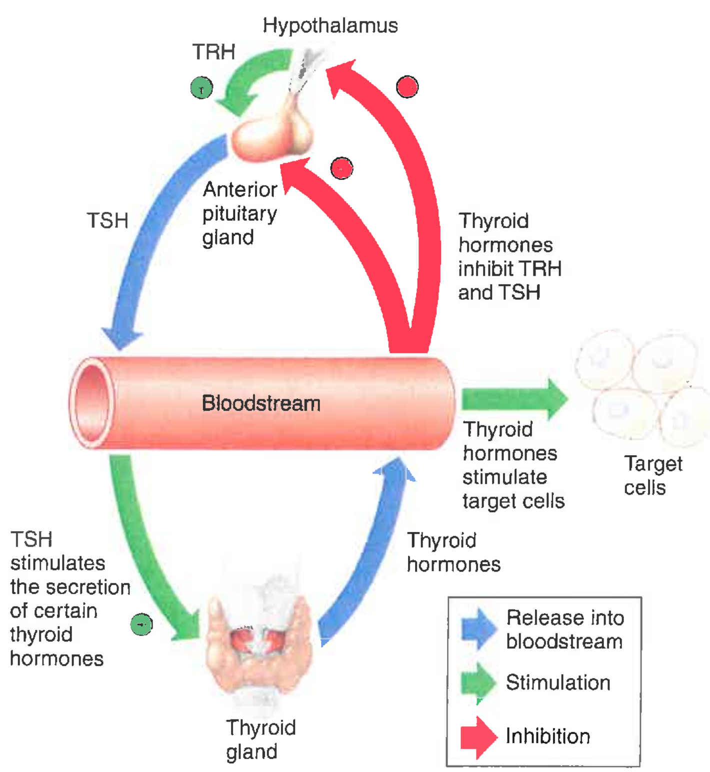


Figure 11.9

Thyrotropin-releasing hormone (TRH) from the hypothalamus stimulates the anterior pituitary gland to release thyroid-stimulating hormone (TSH), which stimulates the thyroid gland to release hormones. These thyroid hormones reduce the secretion of TSH and TRH by negative feedback. (⊕ = stimulation; ⊖ = inhibition)

Table 11.3 Hormones of the Pituitary Gland

Hormone	Action	Source of Control
Anterior Lobe		
Growth hormone (GH)	Stimulates an increase in the size and division rate of body cells; enhances movement of amino acids across membranes	Growth hormone-releasing hormone and growth hormone release-inhibiting hormone from hypothalamus
Prolactin (PRL)	Sustains milk production after birth	Secretion restrained by prolactin release-inhibiting hormone and stimulated by prolactin-releasing factor from hypothalamus
Thyroid-stimulating hormone (TSH)	Controls secretion of hormones from thyroid gland	Thyrotropin-releasing hormone (TRH) from hypothalamus
Adrenocorticotropic hormone (ACTH)	Controls secretion of certain hormones from adrenal cortex	Corticotropin-releasing hormone (CRH) from hypothalamus
Follicle-stimulating hormone (FSH)	In females, responsible for the development of egg-containing follicles in ovaries and stimulates follicular cells to secrete estrogen; in males, stimulates production of sperm cells	Gonadotropin-releasing hormone from hypothalamus
Luteinizing hormone (LH)	Promotes secretion of sex hormones; plays a role in releasing an egg cell in females	Gonadotropin-releasing hormone from hypothalamus
*Posterior Lobe**		
Antidiuretic hormone (ADH)	Causes kidneys to conserve water; in high concentration, increases blood pressure	Hypothalamus in response to changes in water concentration in body fluids
Oxytocin (OT)	Contracts muscles in the uterine wall; contracts muscles associated with milk-secreting glands	Hypothalamus in response to stretching of uterine and vaginal walls and stimulation of breasts

ese hormones are synthesized in the hypothalamus, as explained in the text.

.1.6 THYROID GLAND

ıe **thyroid gland** (thi′roid gland) is a very vascular ·ucture that consists of two large lobes connected by a oad *isthmus* (is′mus). It is bilateral, just inferior to the ·ynx and anterior to the trachea (fig. 11.10 and referıce plate 4, p. 26).

:ructure of the Gland

capsule of connective tissue covers the thyroid gland, ıich is made up of many secretory parts called *fol-:les*. The follicles have cavities that are lined with a ıgle layer of cuboidal epithelial cells and filled with clear, viscous substance called *colloid*. The follicular lls produce and secrete hormones that may be stored the colloid or released into the blood in nearby pillaries.

ıyroid Hormones

ıe follicular cells of the thyroid gland synthesize two ›rmones—**thyroxine** (thi-rok′sin) (tetraiodothyrone), also known as T_4 because it contains four atoms iodine, and **triiodothyronine** (tri″i-o″do-thi′ro-nēn), ıown as T_3 because it includes three atoms of iodine.

Thyroxine and triiodothyronine have similar actions, although triiodothyronine is five times more potent. These hormones help regulate the metabolism of carbohydrates, lipids, and proteins. They increase the rate at which cells release energy from carbohydrates, increase the rate of protein synthesis, and stimulate breakdown and mobilization of lipids. Thyroid hormones are the major factors determining how many calories the body must consume at rest in order to maintain life, which is known as the *basal metabolic rate (BMR)*. Thyroid hormones are required for normal growth and development, and are essential to nervous system maturation.

> Up to 80% of the iodine in the body is in the thyroid gland.

Follicular cells require iodine salts (iodides) to produce thyroxine and triiodothyronine. Foods normally provide iodides, and after the iodides have been absorbed from the intestine, blood transports them to the thyroid gland. An efficient active transport mechanism moves the iodides into the follicular cells, where they are used to synthesize the hormones. The hypothalamus and anterior pituitary gland control the synthesis and release of thyroid hormones. Once in the blood, thyroxine and

Thyroid disorders may produce underactivity (*hypothyroidism*) or overactivity (*hyperthyroidism*) of the glandular cells. A child with one form of hypothyroidism, called cretinism, may appear normal at birth because the mother provided enough thyroid hormones. When the infant's own thyroid gland does not produce enough of these hormones after birth, symptoms develop, including stunted growth, abnormal bone formation, retarded mental development, low body temperature, and sluggishness. Without receiving thyroid hormone within a month or so following birth, the child may suffer permanent mental retardation. Hypothyroidism is also common among older adults, producing fatigue and weight gain. Hyperthyroidism produces an elevated metabolic rate, restlessness, and overeating. The eyes protrude (exophthalmia) because of swelling in the tissues behind them, and the thyroid gland enlarges, producing a bulge in the neck called a *goiter*.

11.7 PARATHYROID GLANDS

The **parathyroid glands** (par″ah-thi′roid glandz) are on the posterior surface of the thyroid gland, as figure 11.11 shows. Usually, there are four parathyroid glands—a superior and an inferior gland associated with each of the thyroid's lateral lobes.

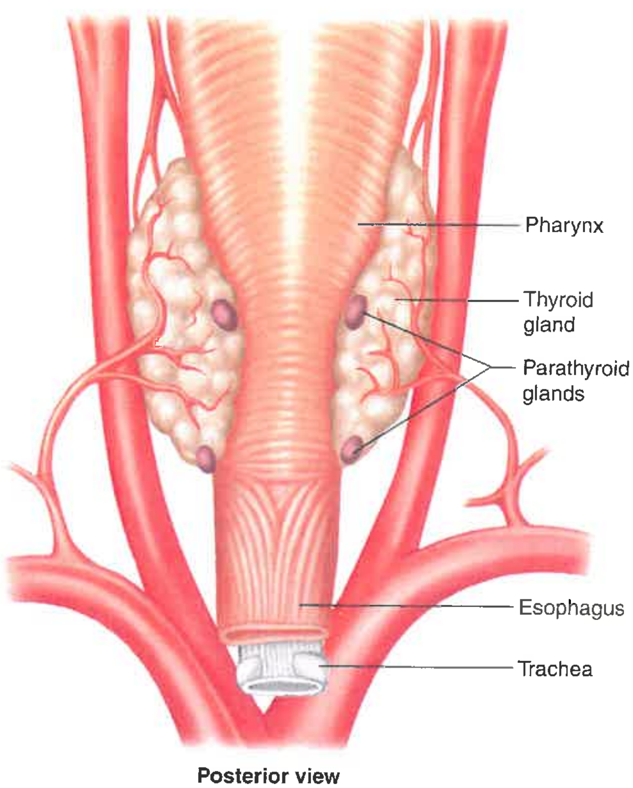


Figure 11.11

The parathyroid glands are embedded in the posterior surface of the thyroid gland.

Structure of the Glands

A thin capsule of connective tissue covers each small, yellowish-brown parathyroid gland. The body of the gland consists of many tightly packed secretory cells closely associated with capillary networks.

Parathyroid Hormone

The parathyroid glands secrete **parathyroid hormone (PTH),** which increases blood calcium concentration and decreases blood phosphate ion concentration. PTH affects the bones, kidneys, and intestine.

The extracellular matrix of bone tissue is rich in mineral salts, including calcium phosphate (see chapter 7, p. 141). PTH inhibits the activity of osteoblasts and stimulates osteoclasts to resorb bone and release calcium and phosphate ions into the blood. At the same time, PTH causes the kidneys to conserve blood calcium and to excrete more phosphate ions in the urine. It also stimulates calcium absorption from food in the intestine, further increasing blood calcium concentration.

Negative feedback between the parathyroid glands and the blood calcium concentration regulates PTH secretion. As blood calcium concentration drops, more PTH is secreted; as blood calcium concentration rises, less PTH is released (fig. 11.12).

To summarize, calcitonin and PTH activities maintain stable blood calcium concentration. Calcitonin decreases an above-normal blood calcium concentration, while PTH increases a below-normal blood calcium concentration (see fig. 7.8, p. 141).

Practice

26. Where are the parathyroid glands?
27. How does parathyroid hormone help regulate concentrations of blood calcium and phosphate ions?

Injury to the parathyroids or their surgical removal can cause *hypoparathyroidism*, in which decreased PTH secretion reduces osteoclast activity. Although the bones remain strong, the blood calcium concentration decreases. The nervous system may become abnormally excitable, triggering spontaneous impulses. As a result, muscles may undergo tetanic contractions, possibly leading to respiratory failure and death.

A tumor in a parathyroid gland may cause *hyperparathyroidism*, which increases PTH secretion. This stimulates osteoclast activity, and as bone tissue is resorbed, the bones soften, deform, and more easily fracture spontaneously. In addition, excess calcium and phosphate released into body fluids may be deposited in abnormal places, causing new problems, such as kidney stones.

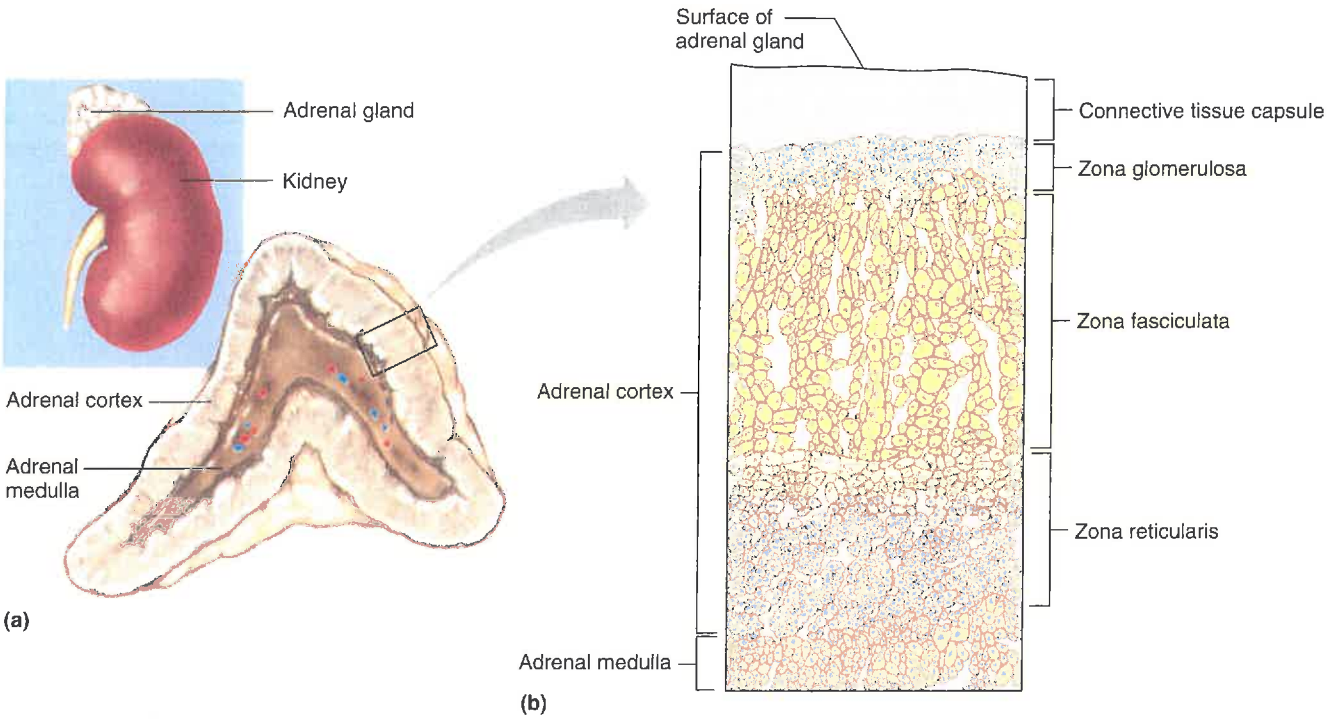


Figure 11.13 APR

Adrenal glands. **(a)** An adrenal gland consists of an outer cortex and an inner medulla. **(b)** The cortex consists of three layers, or zones, of cells.

than neurotransmitters. Epinephrine and norepinephrine increase heart rate, the force of cardiac muscle contraction, breathing rate, and blood glucose level. They also elevate blood pressure and decrease digestive activity.

Impulses arriving on sympathetic nerve fibers stimulate the adrenal medulla to release its hormones at the same time that sympathetic impulses are stimulating other effectors. These sympathetic impulses originate in the hypothalamus in response to stress. In this way, adrenal medullary secretions function with the sympathetic division of the autonomic nervous system in preparing the body for energy-expending action, sometimes called "fight-or-flight responses." Table 11.5 compares some of the effects of the adrenal medullary hormones.

Tumors in the adrenal medulla can increase hormonal secretion. Release of norepinephrine usually predominates, prolonging sympathetic responses—high blood pressure, increased heart rate, elevated blood sugar, and so forth. Surgical removal of the tumor corrects the condition.

Practice

30. Name the hormones the adrenal medulla secretes.
31. What effects do hormones from the adrenal medulla produce?
32. What stimulates release of hormones from the adrenal medulla?

Table 11.5 Comparative Effects of Epinephrine and Norepinephrine

Part or Function Affected	Epinephrine	Norepinephrine
Heart	Increases rate and force of contraction	Increases rate and force of contraction
Blood vessels	Dilates vessels in skeletal muscle, decreasing resistance to blood flow	Increases blood flow to skeletal muscles, resulting from constriction of blood vessels in skin and viscera
Systemic blood pressure	Increases somewhat due to increased cardiac output	Increases greatly due to vasoconstriction
Airways	Dilates	Dilates slightly
Reticular formation of brain	Activates	Activates
Liver	Promotes breakdown of glycogen to glucose, increasing blood sugar concentration	Produces little effect on blood sugar concentration
Metabolic rate	Increases	Increases

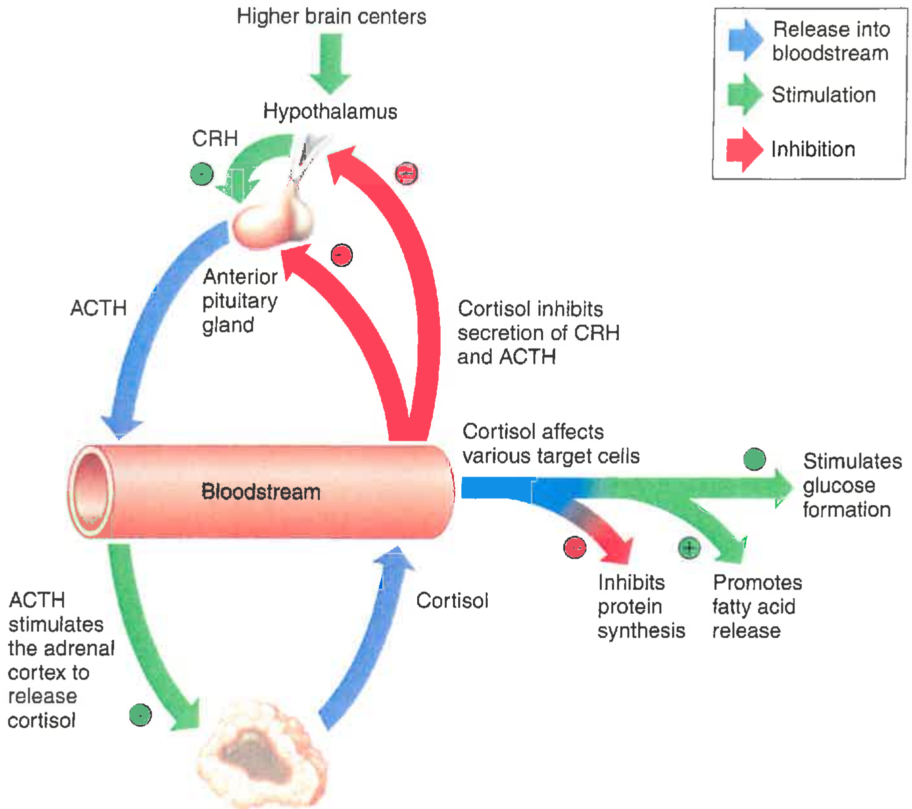


Figure 11.14

Negative feedback regulates cortisol secretion, similar to the regulation of thyroid hormone secretion (see fig. 11.9, p. 299). (⊕ = stimulation; ⊖ = inhibition)

Table 11.6 Hormones of the Adrenal Cortex APR

Hormone	Action	Factor Regulating Secretion
Aldosterone	Helps regulate concentration of extracellular electrolytes by conserving sodium ions and excreting potassium ions	Electrolyte concentrations in body fluids
Cortisol	Decreases protein synthesis, increases fatty acid release, and stimulates glucose synthesis from noncarbohydrates	Corticotropin-releasing hormone from hypothalamus and adrenocorticotropic hormone from anterior pituitary
Adrenal androgens	Supplement sex hormones from the gonads; may be converted to estrogens in females	

digestive juice and an endocrine gland that releases hormones (fig. 11.15 and reference plate 6, p. 28).

Structure of the Gland

The pancreas is an elongated, somewhat flattened organ posterior to the stomach and behind the parietal peritoneum. A duct joins the pancreas to the duodenum (the first section of the small intestine) and transports pancreatic digestive juice to the intestine. The dual nature of the pancreas begins in the embryo. First, ducts form whose walls harbor progenitor cells (see fig. 3.23, p. 72). Some of the progenitor cells divide to yield daughter cells that specialize as exocrine cells, and others divide to yield cells that differentiate into endocrine cells. The two functions are elaborated as the gland develops further.

The endocrine part of the pancreas consists of groups of cells that are closely associated with blood vessels. These groups form "islands" of cells called *pancreatic islets* (islets of Langerhans) (figs. 11.15 and 11.16). The pancreatic islets include two distinct types of cells—alpha cells, which secrete the hormone glucagon, and beta cells, which secrete the hormone insulin.

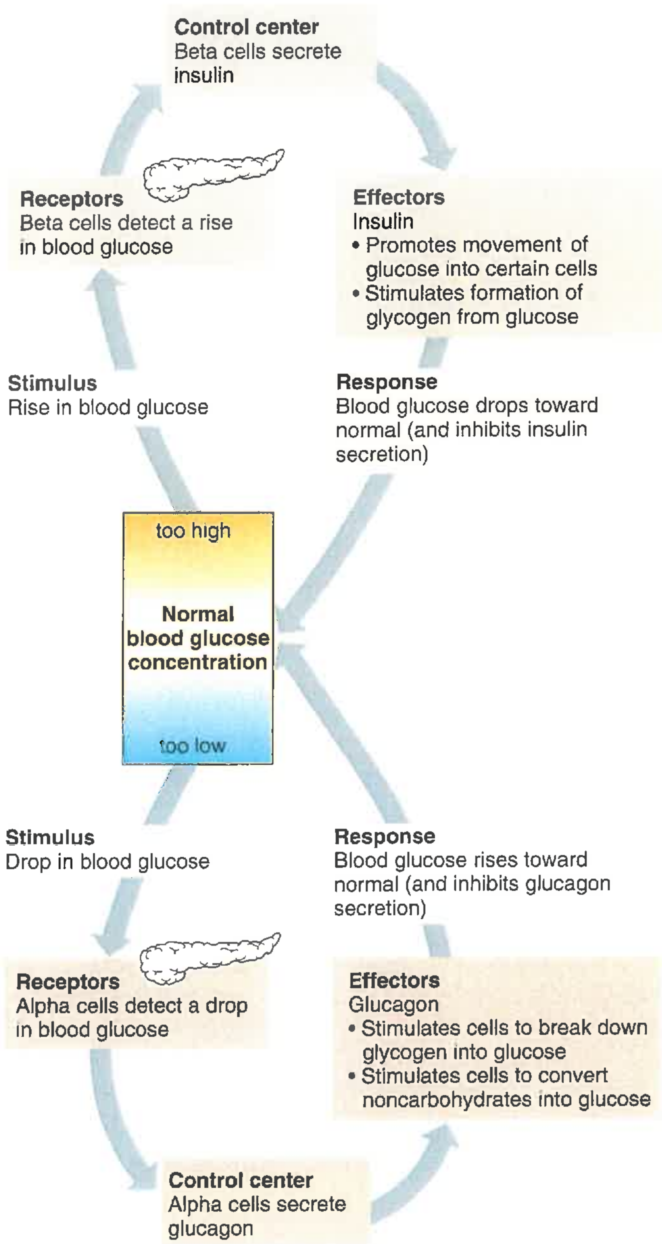


Figure 11.17 APR

Insulin and glucagon function together to help maintain a relatively stable blood glucose concentration. Negative feedback responding to blood glucose concentration controls the levels of both hormones.

centration, and conditions that cause such changes—oversecretion of insulin leading to decreased blood glucose, for example—are likely to alter brain functions.

Cancer cells that develop from nonendocrine tissues sometimes inappropriately synthesize and secrete great amounts of peptide hormones or peptide hormonelike chemicals. For example, in endocrine paraneoplastic syndrome, a person with a non-endocrine cancer overproduces ADH, ACTH, a PTH-like substance, or an insulin-like substance.

Practice

37. What is the endocrine portion of the pancreas called?
38. What is the function of glucagon?
39. What is the function of insulin?
40. How are glucagon and insulin secretion controlled?
41. Why are nerve cells particularly sensitive to changes in blood glucose concentration?

11.10 OTHER ENDOCRINE GLANDS

Other glands that produce hormones and thus are parts of the endocrine system include the pineal gland, the thymus, reproductive organs, and certain glands of the digestive tract, heart, and kidneys.

The **pineal gland** (pin′e-al gland) is a small structure located deep between the cerebral hemispheres, where it attaches to the upper part of the thalamus near the roof of the third ventricle (see fig. 11.2). The pineal gland secretes the hormone **melatonin** (mel″ah-to′nin) in response to light conditions outside the body. Nerve impulses originating in the retinas of the eyes send this information to the pineal gland. In the dark, nerve impulses from the eyes decrease, and melatonin secretion increases.

Melatonin acts on certain brain regions that function as a "biological clock," and may thereby help to regulate **circadian rhythms** (ser″kah-de′an rithmz), which are patterns of repeated activity associated with the environmental cycles of day and night. The changing levels of melatonin throughout the 24-hour day may enable the body to distinguish day from night. Circadian rhythms include the sleep–wake rhythm and seasonal cycles of fertility in many mammals. Clinical Application 11.2 discusses biological rhythms.

The fact that melatonin secretion responds to day length explains why traveling across several time zones produces the temporary insomnia of jet lag. Melatonin supplements are advertised as preventing jet lag, shift work disorder, and other sleeping disorders, but clinical trials for these applications are still in progress.

The mechanism of melatonin action is poorly understood, but the hormone inhibits the secretion of gonadotropins from the anterior pituitary and may help regulate the female reproductive cycle. It may also control the onset of puberty.

The **thymus** (thi′mus), which lies in the mediastinum posterior to the sternum and between the lungs, is relatively large in young children but shrinks with age (see the blood, which lowers pH (acidosis). Dehydration and acidosis may harm brain cells, causing disorientation, coma, and, eventually, death.

There are two common forms of diabetes mellitus. These are type 1 (insulin-dependent or juvenile diabetes) and type 2 (non-insulin-dependent or maturity-onset diabetes).

Type 1 Diabetes Mellitus

Type 1 diabetes mellitus usually appears before age twenty. It is an autoimmune disease: the immune system destroys the beta cells of the pancreas (see chapter 14, pp. 394–395).

People with type 1 diabetes must carefully monitor their blood glucose levels. They do this in two ways. Every three or four months, a laboratory test checks the levels of hemoglobin molecules in the blood that bind glucose. This measurement is called "A1c," and should be between 6% and 7%. It provides a view of blood glucose level over the preceding months. The second type of test is called self-monitoring of blood glucose. A person uses a test kit to draw a drop of blood, applies it to a test strip, then uses a meter to read the concentration of glucose in the blood (in milligrams per deciliter). Normal plasma levels of glucose should range from 90 to 130 mg/dL before meals and less than 180 mg/dL one to two hours after meals. Most people with type 1 diabetes check their glucose this way two to four times a day.

Treatment for type 1 diabetes is still to give insulin, but delivery has improved so that treatment better mimics normal pancreatic function. Before 1978, for example, people with diabetes used insulin from pigs. Then genetically modified bacteria began to supply the human version of the hormone, to which allergy is far less likely. People with type 1 diabetes typically inject insulin several times a day, or receive the hormone from an implanted insulin pump. Delivery of insulin through nasal sprays or skin patches is still experimental. Replacing a diabetic pancreas with a healthy transplanted organ is too difficult to be practical—the surgery is complex, the supply of organs very limited, and immune rejection difficult to prevent or control. Instead, much research has focused on islet transplantation, which can decrease the need for insulin supplements for a few years.

Type 2 Diabetes Mellitus

About 85–90% of people with diabetes mellitus have type 2, in which the beta cells produce insulin but body cells lose the ability to recognize it. The condition usually develops gradually after age forty and has milder symptoms than type 1 diabetes. Most affected individuals are overweight when symptoms begin. Treatment includes controlling the diet, exercising, and maintaining a desirable body weight. Several oral drugs can help control glucose levels, which can delay the onset of diabetes-related complications.

People with either type of diabetes must monitor their blood glucose level at least daily, and do what they can to regulate it, to forestall complications, which include coronary artery disease, peripheral nerve damage, and retinal damage. Evidence suggests that these complications may begin even before blood glucose level indicates disease. The American Diabetes Association now recognizes "pre-diabetes" as blood glucose levels above the normal range but not yet indicative of type 2 diabetes. About 20 million people in the United States between the ages of forty and seventy-four fall into this category.

11.11 STRESS AND HEALTH

Survival depends on the maintenance of homeostasis. Therefore, factors that change the body's internal environment can threaten life. When the body senses danger, nerve impulses to the hypothalamus trigger physiological responses that preserve homeostasis. These responses include increased activity in the sympathetic division of the autonomic nervous system and increased secretion of adrenal and other hormones. A factor that can stimulate such a response is called a *stressor,* and the condition it produces in the body is called **stress.**

Types of Stress

Stressors include physical factors, such as exposure to extreme heat or cold, decreased oxygen concentration, infections, injuries, prolonged heavy exercise, and loud sounds. Stressors also include psychological factors, such as thoughts about real or imagined dangers, personal losses, and unpleasant social interactions. Feelings of anger, fear, grief, anxiety, depression, and guilt can also produce psychological stress. Sometimes, even pleasant stimuli, such as friendly social contact, feelings of joy and happiness, or sexual arousal, may be stressful.

Responses to Stress

Physiological responses to stress consist of reactions called the *stress response* or *general adaptation syndrome,* which is under hypothalamic control. These reactions proceed through two stages: the immediate "alarm" stage and the long-term "resistance" stage. Initially, the hypothalamus activates mechanisms that prepare the body for "fight or flight." These responses include raising

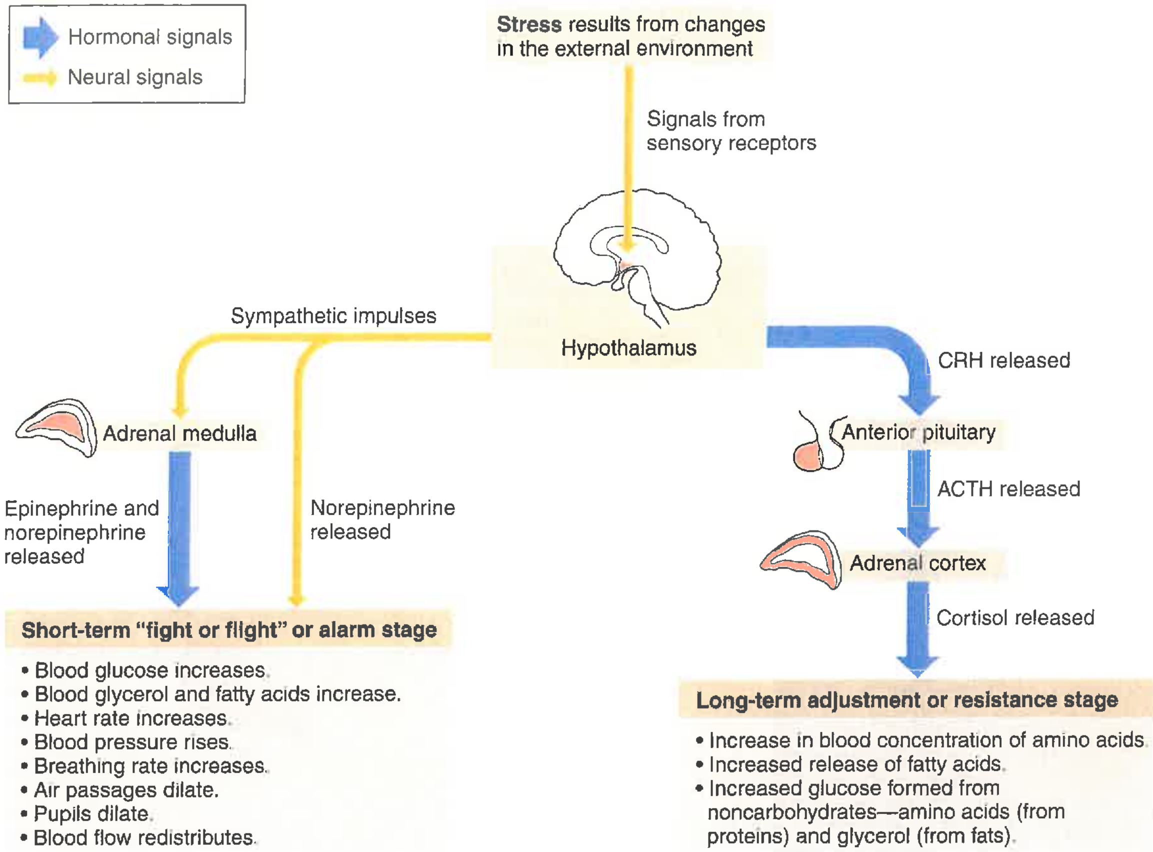


Figure 11.18

Stress response. During stress, the hypothalamus helps prepare the body for "fight or flight" by triggering sympathetic impulses to various organs. It also stimulates epinephrine release, intensifying the sympathetic responses. The hypothalamus additionally secretes corticotropin-releasing hormone, which sets into motion more lasting responses to stress.

Summary Outline

11.1 Introduction (p. 292)

The endocrine and nervous systems maintain homeostasis.

1. The endocrine system is a network of glands that secrete hormones, which travel in the bloodstream and affect the functioning of target cells.
2. Paracrine secretions act locally, and autocrine secretions act on the cells that produce them.
3. Exocrine glands secrete through tubes or ducts.

11.2 General Characteristics of the Endocrine System (p. 292)

Like the nervous system, the endocrine system exerts precise effects in helping regulate metabolic processes.

11.3 Hormone Action (p. 293)

Endocrine glands secrete hormones that affect target cells with specific receptors. Hormones are very potent.

1. Chemically, hormones are steroids, amines, peptides, proteins, or glycoproteins.
2. Steroid hormones
   a. Steroid hormones enter a target cell and bind receptors, forming complexes in the nucleus.
   b. These complexes activate specific genes, so that specific proteins are synthesized.
3. Nonsteroid hormones
   a. Nonsteroid hormones bind receptors in the target cell membrane.
   b. The hormone-receptor complex signals a G protein to stimulate a membrane protein, such as adenylate cyclase, to induce formation of second messenger molecules.
   c. A second messenger, such as cyclic adenosine monophosphate (cAMP), diacylglycerol (DAG), or inositol triphosphate (IP_3), activates protein kinases.
   d. Protein kinases activate protein substrate molecules, which in turn change a cellular process.
4. Prostaglandins
   a. Prostaglandins act on the cells of the organs that produce them.
   b. Prostaglandins are present in small amounts and have powerful hormonelike effects.

11.4 Control of Hormonal Secretions (p. 296)

The concentration of each hormone in body fluids is regulated.

1. Some endocrine glands secrete hormones in response to releasing hormones that the hypothalamus secretes.
2. Other glands secrete their hormones in response to nerve impulses.

3. Some glands respond to levels of a substance in the bloodstream.
4. Negative feedback guides these control mechanisms.
   a. In a negative feedback system, a gland senses the concentration of a substance it regulates.
   b. When the concentration of the regulated substance reaches a certain point, it inhibits the gland.
   c. As the gland secretes less hormone, the amount of the controlled substance also decreases.
   d. Negative feedback systems maintain relatively stable hormone concentrations.

11.5 Pituitary Gland (p. 297)

The pituitary gland has an anterior lobe and a posterior lobe. The hypothalamus controls most pituitary secretions.

1. Anterior pituitary hormones
   a. The anterior pituitary secretes growth hormone (GH), prolactin (PRL), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), and luteinizing hormone (LH).
   b. Growth hormone
      (1) GH stimulates cells to enlarge and divide more frequently.
      (2) GH-releasing hormone and GH release-inhibiting hormone from the hypothalamus control GH secretion.
   c. PRL stimulates and sustains milk production.
   d. Thyroid-stimulating hormone
      (1) TSH controls secretion of hormones from the thyroid gland.
      (2) The hypothalamus secretes thyrotropin-releasing hormone (TRH), which regulates TSH secretion.
   e. Adrenocorticotropic hormone
      (1) ACTH controls secretion of hormones from the adrenal cortex.
      (2) The hypothalamus secretes corticotropin-releasing hormone (CRH), which regulates ACTH secretion.
   f. FSH and LH are gonadotropins.
2. Posterior pituitary hormones
   a. The posterior lobe of the pituitary gland consists largely of neuroglia and nerve fibers.
   b. The hypothalamus produces the hormones of the posterior pituitary.
   c. Antidiuretic hormone (ADH)
      (1) ADH reduces the volume of water the kidneys excrete.
      (2) The hypothalamus regulates ADH secretion.
   d. Oxytocin (OT)
      (1) OT contracts muscles in the uterine wall.
      (2) OT also contracts cells that secrete and eject milk.

11.6 Thyroid Gland (p. 301)

The thyroid gland in the neck consists of two lobes.

1. Structure of the gland
   a. The thyroid gland consists of many follicles.
   b. The follicles are fluid-filled and store hormones.
2. Thyroid hormones
   a. Thyroxine and triiodothyronine increase the metabolic rate of cells, enhance protein synthesis, and stimulate lipid utilization.
   b. Calcitonin decreases blood calcium level and increases blood phosphate ion concentration.

11.7 Parathyroid Glands (p. 303)

The parathyroid glands are on the posterior surface of the thyroid gland.

1. Each parathyroid gland consists of secretory cells that are well supplied with capillaries.
2. Parathyroid hormone (PTH)
   a. PTH increases blood calcium level and decreases blood phosphate ion concentration.
   b. A negative feedback mechanism operates between the parathyroid glands and the blood.

11.8 Adrenal Glands (p. 304)

The adrenal glands are located atop the kidneys.

1. Structure of the glands
   a. Each gland consists of an adrenal medulla and an adrenal cortex.
   b. These parts are functionally distinct, and secrete different hormones.
2. Hormones of the adrenal medulla
   a. The adrenal medulla secretes epinephrine and norepinephrine, which have similar effects.
   b. Sympathetic impulses stimulate secretion of these hormones.
3. Hormones of the adrenal cortex
   a. The adrenal cortex produces several steroid hormones.
   b. Aldosterone is a mineralocorticoid that causes the kidneys to conserve sodium ions and water and to excrete potassium ions.
   c. Cortisol is a glucocorticoid that affects carbohydrate, protein, and fat metabolism.
   d. Adrenal sex hormones
      (1) These hormones are of the male type but may be converted to female hormones.
      (2) They may supplement the sex hormones the gonads produce.

11.9 Pancreas (p. 306)

The pancreas secretes digestive juices as well as hormones.

1. Structure of the gland
   a. The pancreas is attached to the small intestine.
   b. The pancreatic islets secrete glucagon and insulin.
2. Hormones of the pancreatic islets
   a. Glucagon stimulates the liver to produce glucose from glycogen and noncarbohydrates.
   b. Insulin moves glucose across some cell membranes, stimulates glucose and fat storage, and promotes protein synthesis.
   c. Nerve cells do not require insulin to obtain glucose.

11.10 Other Endocrine Glands (p. 309)

1. Pineal gland
   a. The pineal gland attaches to the thalamus.
   b. It secretes melatonin in response to varying light conditions.
   c. Melatonin may help regulate the female reproductive cycle by inhibiting gonadotropin secretion from the anterior pituitary.
2. Thymus
   a. The thymus lies behind the sternum and between the lungs.
   b. It secretes thymosins, which affect the production of certain lymphocytes that function in immunity.
3. Reproductive organs
   a. The testes secrete testosterone.
   b. The ovaries secrete estrogens and progesterone.
   c. The placenta secretes estrogens, progesterone, and gonadotropin.
4. Digestive glands
   Certain glands of the stomach and small intestine secrete hormones.
5. Other hormone-producing organs
   Other organs, such as the heart and the kidneys, also produce hormones.

28. Match the adrenal hormones with their source and actions. (pp. 304–306)

(1) cortisol	A. Cortex; sodium retention
(2) aldosterone	B. Cortex; fatty acid release
(3) epinephrine	C. Medulla; fight-or-flight response

29. Draw a diagram illustrating the regulation of cortisol secretion. (p. 306)

11.9 Pancreas

30. Describe the location and structure of the pancreas. (p. 307)
31. List the hormones secreted by the pancreatic islets, the type of cell that secretes each, and the actions of these hormones. (p. 307)
32. Draw a diagram that shows how the secretion of pancreatic hormones is regulated. (p. 308)

11.10 Other Endocrine Glands

33. Describe the location and general function of the pineal gland. (p. 309)
34. Describe the location and general function of the thymus. (p. 309)
35. Name five additional hormone-secreting organs. (p. 310)

11.11 Stress and Health

36. Define *stress*. (p. 311)
37. List the similarities and differences between the short-term alarm stage of stress and the long-term resistance stage. (p. 311)

Integrative Assessments/Critical Thinking

OUTCOMES 2.2, 11.3, 11.4, 11.5, 11.6

1. When reactor 4 at the Chernobyl Nuclear Power Station in Ukraine exploded at 1:23 P.M. on April 26, 1986, a great plume of radioactive isotopes erupted into the air and spread for thousands of miles. Most of the isotopes emitted immediately following the blast were of the element iodine. Which of the glands of the endocrine system would be most seriously—and immediately—affected by the blast, and how do you think this would become evident in the nearby population?

OUTCOMES 7.3, 11.4, 11.5

2. Growth hormone is administered to people who have pituitary dwarfism. Parents wanting their normal children to be taller have requested the treatment for them. Do you think this is a wise request? Why or why not?

OUTCOMES 11.4, 11.5

3. What hormone supplements would an adult whose anterior pituitary has been removed require?

OUTCOMES 11.4, 11.5, 11.6, 11.11

4. How might a patient with hyperthyroidism modify lifestyle to minimize the drain on body energy resources?

OUTCOMES 11.4, 11.8

5. The adrenal cortex of a patient who has lost a large volume of blood will increase secretion of aldosterone. What effect will this increased secretion have on the patient's blood concentrations of sodium and potassium ions?

OUTCOMES 11.4, 11.9

6. Why might oversecretion of insulin actually reduce glucose uptake by nerve cells?

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