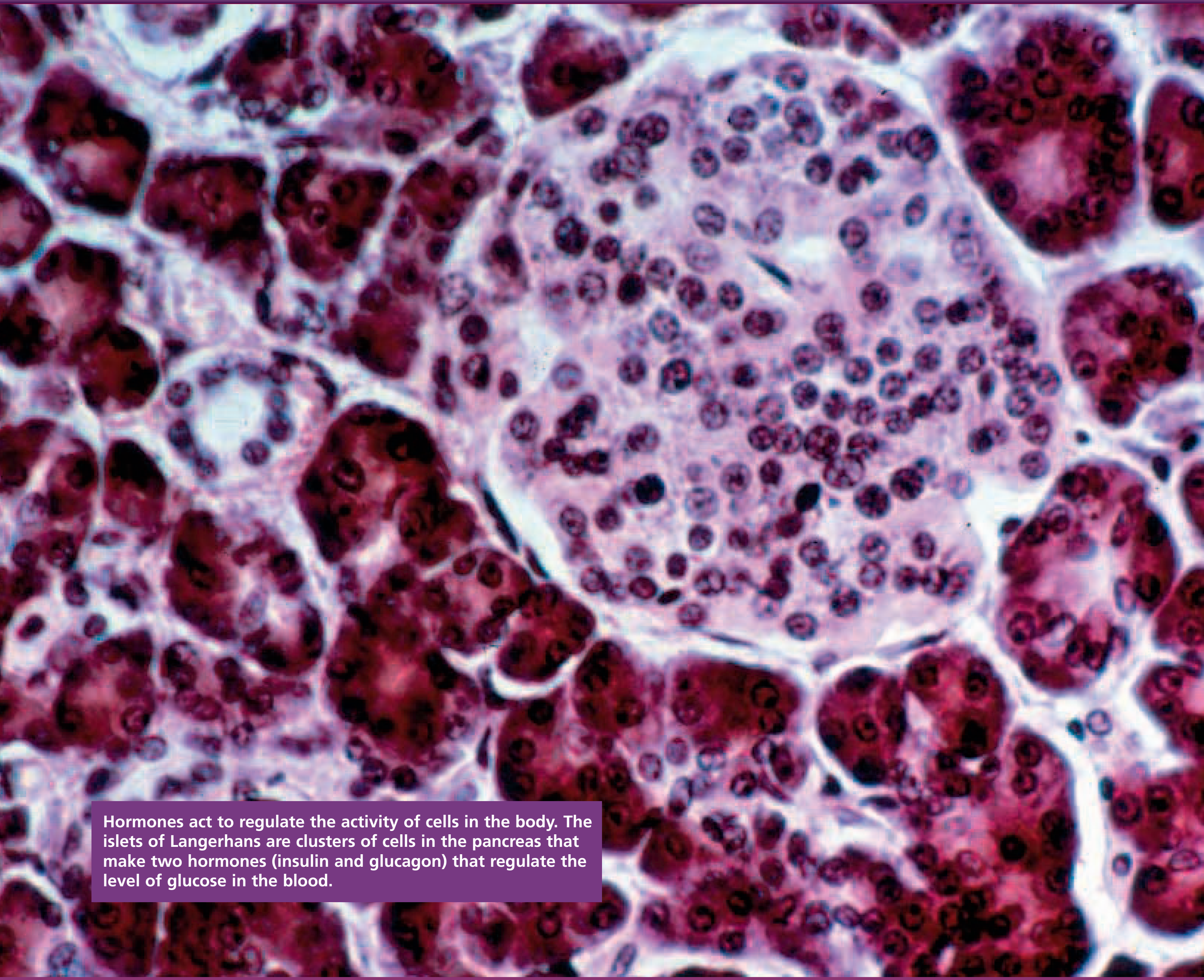
CHAPTER 50

ENDOCRINE SYSTEM



Hormones act to regulate the activity of cells in the body. The islets of Langerhans are clusters of cells in the pancreas that make two hormones (insulin and glucagon) that regulate the level of glucose in the blood.

SECTION 1 ***Hormones***

SECTION 2 ***Endocrine Glands***

HORMONES

Chemical messengers are substances that carry messages and instructions to cells. Hormones (HOHR-MOHNZ) and neurotransmitters are both chemical messengers that coordinate the body's activities. Hormones, however, are part of the endocrine system, while neurotransmitters are part of the nervous system. Hormones are often slower acting and have longer effects than neurotransmitters.

SECTION 1

OBJECTIVES

- **State** the major functions of hormones.
- **Differentiate** between endocrine and exocrine glands.
- **Compare** the structure of amino acid–based hormones with the structure of steroid hormones.
- **Compare** how amino acid–based hormones act on their target cells with how steroid or thyroid hormones act on their target cells.
- **Relate** how neuropeptides and prostaglandins act like hormones.

VOCABULARY

hormone
endocrine gland
endocrine system
exocrine gland
amino acid–based hormone
steroid hormone
target cell
receptor
second messenger
neuropeptide
prostaglandin

FUNCTION AND SECRETION

Hormones influence almost every cell and organ in our bodies. **Hormones** are substances secreted by cells that act to regulate the activity of other cells in the body. Hormones have many functions. For example, hormones regulate growth, development, behavior, and reproduction. They also maintain homeostasis, regulate metabolism and water and mineral balance, and respond to external stimuli.

Hormones are made and secreted by endocrine (EN-doh-KRIN) glands. **Endocrine glands** are ductless organs that secrete hormones either into the bloodstream or the fluid around cells (extracellular fluid). Specialized cells in the brain, stomach, small intestine, liver, heart, and other organs also make and release hormones. The endocrine glands and specialized cells that secrete hormones are collectively called the **endocrine system.**

Some endocrine glands, such as the pancreas, are also exocrine (EKS-oh-KRIN) glands. **Exocrine glands** secrete substances through ducts (tubelike structures). These substances can include water, enzymes, and mucus. The ducts transport the substances to specific locations inside and outside the body. Sweat glands, mucous glands, salivary glands, and other digestive glands are examples of exocrine glands.

TYPES OF HORMONES

Hormones can be grouped into two types based on their structure: amino acid–based hormones and steroid (STIR-OYD) hormones. **Amino acid–based hormones** are hormones made of amino acids. An amino acid–based hormone can be either a single modified amino acid or a protein made of 3 to 200 amino acids. Most amino acid–based hormones are water soluble. **Steroid hormones** are lipid hormones that the body makes from cholesterol. Steroid hormones are fat soluble.

Word Roots and Origins

hormone

from the Greek *hormon,* meaning "to excite"

Quick Lab

Observing Solubilities

Materials 100 mL beakers (4), water, gelatin, cooking oil, vitamin E capsule, dissecting pin, spoon

Procedure

1. Put 75 mL of water into a beaker. Place 2.5 g of gelatin (protein) into the beaker. Stir. Does the gelatin dissolve? Record your observations.
2. Put 75 mL of oil into a beaker. Repeat the procedure in step 1 using oil instead of water.
3. Repeat steps 1 and 2 using the contents of a vitamin capsule (fat) instead of gelatin.

Analysis Which substance is fat soluble? Which substance is water soluble? Relate the solubilities of hormones to whether they enter their target cells or work outside them.

HORMONE ACTION

The body produces many different hormones, but each hormone affects only its target cells. **Target cells** are specific cells to which a hormone travels to produce a specific effect. Target cells have **receptors**—proteins that bind specific signal molecules that cause the cell to respond. Each receptor binds to a specific hormone. When a hormone binds to a receptor, the binding triggers events that lead to changes within the cell. Receptors can be found on the cell membrane, in the cytoplasm, or in the nucleus of a cell.

Amino Acid–Based Hormones

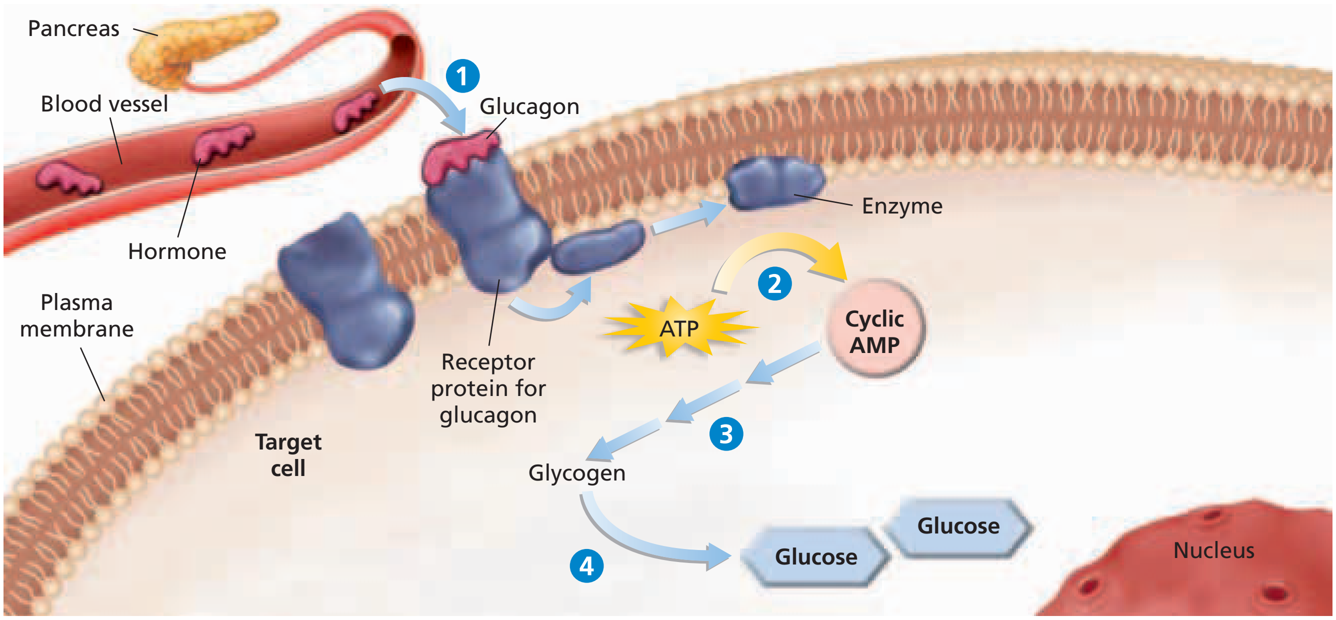
Most amino acid–based hormones bind to receptor proteins on the cell membrane. Thus, the hormone acts as a "first messenger." As the example in Figure 50-1 shows, the resulting hormone-receptor complex activates an enzyme that converts ATP to cyclic AMP (cAMP). Cyclic AMP, in turn, activates additional enzymes and proteins inside the cell. Thus, the hormone acts as a "first messenger" and cAMP acts as a "second messenger." A **second messenger** is a molecule that initiates changes inside a cell in response to the binding of a specific substance to a receptor on the outside of a cell. In addition to cAMP, cells have other second messengers.

Steroid and Thyroid Hormones

Because steroid and thyroid hormones are fat soluble, they diffuse through the cell membranes of their target cells and bind to receptors in the cytoplasm or nucleus. The hormone-receptor complexes cause the cells to activate existing enzymes or to initiate synthesis of new enzymes or proteins. Figure 50-2 shows how a hormone-receptor complex binds to DNA, activates transcription of mRNA, and stimulates production of new proteins. The proteins cause changes in the target cell.

FIGURE 50-1

1 Amino acid–based hormones, such as glucagon, bind to receptor proteins on the cell membrane. 2 The binding activates an enzyme, which converts ATP to cyclic AMP. 3 Cyclic AMP starts a cascade of enzyme activations. 4 Eventually, glycogen is broken down to individual glucose molecules.



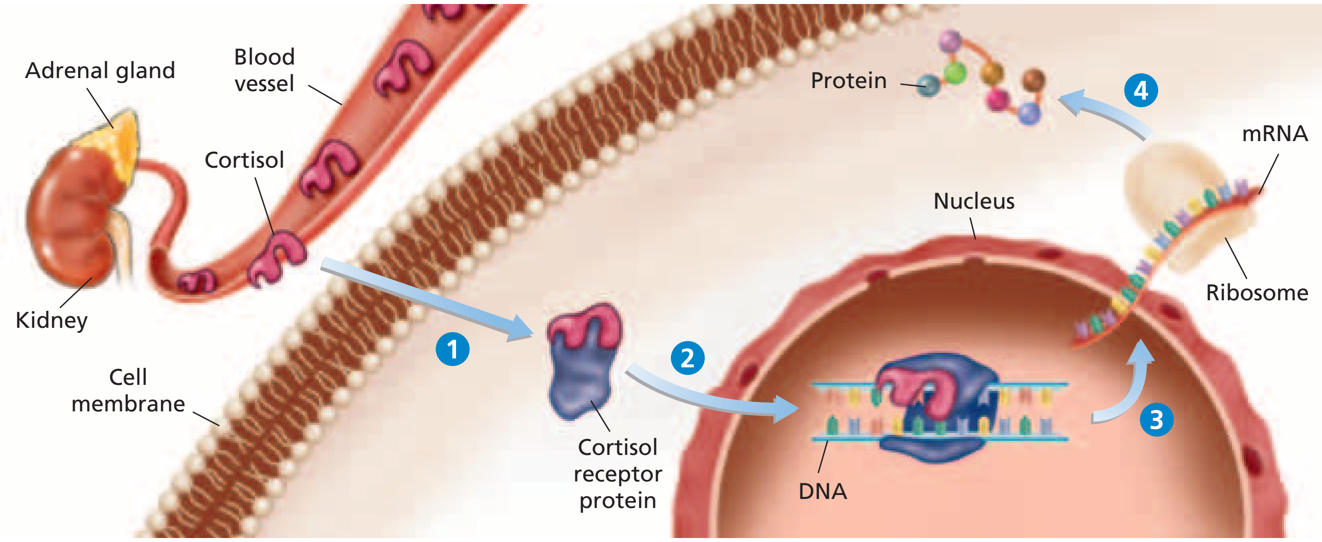


FIGURE 50-2

(1) Steroid hormones, such as cortisol, diffuse through the cell membrane and attach to receptors in the cytoplasm of the cell. (2) The hormone-receptor complex enters the nucleus and binds to DNA. (3) Genes are activated. (4) Proteins are made that become active in cells.

OTHER TYPES OF HORMONES

Many other chemical messengers are now classified as hormones. These substances include neuropeptides and prostaglandins (PRAHS-tuh-GLAN-dinz).

Neuropeptides are hormones secreted by the nervous system. Unlike neurotransmitters, neuropeptides tend to affect many cells near the nerve cells that release them. One group of neuropeptides, called *endorphins* (en-DAWR finz), regulate emotions, influence pain, and affect reproduction. Another group of neuropeptides, *enkephalins* (en-KEF-uh-linz), inhibit pain messages traveling toward the brain.

Prostaglandins are modified fatty acids that are secreted by most cells. Prostaglandins accumulate in areas where tissues are disturbed or injured. Some prostaglandins reduce blood pressure; others raise blood pressure. Some prostaglandins cause smooth muscle to relax; others cause smooth muscle to contract. Some prostaglandins cause fever. Aspirin and acetaminophen reduce fever and decrease pain by inhibiting prostaglandin synthesis.

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SECTION 1 REVIEW

1. Name four functions of hormones.
2. How do endocrine glands differ from exocrine glands?
3. Explain how most amino acid–based hormones affect their target cells.
4. Explain how steroid and thyroid hormones affect their target cells.
5. Why are neuropeptides and prostaglandins now classified as hormones?

CRITICAL THINKING

6. **Applying Information** Why can steroid and thyroid hormones, but not amino acid–based hormones, move across cell membranes?
7. **Organizing Information** Which types of hormones, amino acid–based, steroid, or thyroid, activate transcription and translation of a gene?
8. **Recognizing Relationships** Why are both hormones and neurotransmitters considered chemical messengers?

OBJECTIVES

- **Identify** the relationship between the hypothalamus and the pituitary gland in the release of hormones.
- **List** the functions of the major endocrine glands and hormones.
- **Explain** the role of feedback mechanisms in maintaining homeostasis.
- **Compare** how negative feedback and positive feedback mechanisms are used to regulate hormone levels.
- **Summarize** how antagonistic hormones work as pairs to maintain homeostasis.

VOCABULARY

hypothalamus
pituitary gland
thyroid gland
adrenal gland
epinephrine
norepinephrine
cortisol
gonad
puberty
luteinizing hormone
follicle-stimulating hormone
estrogen
progesterone
androgen
testosterone
insulin
diabetes mellitus
melatonin
negative feedback
positive feedback

ENDOCRINE GLANDS

The endocrine glands regulate many vital processes. This section discusses the major hormones that endocrine glands make and the effects of these hormones.

HYPOTHALAMUS AND PITUITARY GLAND

As shown in Figure 50-3, endocrine glands are located throughout the body. Two organs, the hypothalamus (HIE-poh-THAL-uh-muhs) and the pituitary (pi-TOO-uh-TER-ee) gland, control the initial release of many hormones.

The **hypothalamus** is the area of the brain that coordinates many activities of the nervous and endocrine systems. It receives information from other brain regions and then responds to these signals as well as to blood concentrations of circulating hormones. The hypothalmus responds by issuing instructions in the form of hormones to the pituitary gland. As shown in Figure 50-4, the **pituitary gland** is suspended from the hypothalamus by a short stalk. The hypothalamus produces hormones that are stored in the pituitary gland or that regulate the pituitary gland's activity.

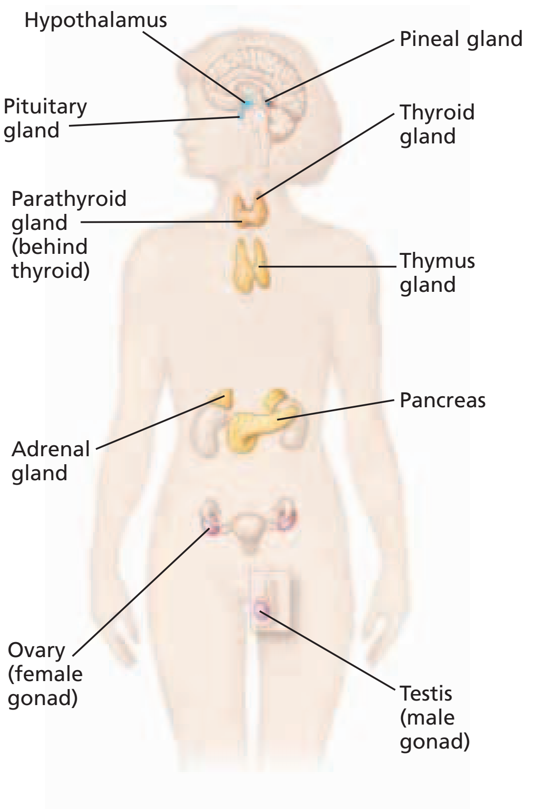


FIGURE 50-3

Endocrine glands are located throughout the body. All of these glands contain cells that secrete hormones. In addition to the organs shown, many other organs secrete hormones.

Two hormones—oxytocin (AHKS-ee-TOH-sin) and antidiuretic (AN-TIE-DIE-yoo-RET-ik) hormone (ADH)—are made by nerve cells in the hypothalamus. These nerve cells that secrete hormones are called *neurosecretory cells.* The axons of the neurosecretory cells in the hypothalamus extend into the posterior lobe of the pituitary, as shown in Figure 50-4b. Oxytocin and ADH are transported through these axons into the posterior pituitary, where they are stored for eventual release into the bloodstream.

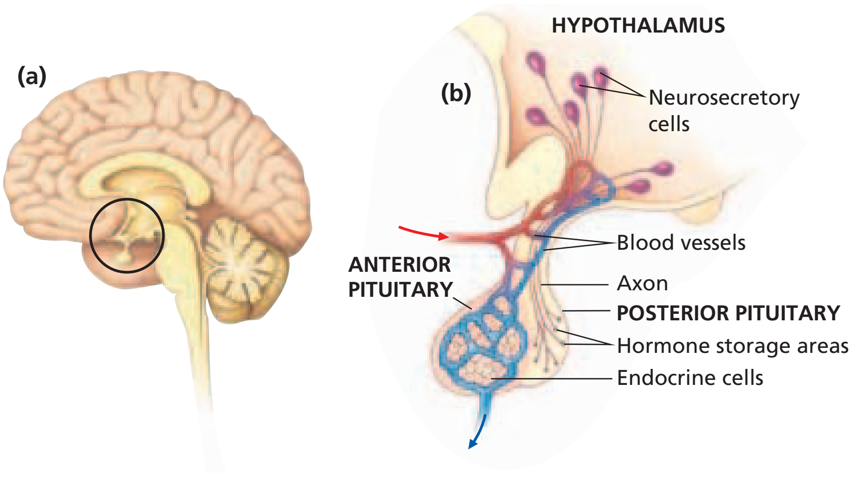


FIGURE 50-4

Neurosecretory cells in the hypothalamus produce hormones that affect the pituitary gland. The area of the brain where the hypothalamus and pituitary gland are found is circled in (a). The hypothalamus regulates the posterior pituitary through axons and the anterior pituitary through blood vessels, as shown in (b). (Blood vessels in the posterior pituitary have been omitted in order to show axon projections.)

As shown in Figure 50-4b, a special system of blood vessels connects the hypothalamus with the anterior pituitary. Nerve cells in the hypothalamus secrete releasing and release-inhibiting hormones that travel to the anterior pituitary through the blood vessels. *Releasing hormones* stimulate the anterior pituitary to make and secrete hormones. *Release-inhibiting hormones* inhibit production and secretion of anterior-pituitary hormones.

Some anterior-pituitary hormones, such as prolactin and growth hormone, are regulated through both a releasing hormone and a release-inhibiting hormone. Other hormones regulated by releasing hormones, such as follicle–stimulating hormone, thyroid-stimulating hormone, and adrenocorticotropic hormone (ACTH), in turn stimulate other endocrine glands. Table 50-1 summarizes the function of the hormones secreted by the pituitary gland.

TABLE 50-1 ***Hormones Secreted by the Pituitary Gland***

Hormone	Target	Major function
Adrenocorticotropic hormone (ACTH)	adrenal cortex	stimulates secretion of cortisol and aldosterone by the adrenal cortex
Antidiuretic hormone (ADH)	kidney tubules	stimulates reabsorption of water by kidneys, reducing the concentration of solutes in the blood
Follicle-stimulating hormone (FSH)	ovaries in females; testes in males	stimulates egg production in females; stimulates sperm production in males
Growth hormone (GH)	muscle and bone	regulates development of muscles and bones
Luteinizing hormone (LH)	ovaries in females; testes in males	stimulates progesterone and estrogen production; initiates ovulation in females; stimulates testosterone production in males
Oxytocin	uterine muscles and mammary glands	initiates uterine contractions during childbirth; stimulates flow of milk from breasts during lactation
Prolactin (PRL)	mammary glands	stimulates milk production in breasts during lactation
Thyroid-stimulating hormone (TSH)	thyroid gland	regulates secretion of the thyroid hormones—thyroxine and triiodothyronine

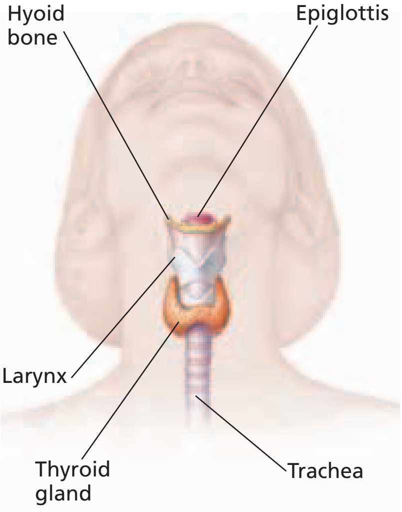


FIGURE 50-5

The thyroid gland is located under the larynx and on the trachea.

THYROID GLAND

The two lobes of the **thyroid** (THIE-ROYD) **gland** are located near the lower part of the larynx, as shown in Figure 50-5. The thyroid gland produces and secretes the hormones thyroxine (thie-RAHKS-een) and triiodothyronine (TRIE-ie-oh-DOH-THIE-roh-NEEN). Both of these hormones are derived from the same amino acid and are synthesized with iodine atoms. Thyroid-stimulating hormone (TSH) regulates the release of the thyroid hormones. Release of TSH from the anterior pituitary is regulated primarily by a releasing hormone as well as release-inhibiting hormones secreted by the hypothalamus.

The thyroid hormones help maintain normal heart rate, blood pressure, and body temperature. They stimulate enzymes that are associated with glucose oxidation and oxygen consumption, generating heat and increasing cellular metabolic rates. They also promote carbohydrate usage over fat usage for energy.

The thyroid gland is important to human development because thyroid hormones promote the development of many of the body's systems. The thyroid gland also produces calcitonin (KAL-sih-TOH-nin), a hormone that stimulates the transfer of calcium ions from blood to bone, where the calcium ions can be used to generate bone tissue. Calcitonin acts to decrease blood calcium levels.

Abnormal thyroid activity can be detrimental to the body's metabolism. Overproduction of the thyroid hormones is called hyperthyroidism (HIE-puhr-THIE-royd-iz-uhm). Symptoms of hyperthyroidism include overactivity; weight loss; and high blood pressure, heart rate, and body temperature. Hyperthyroidism can be treated with medication or by surgical removal of part of the thyroid gland.

Thyroid-hormone deficiency is known as *hypothyroidism* (HIE-poh-THIE-royd-iz-uhm). Symptoms of hypothyroidism include growth retardation, lethargy, weight gain, and low heart rate and body temperature. Hypothydroidism can also cause cretinism (KREET-uhn-IZ-uhm), a form of mental retardation, if the hypothyroidism occurs during fetal and childhood development. If hypothyroidism is caused by iodine deficiency, then goiter (GOY-tuhr), or swelling of the thyroid gland, results. Goiters resulting from iodine deficiency are now rare in the United States because iodine is added to commercially available table salt. Hypothyroidism can be treated with supplementary thyroxine.

ADRENAL GLANDS

One **adrenal gland** (uh-DREE-nuhl gland) is located above each kidney, as shown in Figure 50-6. Each adrenal gland has an inner core, the medulla, and an outer layer, the cortex. The medulla and cortex function as separate endocrine glands. Secretion of hormones in the medulla is controlled by the nervous system, whereas hormones in the anterior pituitary regulate secretion of hormones in the cortex.

Adrenal Medulla

The adrenal medulla produces two amino acid–based hormones: **epinephrine** (EP-uh-NEF-rin) and **norepinephrine** (NAWR-EP-uh-NEF-rin), also known as adrenaline (uh-DREN-uh-lin) and noradrenaline (NOR-uh-DREN-uh-lin), respectively. These hormones orchestrate the nervous system's reaction to stress and its "fight-or-flight" response to danger. When a person is stressed, the medulla secretes epinephrine and norepinephrine into the bloodstream. These hormones increase heart rate, blood pressure, blood glucose level, and blood flow to the heart and lungs. Epinephrine and norepinephrine also stimulate enlargement of the bronchial tubes and dilation of the pupils.

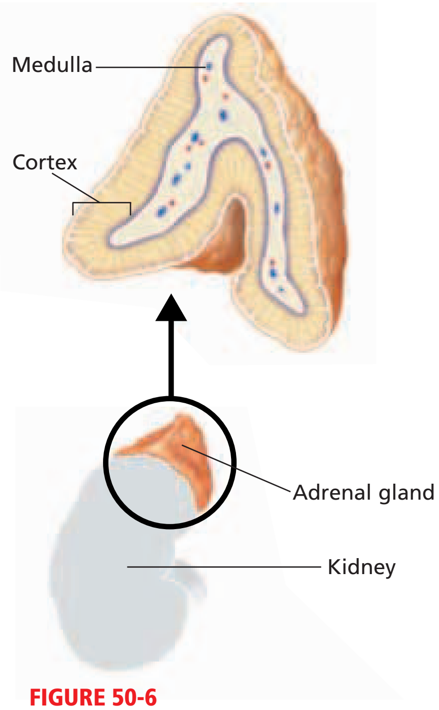


FIGURE 50-6
The adrenal glands, located above each kidney, consist of an inner medulla and an outer cortex. Epinephrine and norepinephrine are produced in the medulla. Cortisol and aldosterone are produced in the cortex.

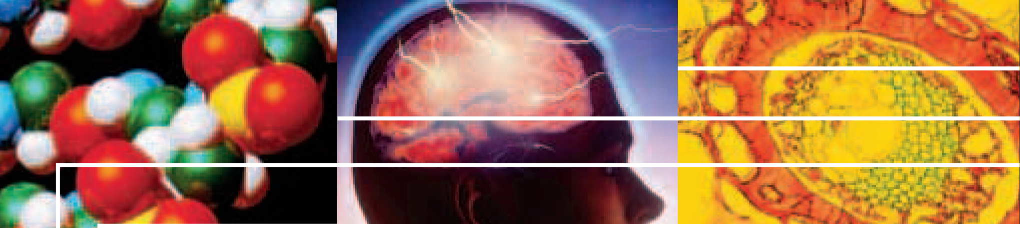
Adrenal Cortex

The adrenal cortex responds to adrenocorticotropic (uh-DRE-noh-KOHR-ti-koh-TROH-pik) hormone (ACTH), which is secreted by the anterior pituitary. Stress causes the hypothalamus to secrete ACTH-releasing hormone. ACTH then stimulates the adrenal cortex to produce the steroid hormone cortisol (KOHRT-uh-SAWL) and aldosterone. **Cortisol** promotes the production of glucose from proteins making usable energy available to cells. Aldosterone (al-DAHS-tuh-ROHN), helps raise blood pressure and volume by stimulating salt and water retention by the kidneys.

GONADS

Gonads—the ovaries in females and the testes in males—are gamete-producing organs that also produce a group of steroid sex hormones. Sex hormones regulate body changes that begin at puberty. **Puberty** (PYOO-buhr-tee) is the adolescent stage during which the sex organs mature and secondary sex characteristics, such as facial hair, appear. During puberty in males, sperm production begins, the voice deepens, the chest broadens, and hair grows on the body and face. In females, the menstrual cycle begins, the breasts grow, and the hips widen.

When secreted by the anterior pituitary, the hormones **luteinizing** (LOO-tee-in-IZE-ing) **hormone (LH)** and **follicle-stimulating** (FOL-uh-kuhl STIM-yoo-LAYT-ing) **hormone (FSH)** stimulate secretion of sex hormones from the gonads. In females, LH and FSH stimulate secretion of **estrogen** (ES-truh-jen) and **progesterone** (proh-JES-tuh-ROHN) from the ovaries. In preparation for a possible pregnancy, these sex hormones cause the monthly release of an egg by an ovary and buildup of the uterine lining. Estrogen also regulates female secondary sex characteristics. In males, LH stimulates the testes to secrete a group of sex hormones called **androgens** (AN-druh-jenz). **Testosterone** (tes-TAHS-tuh-rohn) is an androgen that regulates male secondary sex characteristics. Along with FSH, testosterone also stimulates sperm production.



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EARLY ONSET OF PUBERTY IN GIRLS

Until a few decades ago, girls began puberty at about age 11 and completed puberty by about age 13. Now, it is more common to see puberty in girls beginning at about 9 and 10 years of age and sometimes as early as 6 or 7 years of age. Researchers are investigating why puberty starts earlier in girls than it used to and what type of implications this may have for a person's health.

What is Causing the Early Onset of Puberty?

Genetics is one of several factors that influence the onset of puberty in girls. One study showed that girls with two copies of a specific version of a gene that breaks down testosterone began puberty earlier than girls with a different version of the gene.

Some researchers hypothesize that the increasing prevalence of obesity in young girls could be one factor triggering puberty. These researchers found that girls who were overweight or obese started puberty earlier than girls who were not.

Other researchers hypothesize that pollutants could be triggering the onset of early puberty. For example, there are pollutants called *hormone mimics* that behave like natural hormones. Some pollutants, called *hormone disrupters*, prevent natural hormones from functioning normally.

Most hormone disrupters interfere with the sex hormones. Such hormone disrupters prevent normal production of testosterone in males or increase the chances of sexual abnormality in females. Examples of hormone disrupters include phthalate *(THAH-late)* esters (found in plastic toys, vinyl flooring, and cosmetics), and bisphenol A and polybrominated biphenyls (used to make plastic food and drink containers).

Does Early Puberty Affect a Person's Health?

Researchers have studied the effect of early puberty on a person's health. One study investigated 1,811 sets of female twins in which one or both of the twins developed breast cancer as adults. The twin who entered puberty first was five times more likely to develop breast cancer first. The link was stronger if menstruation started earlier than average. As a result of these and other findings, many scientists and physicians are calling for more research to determine the causes of early puberty.

Many factors influence the age at which a girl begins puberty. Researchers are studying why girls today are starting puberty earlier than girls 30 years ago and what effect this may have on their health.

REVIEW

1. What are three hypotheses for the early onset of puberty?
2. **Applying Information** If humans are increasingly exposed to pollutants that act as hormone mimics or hormone disrupters, what are some possible results?
3. **Supporting Reasoned Opinions** Do you think government research agencies should fund research investigating the effects of hormone mimics and hormone disrupters on the onset of puberty? Explain.

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PANCREAS

The pancreas mostly contains exocrine cells, but specialized cells in the pancreas called the *islets of Langerhans* (LANG-uhr-HANZ) function as an endocrine gland. Shown in Figure 50-7, these endocrine cells secrete two amino acid–based hormones that regulate the level of sugar in the blood. **Insulin** (IN-suh-lin) lowers the blood sugar level by stimulating body cells, especially muscles, to store glucose or use it for energy. In contrast, glucagon (GLOO-kuh-gahn) stimulates release of glucose into the bloodstream by liver cells.

Insulin deficiency causes **diabetes mellitus** (die-uh-BEET-eez muh-LIET-uhs), a condition in which cells are unable to obtain glucose, resulting in abnormally high blood glucose concentrations. In type I diabetes the immune system attacks the insulin-producing islet cells. The cells die. Type I generally is treated with daily injections of insulin into the blood and sometimes with islet cell transplant. Type II diabetes usually occurs after age 40, and it is more common than type I. Type II is caused by insufficient insulin or less responsive target cell receptors. Although type II is hereditary, its onset correlates with obesity and an inactive lifestyle. Type II diabetes can often be controlled through exercise and diet. In diabetes, excess glucose inhibits water reabsorption by the kidneys, producing large amounts of urine. Dehydration and kidney damage can result. Lack of insulin can lead to acid-base and electrolyte imbalances. These changes may result in nausea, rapid breathing, heart irregularities, depression of the nervous system, coma, or even death.

FIGURE 50-7

A cross section of pancreatic tissue shows the islets of Langerhans (lightly colored region). These endocrine cells are surrounded by exocrine cells that produce digestive fluids. (LM 315×)

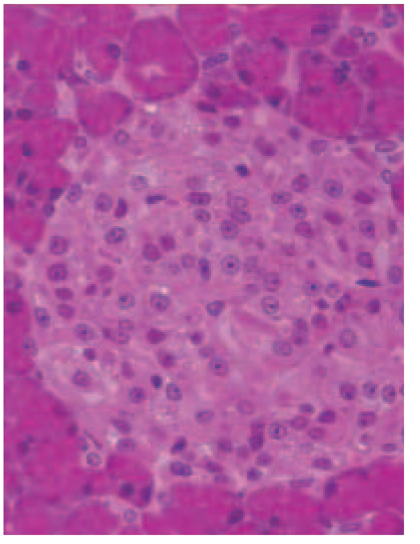


TABLE 50-2 ***Summary of Major Endocrine Glands and Their Functions***

Glands	Hormone	Function
Adrenal cortex	aldosterone cortisol	promotes salt and water retention promotes production of glucose from proteins
Adrenal medulla	epinephrine, norepinephrine	initiate body's response to stress and the "fight-or-flight" response to danger
Ovaries	estrogen progesterone	regulates female secondary sex characteristics maintains growth of uterine lining
Pancreas (islets of Langerhans)	glucagon insulin	stimulates release of glucose stimulates absorption of glucose by cells
Parathyroid glands	parathyroid hormone	increases blood calcium concentration
Pineal gland	melatonin	regulates sleep patterns
Pituitary gland	see Table 50-1	see Table 50-1
Testes	androgens (testosterone)	regulate male secondary sex characteristics; stimulate sperm production
Thymus gland	thymosin	stimulates T-cell maturation
Thyroid gland	thyroxine, triiodothyronine calcitonin	regulate metabolism and development decreases blood calcium concentration

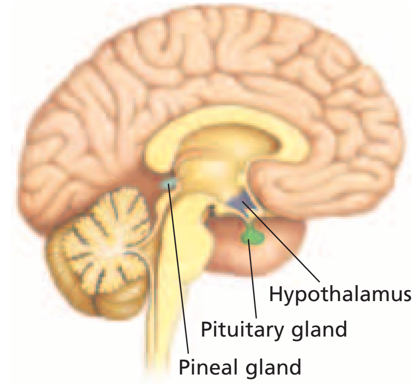


FIGURE 50-8

The pineal gland, located near the base of the brain, secretes the hormone melatonin at night.

Excessive insulin causes *hypoglycemia* (HIE-poh-glie-SEE-mee-uh), a disorder in which glucose is stored, rather than being properly delivered to body cells. This leads to a lowered blood glucose concentration and subsequent release of glucagon and epinephrine. Symptoms of hypoglycemia include lethargy, dizziness, nervousness, overactivity, and in extreme cases, unconsciousness and death.

OTHER ENDOCRINE GLANDS

There are several other glands in the endocrine system, including the thymus gland, the pineal gland, and the parathyroid glands. There are also specialized endocrine cells in the brain, stomach, small intestine, liver, and other organs. The major endocrine glands and their functions are listed in Table 50-2.

Thymus Gland

The thymus (THIE-muhs) gland, located beneath the sternum and between the lungs, plays a role in the development of the immune system. The thymus gland secretes *thymosin* (THIE-moh-sin), an amino acid–based hormone that stimulates maturation of T cells, which help defend the body from pathogens.

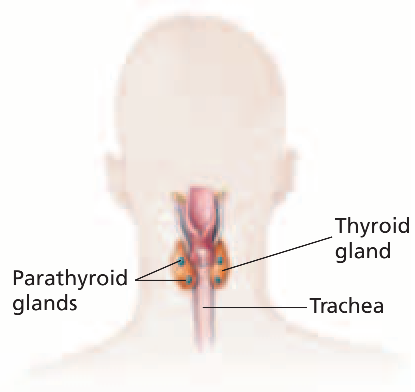
Pineal Gland

The pineal (PIEN-ee-uhl) gland is located near the base of the brain, as shown in Figure 50-8. It secretes the hormone melatonin. **Melatonin** (mel-uh-TOH-nin) concentrations increase sharply at night and decrease dramatically during the day. This cyclic release of melatonin suggests that it helps regulate sleep patterns.

Parathyroid Glands

FIGURE 50-9

As shown from this back view of the head, the four parathyroid glands are located on the posterior side of the thyroid gland. They secrete a hormone that regulates the concentration of calcium ions in the blood.



As Figure 50-9 shows, the four parathyroid glands are embedded in the back of the thyroid gland, two in each lobe. These glands secrete *parathyroid hormone,* which stimulates the transfer of calcium ions from the bones to the blood. Thus, parathyroid hormone has the opposite effect of calcitonin. A proper balance of calcium ions is necessary for cell division, muscle contraction, blood clotting, and neural signaling.

Digestive Cells

Endocrine cells within the walls of some digestive organs also secrete a variety of hormones that control digestive processes. For example, when food is eaten, endocrine cells in the stomach lining secrete *gastrin* (GAS-trin), a hormone that stimulates other stomach cells to release digestive enzymes and hydrochloric acid. Endocrine cells of the small intestine release *secretin* (si-KREE-tin), a hormone that stimulates the release of various digestive fluids from the pancreas.

FEEDBACK MECHANISMS

Homeostasis is defined as a stable internal environment. The endocrine system plays an important role in the maintenance of homeostasis because hormones regulate the activities of cells, tissues, and organs throughout the body. To maintain homeostasis, feedback mechanisms control hormone secretion. A feedback mechanism is one in which the last step in a series of events controls the first. Feedback mechanisms can be negative or positive. Most hormone systems use negative feedback.

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Negative Feedback

In **negative feedback,** the final step in a series of events inhibits the initial signal in the series. An example of negative feedback in regulating the levels of thyroid hormones is shown in Figure 50-10. When the hypothalamus detects low levels of thyroid hormones, it secretes a hormone called thyrotropin releasing hormone (TRH) to the anterior pituitary. TRH stimulates the anterior pituitary to secrete thyroid-stimulating hormone (TSH) into the bloodstream. TSH stimulates the thyroid gland to secrete thyroid hormones. When the thyroid hormone levels are high, two major negative feedback loops operate, as shown by the negative signs in Figure 50-10. In one loop, the thyroid hormones act on the hypothalamus to inhibit the release of TRH. In the second loop, the thyroid hormones act on the anterior pituitary to inhibit the release of TSH. The result is that the level of thyroid hormones in the blood decreases. In turn, this decrease causes the amount of negative feedback inhibition to decline. The interplay of these mechanisms helps to keep the concentration of thyroid hormones relatively stable.

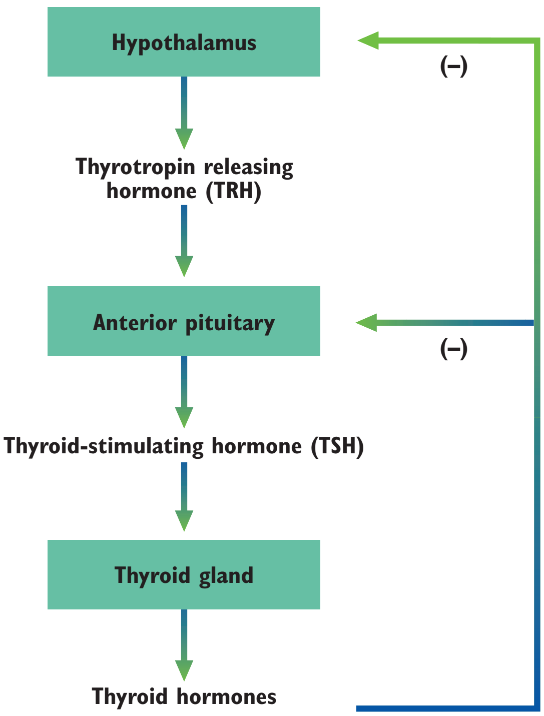
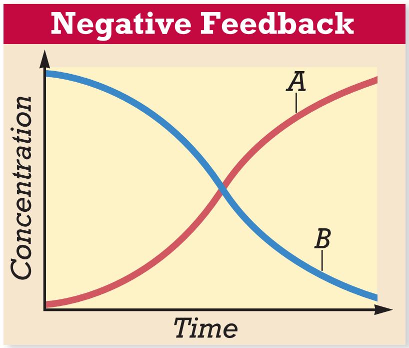


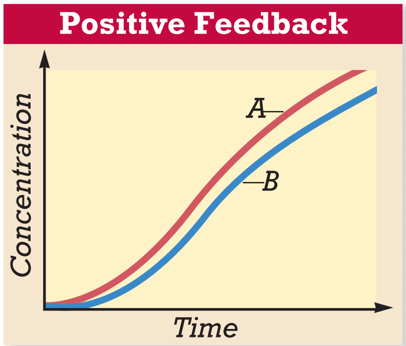
FIGURE 50-10

The thyroid hormones regulate cellular metabolic rates through several negative feedback mechanisms. Two are shown. High concentrations of thyroid hormones inhibit the hypothalamus from releasing TRH and the anterior pituitary from releasing TSH.

FIGURE 50-11

In negative feedback, a secondary substance (A) inhibits production of the initial stimulating substance (B). In positive feedback, a secondary substance (A) stimulates production of the initial stimulating substance (B).





Positive Feedback

When hormones are regulated by **positive feedback,** release of an initial hormone stimulates release or production of other hormones or substances, which stimulate further release of the initial hormone. For example, increased estrogen concentrations stimulate a surge in luteinizing hormone secretion prior to ovulation. Figure 50-11 illustrates the difference between negative and positive feedback systems.

Antagonistic Hormones

A number of hormones work together in pairs to regulate the levels of critical substances. These hormones are referred to as *antagonistic hormones* because their actions have opposite effects.

Glucagon and insulin are examples of antagonistic hormones. They maintain a specific level of blood glucose in the blood. When the level of glucose in the blood is high, such as after eating a meal, insulin triggers the transfer of glucose from the blood into the body cells for storage or immediate use. In contrast, when the level of glucose in the blood is low, such as between meals, glucagon promotes the release of glucose into the blood from storage sites in the liver and elsewhere. Together, insulin and glucagon ensure that the level of glucose in the blood is maintained. Calcitonin and parathyroid hormone are other examples of antagonistic hormones.

Word Roots and Origins

antagonistic

from the Greek *anti,* meaning "against" and *agonizesthai,* meaning "to contend for a prize"

SECTION 2 REVIEW

1. How do the hypothalamus and the pituitary gland interact to control the release of some of the hormones in the endocrine system?
2. List six major endocrine glands and the function of these glands.
3. How do feedback mechanisms help maintain homeostasis?
4. How do negative feedback mechanisms differ from positive feedback mechanisms?
5. Compare the effects of glucagon and insulin on blood glucose levels.

CRITICAL THINKING

6. **Relating Concepts** A classmate states that hormones from the adrenal medulla, but not from the adrenal cortex, are secreted in response to stress. Do you agree? Explain.
7. **Applying Information** Why might overactive parathyroid glands cause bone problems?
8. **Evaluating Models** Dietary iodine is needed for the body to make thyroid hormones. How would lack of dietary iodine affect the negative feedback of the thyroid hormones?

CHAPTER HIGHLIGHTS

SECTION 1 Hormones

- Hormones are chemical messengers secreted by cells that act to regulate the activity of other cells.
- Hormones have many functions, including regulation of growth; maintenance of homeostasis; and regulation of energy production, use, and storage.
- Ductless glands called endocrine glands make most of the body's hormones. Specialized cells in the brain, stomach, and other organs also make and release hormones. Exocrine glands secrete nonhormonal chemicals into specific body locations.
- Amino acid–based hormones bind to cell-membrane receptors of their target cells, activating a second messenger that then activates or deactivates enzymes in a cascade fashion.
- Steroid and thyroid hormones bind to receptors inside the cell. The hormone-receptor complex binds to DNA in the nucleus and turns genes either on or off.
- Similar to hormones, neuropeptides and prostaglandins act on nearby cells to regulate cellular activities.

Vocabulary

hormone (p. 1031)
endocrine gland (p. 1031)
endocrine system (p. 1031)
exocrine gland (p. 1031)
amino acid–based hormone (p. 1031)
steroid hormone (p. 1031)
target cell (p. 1032)
receptor (p. 1032)
second messenger (p. 1032)
neuropeptide (p. 1033)
prostaglandin (p. 1033)

SECTION 2 Endocrine Glands

- The hypothalamus and pituitary gland serve as the major control centers for the release of many hormones.
- The thyroid gland secretes thyroid hormones that regulate metabolism and development and calcitonin that helps regulate blood calcium levels.
- The adrenal glands secrete epinephrine, norepinephrine, cortisol, aldosterone, and other hormones that help regulate metabolism, the body's responses to stress and danger, and water balance.
- The gonads secrete estrogen and progesterone in females and androgens, including testosterone, in males. These hormones regulate reproductive functions.
- The islets of Langerhans of the pancreas secrete glucagon and insulin, which regulate blood glucose levels.
- Other endocrine glands include the thymus gland, the pineal gland, the parathyroid glands, and endocrine cells of the digestive system.
- Feedback mechanisms help maintain homeostasis.
- In negative feedback, the final product in a series inhibits the first step. Many hormones use negative feedback systems because they prevent excess accumulation of a hormone product.
- In positive feedback, the final product in a series stimulates the first step.
- Antagonistic hormones, such as glucagon and insulin, work together to regulate the levels of critical substances.

Vocabulary

hypothalamus (p. 1034)
pituitary gland (p. 1034)
thyroid gland (p. 1036)
adrenal gland (p. 1036)
epinephrine (p. 1037)
norepinephrine (p. 1037)
cortisol (p. 1037)
gonad (p. 1037)
puberty (p. 1037)
luteinizing hormone (p. 1037)
follicle-stimulating hormone (p. 1037)
estrogen (p. 1037)
progesterone (p. 1037)
androgen (p. 1037)
testosterone (p. 1037)
insulin (p. 1039)
diabetes mellitus (p. 1039)
melatonin (p. 1040)
negative feedback (p. 1041)
positive feedback (p. 1042)

CHAPTER REVIEW

USING VOCABULARY

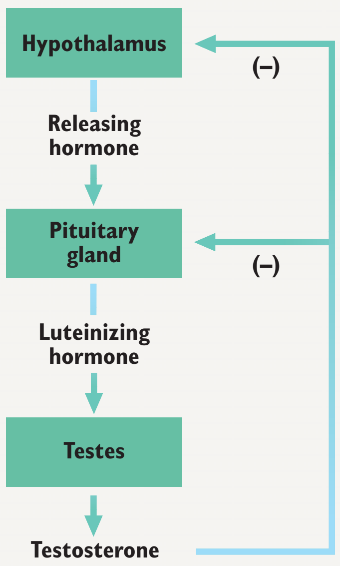
1. For each set of terms, choose the one that does not belong, and then explain why it does not belong.
   a. *insulin, prostaglandin, glucagon*
   b. *oxytocin, epinephrine, antidiuretic hormone*
   c. *aldosterone, cortisol, glucagon*
2. Explain the relationship between the following pairs of terms:
   a. *target cells* and *receptors*
   b. *pituitary gland* and *thyroid gland*
   c. *exocrine gland* and *endocrine gland*
3. Use the following terms in the same sentence: *estrogen, progesterone,* and *testosterone.*
4. **Word Roots and Origins** In Greek, the word *hormon* means "to excite." Why was the name *hormones* chosen for these molecules?

UNDERSTANDING KEY CONCEPTS

5. **Identify** four major functions of hormones.
6. **Differentiate** how endocrine glands differ from exocrine glands.
7. **Sequence** the steps that occur when most amino acid–based hormones act on their target cells.
8. **Sequence** the steps that occur when a steroid or thyroid hormone acts on its target cell.
9. **Describe** why neuropeptides and prostaglandins are hormones.
10. **Describe** two ways in which the endocrine system and the nervous system are similar.
11. **Discuss** how the hypothalamus and the pituitary gland interact to control the release of many hormones.
12. **Summarize** the major functions of the thyroid hormones.
13. **Name** the two hormones in the adrenal medulla that are released when a person experiences stress.
14. **State** the two hormones that stimulate secretion of the sex hormones from the gonads.
15. **Summarize** the nonhereditary factors that are associated with the onset of type II diabetes.
16. **Describe** how the hormone gastrin helps in the process of digestion.
17. **Summarize** the role of feedback mechanisms in maintaining homeostasis.
18. **Explain** why positive feedback is not an efficient way to control hormone levels.
19. **Explain** how negative feedback regulates the level of thyroid hormones.
20. **Describe** how insulin and glucagon work together as antagonistic hormones to control the level of glucose in the blood.
21. **CONCEPT MAPPING** Use the following terms to create a concept map that describes the endocrine system: *hypothalamus, pituitary gland, thyroid gland, hormones, adrenal glands, pancreas,* and *target cell.*

CRITICAL THINKING

22. **Making Comparisons** Why might damage to the pituitary gland be considered far more serious than damage to one of the other endocrine glands?
23. **Inferring Relationships** Describe the importance of "fit" between a receptor protein and a hormone.
24. **Analyzing Graphics** Identify and describe the type of feedback mechanism operating in the diagram shown below.



Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

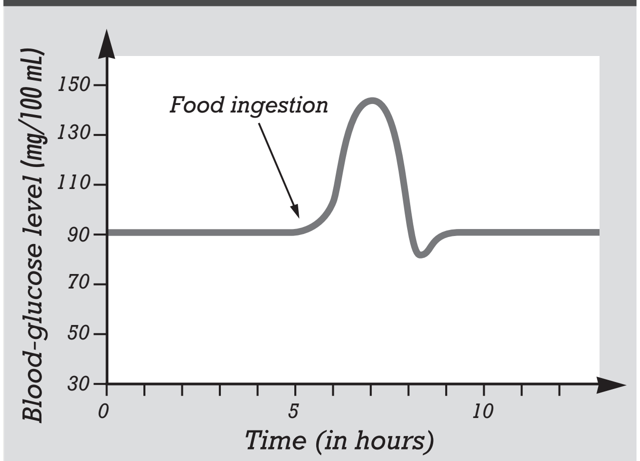
1. What are the chemical messengers of the endocrine system called?
   A. neurons
   B. hormones
   C. blood cells
   D. carbohydrates

2. *X* and *Y* are hormones. *X* stimulates the secretion of Y, which exerts negative feedback on the cells that secrete *X*. Suppose the level of Y decreases. What should happen immediately afterwards?
   F. Less *X* is secreted.
   G. More *X* is secreted.
   H. Secretion of *Y* stops.
   J. Secretion of *X* stops.

3. Endocrine glands
   A. function only after puberty.
   B. function only before puberty.
   C. release products through ducts.
   D. release products into the bloodstream.

INTERPRETING GRAPHICS: Study the figure below to answer the following questions.

Blood-Glucose Level



4. What happens after food is eaten?
   F. Blood glucose levels increase.
   G. Blood glucose levels decrease.
   H. Blood glucose levels remain the same.
   J. Blood glucose levels decrease and then increase.

5. Which hormones are primarily responsible for the changes in blood glucose levels about 2 hours after food is eaten?
   A. insulin
   B. estrogen and progesterone
   C. epinephrine and norepinephrine
   D. aldosterone and parathyroid hormones

DIRECTIONS: Complete the following analogy:

6. neurotransmitters : nervous system :: hormones :
   F. feedback system
   G. endocrine system
   H. circulatory system
   J. respiratory system

INTERPRETING GRAPHICS: The table below gives the relative levels of thyroid-stimulating hormone (TSH) during a 12 hour period. Use the table below to answer the question that follows.

Time (hours)	Blood level of thyroid-stimulating hormone
0	normal
4	high
8	normal
12	low

7. Thyroid-stimulating hormone (TSH) is a hormone that stimulates the release of the thyroid hormones from the thyroid gland. At what time would you expect thyroid hormone levels to be at their lowest?
   A. 0 hours
   B. 4 hours
   C. 8 hours
   D. 12 hours

SHORT RESPONSE

The pancreas is an organ that carries out many functions related to digestion.

Explain why the pancreas is considered to be both an exocrine gland and an endocrine gland.

EXTENDED RESPONSE

The endocrine system is involved in maintaining homeostasis. Many of the activities regulated by the endocrine system require maintaining a critical substance at levels that do not vary much.

Part A Explain how pairs of hormones are involved in regulating levels of critical substances.

Part B Describe a specific example of a pair of hormones that work together to maintain the level of a critical substance.

Test TIP Sometimes, only one part of a graph or table is needed to answer a question. In such cases, focus only on that information to answer the question.

Observing the Effects of Thyroxine on Frog Metamorphosis

OBJECTIVES

- Observe the effects of the hormone thyroxine on the development of tadpoles.

PROCESS SKILLS

- observing
- measuring
- comparing and contrasting
- organizing data
- inferring

MATERIALS

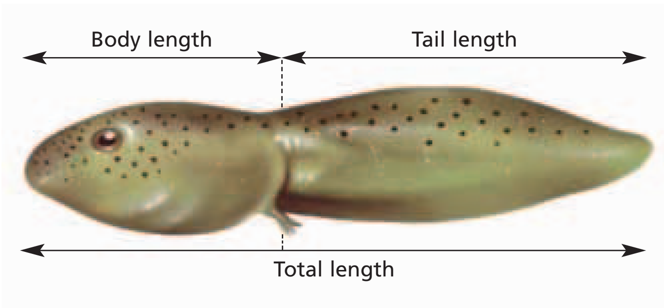
- safety goggles
- protective gloves
- lab apron
- glass-marking pencil
- six 600 mL beakers
- pond water
- 10 mL graduated cylinder
- 0.01% thyroxine solution
- strained spinach
- graph paper marked in 1 mm squares
- Petri dish
- small fish net
- 9 tadpoles with budding hind legs
- 3 pencils in different colors

Background

1. What is a hormone?
2. What is metamorphosis?
3. Describe the stages of frog development.
4. What are the effects of thyroxine in humans?
5. What effects do you predict the hormone thyroxine will have on tadpole growth and development?

PART A Setting Up the Experiment

1. In your lab report, make a data table similar to the one shown on the facing page.
2. Use a glass-marking pencil to label three beakers "A" "B" and "C". Also, write your initials on the beakers.
3. Add 500 mL of pond water to each beaker.
4. CAUTION **Put on a lab apron and safety goggles. If you get thyroxine on your skin or clothing, rinse with water while calling to your teacher. If you get thyroxine in your eyes, immediately flush them with water at the eyewash station while calling to your teacher.**
5. Use a graduated cylinder to measure 10 mL of thyroxine solution. Add the 10 mL of solution to beaker A. Measure and add 5 mL of thyroxine solution to beaker B.
6. Add equal amounts (about 1 mL) of strained spinach to beakers A, B, and C.
7. Place a sheet of graph paper, ruled side up, under a Petri dish.
8. CAUTION **You will be working with live animals. Handle them with care, and follow directions carefully.** Catch a tadpole with a fish net, and place the tadpole in the Petri dish. Measure the tadpole's total length, tail length, and body length in millimeters by counting the number of squares that it covers on the graph paper. Then, place the tadpole in beaker A.



9. Repeat step 8 with two more tadpoles. Average the total length, tail length, and body length of the three tadpoles that you placed in beaker A. In your data table, record the average measurements under the column labeled "Beaker A."

10. Repeat step 8 with three more tadpoles, this time placing the tadpoles in beaker B. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker B."
11. Repeat step 8 with three more tadpoles. Place these three tadpoles in beaker C. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker C." You should have measured a total of nine tadpoles and placed three in each beaker.
12. Clean up your materials, and wash your hands before leaving the lab.

PART B Observing the Effects of Thyroxine on Tadpoles

13. Feed each beaker of tadpoles 1 mL of spinach every other day. Be careful not to overfeed the tadpoles. Change the water in the beakers every 4 days, adding thyroxine solution in the original amounts to beakers A and B. Label the beakers, and do not mix up the tadpoles during the water changes.
14. Measure the tadpoles once a week for 3 weeks, and average the length of the tadpoles in each beaker. Record the average lengths in your data table.
15. Calculate the average growth per week for each set of three tadpoles. For example, the average growth in total length during the second week is equal to the average total length at the end of week 2 minus the average total length at the end of week 1. Record your values in the appropriate spaces of your data table.
16. Graph your data using a different colored pencil for the tadpoles in each beaker. Label the horizontal axis "Time in weeks," and label the vertical axis "Length in centimeters." You should have three graphs. Each graph should include the changes in average total length, average tail length, and average body length for one group of tadpoles.
17. Clean up your materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. Did this investigation include a control group? If so, describe it. If not, suggest a possible control that you could have used.
2. Why are three tadpoles used for each beaker rather than just one?
3. According to the data that you collected in this investigation, what is the effect of thyroxine on tadpole metamorphosis?
4. Which concentration of thyroxine solution caused the greatest visible change in the tadpoles?
5. How do average body length and tail length change during metamorphosis?

Further Inquiry

Iodine, typically in the form of iodide, is needed to make thyroxine. Design—but do not conduct—an experiment that shows the effect of adding iodine to water that contains tadpoles. **CAUTION: Iodine is a highly poisonous substance.**

MEASUREMENT OF TADPOLE GROWTH

	Beaker A			Beaker B			Beaker C		
	Average total length	**Average tail length**	**Average body length**	**Average total length**	**Average tail length**	**Average body length**	**Average total length**	**Average tail length**	**Average body length**
Initial									
End of week 1									
End of week 2									
End of week 3									