The Endocrine System

CHAPTER OBJECTIVES

After studying this chapter, you should be able to:

1. List the functions of hormones.
2. Classify hormones into their major chemical categories.
3. Describe how the hypothalamus of the brain controls the endocrine system.
4. Name the endocrine glands and state where they are located.
5. List the major hormones and their effects on the body.
6. Discuss some of the major diseases of the endocrine system and their causes.
# Key Terms

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INTRODUCTION

The endocrine system exerts chemical control over the human body by maintaining the body's internal environment within certain narrow ranges. See Concept Maps 12-1 and 12-2: Endocrine System. This is known as homeostasis (hom-ee-oh-STAAY-sis). This maintenance of homeostasis, which involves growth, maturation, reproduction, metabolism, and human behavior, is shared by both the endocrine system and the nervous system in a unique partnership. It is the hypothalamus of the brain (a part of the nervous system) that sends directions via chemical signals (neurotransmitters) to the pituitary gland (a part of the endocrine system). The pituitary is occasionally referred to as the master gland of the system because many of its hormones (chemical signals) stimulate the other endocrine glands to secrete their hormones.

The endocrine glands are ductless glands that secrete their hormones directly into the bloodstream. The blood circulatory system then carries these chemical signals...
to target organs where their effects are seen as specific responses. These chemical signals or hormones help regulate metabolism, water and electrolyte concentrations in cells, growth, development, and the reproductive cycles. Endocrine glands are ductless, as opposed to exocrine glands, which have ducts by which their secretions are transported directly to an organ or the body surface, such as sweat glands to the surface of the body and salivary glands to the mouth.

**THE FUNCTIONS OF HORMONES**

Hormones control the internal environment of the body from the cellular level to the organ level of organization. They control cellular respiration, cellular growth, and cellular reproduction. They control the fluids in the body, such as water amounts and balances of electrolytes. They control the secretion of other hormones. They control our behavior patterns. They play a vital role in the reproductive cycles of men and women. In addition, they regulate our growth and development cycles.

This chemical control of the body functions primarily as a **negative feedback loop**. In our homes, our furnaces and thermostats operate as a negative feedback loop. We set our thermostat to a particular temperature and when the temperature of our home falls below that set temperature, the thermostat causes the furnace to turn on. Once the temperature inside reaches the set temperature on the thermostat, it sends another signal to the furnace to shut off. Hormonal systems function in the same way. When the concentration of a particular hormone reaches a certain level in the body, the endocrine gland that secreted that hormone is inhibited (the negative feedback) and the secretion of that hormone ceases or decreases significantly. Later as the concentration of that gland’s hormone falls below normal levels, the inhibition of the gland ceases and it begins to produce and secrete the hormone once again. This kind of a negative feedback loop helps to control the concentrations of a number of hormones in our bodies.
FIGURE 12-1. The relationship of the hypothalamus of the brain with the anterior lobe of the pituitary gland.
THE CLASSIFICATION OF HORMONES

Hormones can be classified into three general chemical categories. The simplest group includes hormones that are modified amino acids. Examples are the hormones secreted by the adrenal medulla: epinephrine and norepinephrine, and the hormones secreted by the posterior pituitary gland: oxytocin and vasopressin. The second category is the protein hormones: insulin from the pancreatic islets and the gonad-stimulating hormones and growth hormone from the anterior pituitary gland. The third category of hormones is the steroid hormones, which are lipids. Examples are cortisol from the adrenal cortex and estrogen and testosterone produced by the gonads.

The modified amino acid and protein hormones bind to membrane-bound receptor sites on the cells of target organs. The steroid hormones diffuse across the cell membrane and bind to intracellular (inside the cell) receptor molecules. The steroid hormones are soluble in lipids and can diffuse across the lining of the stomach and intestine and get to the circulatory system. They can be taken orally to treat illnesses. Birth control pills made of synthetic estrogen and progesterone hormones and steroids that combat inflammation are taken orally. However, the protein and modified amino acid hormones, like insulin, must be injected because they cannot diffuse across the intestinal lining because they are not soluble in lipids. They are broken down before they are transported across the lining of the digestive tract and thus their effect is destroyed. Therefore, insulin must be injected to treat diabetes mellitus. Another form of diabetes is diabetes insipidus, which is caused by a deficiency in the antidiuretic hormone (ADH).

THE HYPOTHALAMUS OF THE BRAIN

The hypothalamus (high-poh-THAL-ah-mus) of the brain is the inferior part of the diencephalon. It has a unique role with the endocrine system because it plays a major role in controlling secretions from the pituitary gland. There is a funnel-shaped stalk, called the infundibulum (in-fun-DIB-yoo-lum), that extends from the floor of the hypothalamus connecting it to the pituitary gland. Historically, the pituitary gland is referred to as the master gland of the endocrine system because it controls the secretions of many other endocrine glands. However, in actuality, it is the hypothalamus of the brain that sends neural and chemical signals to the pituitary gland; hence, the hypothalamus controls the pituitary gland. This relationship is akin to a concert performance. The conductor, like the pituitary gland, tells the various sections of the orchestra (the other endocrine glands) when and how to play the music. However, the conductor gets information from the sheet music or score (like the role of the hypothalamus).

Nerve cells in the hypothalamus produce chemical signals called releasing hormones and releasing inhibitory hormones. These hormones, which are actually neurotranscretions, either stimulate or inhibit the release of a particular hormone from the pituitary gland (Figures 12-1 and 12-2). These releasing hormones enter a capillary bed in the hypothalamus and are transported through a portal vein in the infundibulum to a second capillary bed of the anterior pituitary gland. After leaving the capillaries, they bind to receptors controlling the regulation of hormone secretion from the pituitary gland. It is within the hypothalamus of the brain and the pituitary gland that the interactions and relationships between the endocrine and nervous systems are controlled and maintained. Conversely, due to negative feedback, the hormones of the endocrine system can influence the functions of the hypothalamus.

THE MAJOR ENDOCRINE GLANDS AND THEIR HORMONES

The endocrine glands include the pituitary gland, the pineal gland, the thyroid gland, the parathyroid glands, the thymus gland, the adrenal glands, the islets of Langerhans of the pancreas, the ovaries in women, and the testes in men (Figure 12-3).

The Anterior Pituitary Gland, Its Hormones, and Some Disorders

The pituitary (pih-TYOO-ih-tayr-ee) gland is also called the hypophysis (high-POFF-ih-sis). A small gland about the size of a pea, some of its hormones affect the functions of many other endocrine glands such as the testes, ovaries, the adrenal cortex, and the thyroid gland. It is situated in a depression of the sphenoid bone below the hypothalamus of the brain. It is divided into two lobes, a larger anterior pituitary lobe and a smaller posterior pituitary lobe.

The anterior pituitary lobe produces seven hormones (see Figure 12-1). Growth hormone (GH) stimulates cell metabolism in most tissues of the body, causing cells to divide and increase in size. It increases protein synthesis...
and the breakdown of fats and carbohydrates. It stimulates the growth of bones and muscles. If a young person suffers from too little GH as a result of abnormal development of the pituitary gland, a condition called pituitary dwarfism results. The person remains small, although body proportions are normal. The most famous pituitary dwarf was Charles Stratton, known as Tom Thumb, who was employed by P.T. Barnum in his circus. He died in 1888 at the age of 45 and was less than 1 meter tall. On the other hand, too much GH during childhood results in gigantism. Excess secretion of GH after childhood when bone has stopped growing results in acromegaly. Bones widen especially in the face, hands, and feet. However, in the majority of children, the anterior pituitary produces just the right amount of GH, resulting in normal growth rates. Checkups with the family doctor during childhood help to monitor the rate of growth and development. In the United States, it is now rare to see a pituitary dwarf or giant.
Secretion of GH is controlled by two releasing hormones from the hypothalamus: one stimulates secretion and the other inhibits it. Peak secretions of GH occur during periods of sleep, exercise, and fasting. Growth is also influenced by nutrition, genetics, and the sex hormones during puberty.

**Thyroid-stimulating hormone (TSH)** stimulates the thyroid gland to produce its hormone. The rate of TSH secretion is regulated by the hypothalamus, which produces thyrotropin-releasing hormone (TRH), which stimulates the anterior pituitary lobe to secrete TSH.

**Adrenocorticotropic** (ad-ree-noh-KOR-tih-koh-TROH-pik) hormone (ACTH) stimulates the adrenal cortex to secrete its hormone called cortisol. ACTH secretion is regulated by corticotropin-releasing hormone (CRH) produced by the hypothalamus. ACTH is involved with the glucose-sparing effect and helps reduce inflammation as well as stimulating the adrenal cortex.

**Melanocyte-stimulating hormone (MSH)** increases the production of melanin in melanocytes in the skin, thus causing a deepening pigmentation or darkening of the skin.

**Follicle-stimulating hormone (FSH)** stimulates development of the follicles in the ovaries of females. In males, it stimulates the production of sperm cells in the seminiferous tubules of the testes.

**Luteinizing** (LOO-tee-in-eye-zing) hormone (LH) stimulates ovulation in the female ovary and production of the female sex hormone progesterone. It helps maintain pregnancy. In males, it stimulates the synthesis of testosterone in the testes to maintain sperm cell production.

**Lactogenic hormone (LTH)**, also known as prolactin (proh-LACK-tin), stimulates milk production in the mammary glands following delivery in a pregnant female. It also maintains progesterone levels following ovulation and during pregnancy in women. In males, it appears to increase sensitivity to LH and may cause a decrease in male sex hormones.
The Posterior Pituitary Gland and Its Hormones

The posterior pituitary lobe consists primarily of nerve fibers and neuroglial cells that support the nerve fibers, whereas the anterior lobe is primarily glandular epithelial cells. Special neurons in the hypothalamus produce the hormones of the posterior pituitary lobe. These hormones pass down axons through the pituitary stalk to the posterior lobe, and secretory granules near the ends of the axons store the hormones (see Figure 12-2).

Antidiuretic (an-tye-dye-yoo-RET-ik) hormone (ADH), also known as vasopressin (vaz-oh-PRES-sin), maintains the body’s water balance by promoting increased water reabsorption in the tubules of the nephrons of kidneys, resulting in less water in the urine. If secreted in large amounts, ADH can cause constriction of blood vessels, hence its other name vasopressin. A deficiency of ADH can result in a condition known as diabetes insipidus. Individuals with this condition produce 20 to 30 liters of urine daily. They lose essential electrolytes, resulting in abnormal nerve and cardiac muscle functions. This condition can be treated by taking ADH as injections or in the form of a nasal spray. Again the hypothalamus regulates ADH secretion through osmoreceptors that detect changes in the osmotic pressure of body fluids. Dehydration, caused by lack of sufficient water intake, increases blood solute concentrations and these osmoreceptors signal the posterior lobe to release ADH. This causes the kidneys to conserve water. Conversely, taking in too much water or drinking too much fluid dilutes blood solutes, inhibiting ADH secretion so the kidneys excrete a more dilute (more water in it) urine until the concentration of solutes in body fluids returns to normal. In contrast, a diuretic increases urine secretion.

Oxytocin (ok-see-TOH-sin) (OT) stimulates contraction of smooth muscles in the wall of the uterus. Stretching of uterine and vaginal tissues late in pregnancy stimulates production of OT so that uterine contractions develop in the late stages of childbirth. OT also causes contraction of cells in the mammary glands causing milk ejection or lactation, forcing the milk from the glandular ducts into the nipple during breastfeeding of the newborn infant.

HEALTH ALERT

During the 1950s, pharmaceutical companies developed anabolic steroids, which are variants of the male sex hormone testosterone. Testosterone is responsible for building muscle mass and during puberty causes bone development, deepened voice, and facial and chest hair growth in boys. The anabolic steroids were developed to treat patients who were immobile after surgeries or who had degenerating diseases of muscle, to prevent muscle atrophy in these individuals.

Bodybuilders and athletes believed that megadoses of the steroids would build muscle bulk and increase their athletic abilities. They began using the anabolic steroids in the 1960s. Although the use of these steroids has been banned by most competitions, some athletes still use them. In fact, not only athletes, but some men and women who want to add muscle bulk and increase their competitive capability in sports have also used these drugs. They can be acquired either legally by prescription or illegally from the drug market. Sports figures have admitted to their use. The advantages of anabolic steroids, according to athletes who have used them, are increased muscle bulk, greater volume of red blood cells resulting in more oxygen-carrying capabilities to muscle cells, and an increase in aggression. This results in greater athletic stamina and having a “good-looking body.”

However, dangers are associated with the use of anabolic steroids. Some of the side effects are shriveled testes and infertility, changes in blood cholesterol levels that could lead to heart disease, damage to the liver that could lead to liver cancer, puffy faces (known as the cushingoid sign), and mental problems. Psychological effects range from depression, delusions, and manic personality swings that can turn violent.

Yet some athletes continue to use these drugs despite the dangers associated with them. The desire to be a winner in our society seems to cloud common sense decisions.
Occasionally, commercial preparations of OT are administered to induce labor if the uterus does not contract sufficiently on its own during childbirth. It is also given to women after childbirth to constrict blood vessels of the uterus to minimize the risk of hemorrhage.

The Thyroid Gland, Its Hormones, and Some Disorders

The thyroid gland consists of two lobes connected by a smaller band called the isthmus (Figure 12-4). The lobes are situated on the right and left sides of the trachea and thyroid cartilage just below the larynx. It is a highly vascular, large endocrine gland covered with a capsule of connective tissue. It is made up of spheres of cells called follicles. These follicles are composed of simple cuboidal epithelium, which produces and secretes the thyroid hormones. Thyroid output is regulated by the hypothalamus, which signals the pituitary to release TSH to increase thyroid production.

The thyroid gland requires iodine to function properly. In the United States iodized salt is used as a way to ensure the intake of adequate amounts of iodine in the diet. In countries without adequate amounts of iodine in the diet, the thyroid gland enlarges forming a goiter (GOT-ter). However, proper amounts of iodine cause the thyroid gland to effectively produce its hormones. One hormone is thyroxine (thigh-ROX-in), also known as tetraiodothyronine (teh-trah-ye-oh-doh-THIGH-roh-neen), which contains four iodine atoms and is abbreviated as T₄. The other hormone is triiodothyronine (try-ye-oh-doh-THIGH-roh-neen), which contains three iodine atoms and is abbreviated as T₃.

These hormones regulate the metabolism of carbohydrates, fats, and proteins. These hormones are necessary for normal growth and development as well as for nervous system maturation. They cause an increase in the rate of carbohydrate and lipid breakdown into energy molecules as well as increasing the rate of protein synthesis. A lack of or low level of thyroid hormones is called hypothyroidism (high-poh-THIGH-royd-izm). In young children, this can result in a condition known as cretinism (KREE-tin-izm). The child with this condition is mentally retarded and does not grow to normal stature. In adults, this condition results in a lowered rate of metabolism, causing sluggishness, being too tired to perform normal daily tasks, and an accumulation of fluid in subcutaneous tissues called myxedema (mikseh-DEE-mah). Too much secretion of thyroid hormones causes hyperthyroidism (high-per-THIGH-royd-izm). This results in extreme nervousness, fatigue, and an elevated rate of body metabolism. Graves’ disease is a type of hyperthyroidism caused by overproduction of thyroid hormone. It is often associated with an enlarged thyroid gland or goiter and bulging of the eyeballs known as exophthalmia (eks-off-THAL-mee-ah).

Besides secreting these two thyroid hormones, the extrafollicular cells of the thyroid gland secrete a hormone called calcitonin (kal-sih-TOH-nin). This hormone lowers the calcium and phosphate ion concentration of the blood by inhibiting the release of calcium and phosphate ions from the bones and by increasing the excretion of these ions by the kidneys.

Thyroid hormone secretion is controlled by TSH produced by the anterior pituitary gland. Increased levels of thyroid hormones, through the negative feedback mechanism, inhibit the anterior pituitary gland from releasing more TSH and the hypothalamus from secreting TSH-releasing hormone. Because of negative feedback, the thyroid hormones fluctuate daily within a narrow range of concentration in the blood.

The Parathyroid Glands, Their Hormone, and Some Disorders

The parathyroid glands are four glands about the size of raisins that are embedded in the posterior surface of the thyroid gland (Figure 12-5). There are two in each lobe of the thyroid, a superior and an inferior gland. Each gland
consists of many tightly packed secreting cells called chief cells and oxyphil cells close to capillary networks.

The parathyroid glands secrete a single hormone called parathyroid hormone or parathormone (PTH). PTH inhibits the activity of osteoblasts and causes osteoclasts to break down bone matrix tissue, thus releasing calcium and phosphate ions into the blood. In addition, PTH causes the kidneys to conserve blood calcium and stimulates intestinal cells to absorb calcium from digested food in the intestine. This hormone raises blood calcium to normal levels.

Vitamin D also increases absorption of calcium by the intestines. Ultraviolet light from the sun acting on the skin is necessary for the first stage of vitamin D synthesis. The final stage of synthesis occurs in the kidneys and is stimulated by PTH. Vitamin D can also be supplied in the diet.

An abnormally high level of PTH secretion is known as hyperparathyroidism and can be caused by a tumor in the parathyroid gland. This results in breakdown of bone matrix, and bones become soft and deformed and can easily fracture. Elevated calcium levels in the blood cause muscles and nerves to become less excitable, resulting in muscle weakness and fatigue. Excess calcium and phosphate ions may become deposited in abnormal places resulting in kidney stones. An abnormally low level of PTH is called hypoparathyroidism. This can be caused by surgical removal of the thyroid and parathyroid glands or by injury to the glands. The decreased level of PTH reduces osteoclast activity, reduces rates of bone matrix breakdown or resorption, and reduces vitamin D formation. Bones will remain strong but the blood calcium level decreases result in nerves and muscles becoming abnormally excitable, producing spontaneous action potentials. This can cause frequent muscle cramps or tetanic contractions. If respiratory muscles are affected, breathing failure and death can occur.

The Adrenal Glands, Their Hormones, and Some Disorders

The adrenal (ad-REE-nal) glands are also known as the suprarenal (soo-prah-REE-nal) glands (Figure 12-6). They are small glands found on top of each kidney. The inner part of each gland is called the adrenal medulla and the outermost part is called the adrenal cortex. Each section functions as a separate endocrine gland.

The adrenal medulla produces large amounts of the hormone adrenaline (ad-REN-ih-lin), also known as
The adrenal or suprarenal glands, found on top of each kidney, consist of an inner adrenal medulla and an outer adrenal cortex.

**Epinephrine** (ep-ih-NEF-rin), and small amounts of **norepinephrine** (nor-ep-ih-NEF-rin) or **noradrenaline**. These hormones are released in response to signals from the sympathetic division of the autonomic nervous system. Epinephrine and norepinephrine are commonly referred to as the fight-or-flight hormones because they get the body prepared for stressful situations that require vigorous physical activity. When a person senses danger and experiences stress, the hypothalamus of the brain triggers the adrenal gland via the sympathetic division of the autonomic nervous system to secrete its hormones.

These hormones cause the breakdown of glycogen in the liver to glucose and the release of fatty acids from stored fat cells. The glucose and fatty acids are released into the bloodstream as a quick source of energy. The action of cortisol helps the body during stressful situations and helps maintain the proper concentration of glucose in the blood between meals. Cortisol also helps reduce the inflammatory response. **Cortisone** (KOR-tih-zone), a steroid closely related to cortisol, is often given as a medication to reduce inflammation and as a treatment for arthritis.

If the adrenal cortex fails to produce enough hormones, a condition known as **Addison’s disease** develops. President John F. Kennedy suffered from Addison’s disease and was under regular medical care for its treatment. Although President Kennedy always looked tanned and healthy, a bronzing of the skin was a symptom of the disease. In addition, other symptoms include decreased blood sodium, low blood glucose causing fatigue and listlessness, dehydration, and low blood pressure. Without treatment it can lead to death due to severe changes in electrolyte balances in the blood. Too much secretion causes tissue fluid increase, resulting in puffy skin. The patient exhibits obesity, a moon-shaped face, skin atrophy, and menstrual problems in women. Increases in adrenal male sex hormone production results in masculinizing changes in women, such as facial hair growth and lowering of voice pitch.

**Adrenal gland**

**Kidney**

**Cortex**

**Medulla**

**FIGURE 12-6.** The adrenal or suprarenal glands, found on top of each kidney, consist of an inner adrenal medulla and an outer adrenal cortex.

Adrenal gland

Kidney

Cortex

Medulla

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The Pancreas, Its Hormones, and Some Disorders

The pancreas has a dual role in that it is part of the digestive system where its cells, called acini, produce digestive enzymes known as pancreatic juice, and it is part of the endocrine system where its pancreatic islets, also known as the islets of Langerhans, produce the hormones insulin and glucagon (GLOO-kah-gon). These hormones regulate blood glucose levels. The pancreas is a flattened, elongated gland divided into head, body, and tail portions. Refer to its anatomy in Chapter 16. It is found behind the stomach and its pancreatic duct connects to the duodenum of the small intestine. This exocrine portion of the gland (the pancreatic duct) transports its digestive juices to the intestine.

Its endocrine portion consists of two main groups of cells closely associated with blood vessels. These groups of cells are known as the pancreatic islets or islets of Langerhans. Alpha cells secrete the hormone glucagon, and beta cells secrete the hormone insulin.

After a meal that consists primarily of carbohydrates like potatoes or rice, vegetables, salad, or cereals and breads, the blood glucose concentration becomes high due to the digestive processes. At this time, beta cells release insulin into the bloodstream. Insulin promotes the glucose in the blood to be transformed in the liver into glycogen, which is stored animal starch. In addition, glucose is moved into muscle cells and adipose tissue. Through negative feedback, when blood glucose levels fall, as between meals and during the night, the secretion of insulin decreases.

During the time glucose levels decrease, alpha cells in the pancreatic islets secrete the hormone glucagon. Glucagon stimulates the liver to convert the stored glycogen into glucose, thus raising blood glucose levels. Glucagon also causes the breakdown of amino acids and their conversion into glucose to raise blood glucose levels (Figure 12-7). The breakdown of the amino acids of proteins is used by the liver to synthesize more glucose. Fats are also broken down rapidly by other tissues to provide an alternative energy source. Again a negative feedback regulates glucagon secretion. Low blood sugar concentrations stimulate alpha cells to secrete glucagon. As blood sugar levels rise, glucagon secretion decreases. This mechanism helps to prevent hypoglycemia when glucose concentration gets low as during exercise and between meals.

The maintenance of blood glucose levels within a normal range is essential to body maintenance and function. A decline in blood glucose can cause nervous system malfunctions because glucose is the main source of energy for nerve cells. If the blood glucose level gets very low, the breakdown of fats releases fatty acids and...
ketones, causing a lowering of blood pH, a condition known as acidosis (as-ih-DOH-sis). If blood glucose levels are too high, the kidneys produce large amounts of urine containing high amounts of glucose, which can lead to dehydration.

The Testes and the Ovaries

The anatomy of the testes and the ovaries are discussed in detail in Chapter 19. The testes, in addition to producing sperm as exocrine glands, produce the male sex hormones as endocrine glands. The principal male sex hormone is testosterone (tess-TOS-ter-ohn). This hormone is responsible for the development of the male reproductive structures, and at puberty, the enlargement of the testes and penis. It also promotes the development of secondary male sexual characteristics, such as the growth of facial and chest hair, deepening of the voice, muscular development, bone growth resulting in broad shoulders, and narrow hips. It promotes the development of the male sexual drive and aggressiveness.

In the ovaries of the female, two groups of hormones, estrogen (ESS-troh-jen) and progesterone (proh-JES-ter-ohn), promote the development of the female reproductive structures: the uterus, vagina, and fallopian tubes. Secondary female sexual characteristics also develop such as breast enlargement, fat deposits on the hips and thighs, bone development resulting in broad hips, and a higher pitched voice. The menstrual cycle is also controlled by these hormones. Releasing hormones from the hypothalamus affect the anterior pituitary gland to produce the gonad-stimulating hormones: LH and LSH. These hormones control the secretion of hormones from the testes and ovaries. The hormones from the gonads have a negative feedback effect on the hypothalamus and the anterior pituitary gland. Thus, a constant, normal level of sex hormones is maintained in the body.

StudyWARE™ Connection

- Watch an animation about the endocrine system on your StudyWARE™ CD-ROM.
- Play an interactive game labeling the endocrine glands on your StudyWARE™ CD-ROM.

Diabetes mellitus (dye-ah-BEE-teez MELL-ih-tus) is a very common disorder of the endocrine system. It is caused by a deficiency in insulin production and affects about 14 million Americans. Other individuals with diabetes have a decreased number of insulin receptors on target cells so that glucose is unable to move into cells even with normal insulin amounts. These conditions result in chronic elevations of glucose in the blood, a condition known as hyperglycemia (high-per-glye-SEE-mee-ah).

As blood sugar levels rise in diabetics, the amount of glucose filtered by the kidney tubules from the blood exceeds the ability of the tubules to reabsorb the glucose. Thus, there is a large amount of sugar in the urine, a condition known as glycosuria (glye-kos-you-ree-ah). This results in an increase in urine production because additional water is required to transport the extra glucose load. This is known as polyuria. As large amounts of fluids are lost in the urine, the diabetic individual dehydrates and craves large amounts of liquid, a condition known as polydipsia (pall-ee-DIP-see-ah), or excessive thirst. Also, because cells are not getting glucose to burn as energy, the diabetic person experiences intense food cravings or polyphagia (pall-ee-FAY-jee-ah). The diabetic person will eat ravenously but still constantly loses weight.

The disease inhibits fat and protein synthesis. Glucose-deficient cells use proteins as a source of energy, and tissues waste away. The patient is very hungry, eats yet loses body weight, and tires easily. Children will fail to grow, and both children and adults do not repair tissues well. Changes in fat metabolism build up fatty acids and ketones in the blood, resulting in low pH or acidosis. Acidosis (continues)
and dehydration damage brain cells; thus, these individuals can become disoriented or may go into a diabetic coma and die.

There are two major types of diabetes mellitus: type 1 and type 2. Type 1 diabetes is also known as juvenile-onset diabetes because it usually develops between 11 and 13 years of age but before 30. It is an autoimmune disease that destroys the beta cells of the pancreas. Individuals with this type of diabetes must take daily insulin injections. This is also known as insulin-dependent diabetes mellitus (IDDM). This form of diabetes accounts for only 10% of diabetics.

Type 2 diabetes mellitus is known as noninsulin-dependent diabetes mellitus (NIDDM) and is the most common form of the disease, affecting about 90% of people with diabetes. It usually develops after 40 years of age and produces milder symptoms. Most affected persons are overweight when they develop the disease. In this situation, the beta cells still produce insulin but in reduced quantity, and insulin receptors on target cells are lost and glucose uptake diminishes. Treatment includes maintaining a balanced and controlled diet and exercise to maintain a normal body weight. Heredity and ethnic background can predispose individuals to this disease. Native Americans are at increased risk; African Americans and Hispanics are 50% more likely to develop type 2 diabetes than Caucasians. Drugs are available to treat type 2 diabetes.

Individuals with diabetes must monitor their blood glucose levels several times a day. Without monitoring and maintaining proper levels of blood glucose, nerve damage can develop. Hyperglycemia results in reduced blood flow caused by buildup of fatty materials in blood vessels, resulting in possible stroke, heart attack, and reduced circulation in the extremities. Diabetic retinopathy, causing changes in the retina of the eye, can lead to blindness. Kidney disease can be another complication of diabetes. Careful monitoring and regulation of blood sugar levels can control these symptoms. Discovery of insulin in 1921 and the development of drugs help control this disease today.

### COMMON DISEASE, DISORDER, OR CONDITION

#### DIABETES INSIPIDUS

Diabetes insipidus is caused by either not enough antidiuretic hormone (ADH) being produced by the posterior pituitary gland or from ADH receptors that are not functioning properly. This is not to be confused with diabetes mellitus. Individuals with diabetes insipidus excrete copious amounts of urine and thus become severely dehydrated. They also become excessively thirsty. Children with this condition often experience bedwetting. Treatment includes administration of ADH as a nasal spray.

#### SEASONAL AFFECTIVE DISORDER

Seasonal affective disorder occurs in individuals who are sensitive to an overproduction of melatonin that occurs in climate zones that have cloudy winter months with little bright sunshine. It produces a type of depression. Since winter months also have short days, this also contributes to more melatonin being secreted by the pineal gland (less light equals more melatonin). Individuals with this condition can be treated with daily doses of several hours of bright artificial light.

#### ALDOSTERONISM

Aldosteronism is caused by too much secretion of aldosterone, one of the mineralocorticoid hormones from the adrenal cortex. Symptoms of this condition include high blood pressure. This results from sodium and water retention by the kidneys, reduced levels of potassium in the blood, and an increase in blood pH.

(continues)
OTHER DISORDERS OF THE ENDOCRINE SYSTEM (continued)

STRESS

Stress is caused by many and varied external environmental influences such as worry over finances, examinations and grades, relationships, employment, and so forth. Epinephrine from the adrenal medulla and cortisol from the adrenal cortex are hormones that help us cope with stressful situations by increasing both blood glucose levels and the release of fatty acids from the liver and adipose cells as a source of ATP for muscle energy. This includes increased heartbeat rates. When we perceive a stressful situation, our nervous system via the hypothalamus of the brain sends autonomic nervous signals to the adrenal gland. Thus, cooperation exists between the nervous system and the endocrine system to deal with stress. Chronic stress causes excessive secretion of these hormones that can lead to both serious psychological effects (depression) and physiological effects (malaise and susceptibility to infections).

ADRENOGENITAL SYNDROME

Adrenogenital syndrome occurs due to excessive secretion of androgens from the adrenal cortex. This can be caused by being born with an overdeveloped adrenal gland or by the development of a tumor in the gland. Females born with this condition are pseudohermaphroditic with an enlarged clitoris. As they develop, they will have a deep voice with hair distribution on the face and chest as well as more muscle development. Males born with this condition will have early development of an enlarged penis and prostate gland with early pubic and axillary hair. Tumors develop later on in life, around 35 years of age or later, and are more common in women. This causes the development of facial hair, a deep masculine voice, and a decrease in the size of the breasts. Treatment includes surgery to remove the tumor, cosmetic surgery, and hair removal via electrolysis.

GRAVES' DISEASE

Graves’ disease is a symptom of hyperthyroidism. Symptoms include an abnormal protrusion of the eyeballs (exophthalmos) and an enlarged thyroid gland. The disease is more common in women and appears to be genetic in origin. It occurs between 30 and 60 years of age. Other symptoms include weight loss, fatigue, palpitations of the heart, nervousness, and slight tremors in the hands. This disease is treated with drugs or radioactive iodine.

CUSHING'S SYNDROME

Cushing’s syndrome is caused by a long-term excessive production of cortisol by the adrenal cortex. Individuals with this condition have decreased glucose tolerance levels. Symptoms of the condition include excessive weight around the waist, and a round moonlike face caused by the accumulation of excessive adipose tissue on the trunk and face. The skin may become abnormally pigmented, causing reddish blotches on the face of light-skinned individuals. Individuals with this syndrome are susceptible to having infections, which may become difficult to eradicate.
The Thymus Gland and Its Hormone

The **thymus gland** is a bilobed mass of tissue found in the mediastinum behind the sternum between the two lungs. This gland is most important early in life and is relatively large in young children. It is critical in the development of the immune system and is discussed further in Chapter 15. As we age, the gland shrinks and is replaced with fat and connective tissue. The gland secretes the hormone **thymosin** (thigh-MOH-sin), which causes the production of certain white blood cells called T lymphocytes. These T cells protect the body against foreign microorganisms, thus helping to fight infections. The thymus gland has an important role in the development of immunity. Occasionally, an infant will be born without a thymus gland and the immune system will not develop properly. Such children are susceptible to infections and have greater difficulty fighting off microbial organisms.

The Pineal Gland and Its Hormone

The **pineal (PIN-ee-al) gland or body** is a small pinecone-shaped structure found between the two cerebral hemispheres attached to the upper part of the thalamus near the top of the third ventricle (Figure 12-8). The pineal gland produces the hormone **melatonin** (mel-ah-TOH-nil), which is secreted directly into cerebrospinal fluid.

Melatonin has a number of effects on the body and research continues on the hormone. It inhibits the secretion of the gonadotropin hormones LH and LSH from the anterior pituitary gland, thus inhibiting the functions of the reproductive system. Bright light inhibits the secretion of melatonin. Studies have indicated that melatonin regulates circadian rhythms. In bright light, with little melatonin, people "feel good" and their fertility increases. High levels of melatonin produced in the dark cause individuals to feel depressed and tired, bringing on sleep. Melatonin affects our sleep-wake patterns and maintains our biological cycles. Nerve impulses originating in the retina of the eyes send light information to the pineal gland. In dark or dim light, nerve impulses from the eyes decrease and melatonin secretion increases. Melatonin also plays a role in the onset of puberty and in the female reproductive cycle.

**Serotonin** (sayr-oh-TOH-nil) is also secreted by the pineal gland and acts as a neurotransmitter and vasoconstrictor. It stimulates smooth muscle contraction and inhibits gastric secretions.
As individuals age, growth hormone decreases. This causes a decrease in bone mass, which may lead to osteoporosis. There is also a decrease in lean muscle mass with an accompanying increase in the deposition of adipose tissue. Regular exercising helps limit the decrease in growth hormone.

The production of sex hormones also declines in both men and women during the later middle years. This results in menopause in women, which is occasionally treated with sex hormone replacement therapy.

Secretion of thymosin from the thymus gland decreases with age, affecting the number of lymphocytes that can mature and provide functional immunity. This can result in susceptibility to cancers and more frequent bacterial and viral infections. Melatonin secretion from the pineal gland also decreases in older adults, resulting in changes in sleep patterns that cause tiredness during the daylight hours and require short naps during the day in addition to regular nighttime sleeping.

These are careers that are available to individuals who are interested in the endocrine system.

- **Nuclear medicine technologists** are individuals who administer radioactive drugs, known as radiopharmaceuticals, such as radioactive iodine for the treatment of a hyperactive thyroid gland. These radioactive drugs are also used for diagnostic imaging.

- **Endocrinologists** are physicians whose specialty is the endocrine system and the treatment of endocrine problems.

- **Diabetes dieticians** are individuals trained as dieticians who specialize in nutritional therapy, counseling, and the planning of balanced meals for patients with diabetes mellitus.
Excess glucose is stored in the liver as glycogen and is made available to cells between meals by the combined actions of insulin and glucagon.

Hormones also affect digestive activities, such as increased appetites during puberty caused by higher rates of metabolism.

Respiratory System
- Low levels of oxygen in the blood stimulate hormonal production of red blood cell formation in bone marrow.
- Red blood cells transport oxygen from the lungs to body cells and carbon dioxide waste from cells to the lungs.
- Epinephrine increases breathing rates.

Urinary System
- Hormones control kidney function.
- Kidneys control body water levels and balances of the electrolytes in the blood.

Reproductive System
- The sex hormones stimulate the development of the reproductive structures.
- Sex hormones also stimulate the development of secondary male and female sexual characteristics.
- Sex hormones stimulate the development of egg cells and sperm cells.

SUMMARY OUTLINE

INTRODUCTION
1. The endocrine system maintains the internal environment of the body within certain narrow limits via chemical control through its hormones. This is known as homeostasis.
2. The hypothalamus of the brain sends chemical signals that control the pituitary gland, the master gland of the system.
3. The endocrine glands are ductless glands that secrete their hormones directly into the bloodstream, which carries them to target organs.

THE FUNCTIONS OF HORMONES
1. Hormones control cellular respiration, growth, and reproduction.
2. They control body fluids and electrolyte balances.
3. They control the secretion of other hormones.
4. They control behavior patterns.
5. They regulate reproductive cycles and our growth and development.

6. Through negative feedback mechanisms, hormone levels within our bodies are maintained within normal concentrations.

**THE CLASSIFICATION OF HORMONES**

1. Some hormones are modified amino acids: epinephrine, norepinephrine, oxytocin, and vasopressin (ADH).

2. Other hormones are proteins: insulin and growth hormone.

3. A third category are the steroid hormones: cortisol, estrogen, and testosterone.

4. The amino acid and protein hormones bind to membrane receptor sites in the cells of target organs. When prescribed, these must be injected.

5. The steroid hormones diffuse across cell membranes and then bind to intracellular receptor molecules. When prescribed, these can be taken orally.

**THE HYPOTHALAMUS OF THE BRAIN**

1. The hypothalamus of the brain controls the secretions of the pituitary gland, the master gland of the endocrine system.

2. Nerve cells in the hypothalamus produce chemical signals called releasing hormones that stimulate and releasing inhibitory hormones that inhibit the release of a particular hormone from the pituitary gland.

3. The hypothalamus of the nervous system controls the secretions of the endocrine system.

4. Through negative feedback mechanisms, the endocrine system can influence the functions of the hypothalamus.

**THE MAJOR ENDOCRINE GLANDS AND THEIR HORMONES**

1. The endocrine glands are the anterior and posterior lobes of the pituitary gland, the pineal gland, the thyroid, the parathyroids, the thymus, the adrenal glands, the pancreatic islets, the ovaries, and the testes.

   **The Anterior Pituitary Gland, Its Hormones, and Some Disorders**

   1. The pituitary gland is also called the hypophysis. It is divided into a larger anterior lobe and a smaller posterior lobe. It is the master gland of the system.

   2. The anterior pituitary lobe, made mainly of glandular epithelium, produces seven hormones.

   3. Growth hormone (GH) stimulates cell metabolism and the growth of bones and muscles. Too little in childhood produces pituitary dwarfism. Too much secretion in childhood produces a condition called gigantism. Too much secretion after childhood produces enlarged hands, feet, and facial features, a condition called acromegaly.

   4. Thyroid-stimulating hormone (TSH) stimulates the thyroid gland to secrete its hormones, T<sub>3</sub>, T<sub>4</sub>, and calcitonin.

   5. Adrenocorticoid hormone (ACTH) stimulates the adrenal cortex to secrete its hormone cortisol.

   6. Melanocyte-stimulating hormone (MSH) causes a darkening of the skin by stimulating melanocytes to produce melanin.

   7. Follicle-stimulating hormone (FSH) stimulates the development of follicles in the ovaries of females and the production of sperm cells in males.

   8. Luteinizing hormone (LH) stimulates ovulation and production of progesterone in females and the production of testosterone in males.

   9. Prolactin stimulates milk production in the mammary glands of females following childbirth.

   **The Posterior Pituitary Gland and Its Hormones**

   1. The posterior lobe consists mainly of nerve fibers and neuroglial cells. It produces two hormones: antidiuretic hormone and oxytocin.

   2. Antidiuretic hormone (ADH), also known as vasopressin, causes increased water reabsorption in the tubules of the kidneys, resulting in less water in the urine. A deficiency in ADH can result in a condition known as diabetes insipidus. If secreted in large amounts, it can cause constriction of blood vessels, hence its other name vasopressin.

   3. Oxytocin causes contraction of uterine smooth muscles during childbirth. It also causes constriction of mammary gland cells, resulting in milk ejection or lactation during breastfeeding.

   **The Thyroid Gland, Its Hormones, and Some Disorders**

   1. The thyroid gland consists of two lobes connected by an isthmus. It is found just below the larynx on either side of the trachea. It produces three hormones, T<sub>3</sub>, T<sub>4</sub>, and calcitonin.
2. The thyroid gland requires iodine to function properly. This is a component of iodized salt in the United States.

3. Without sufficient iodine, the thyroid gland enlarges, forming a goiter.

4. Two thyroid hormones are thyroxine or tetraiodothyronine (T₄) and triiodothyronine (T₃). They regulate the metabolism of carbohydrates, fats, and proteins for normal growth and development and nervous system maturation.

5. Hypothyroidism (a lack of thyroid hormone) in children causes cretinism, which results in small stature and mental retardation. In adults, it results in sluggishness, fatigue, and fluid accumulation in subcutaneous tissues.

6. Hyperthyroidism (too much thyroid hormone) causes nervousness, high body metabolism, and fatigue. Graves' disease, associated with an enlarged thyroid or goiter, also has the effect of bulging eyeballs called exophthalmia.

7. The extrafollicular cells of the thyroid secrete the third hormone, calcitonin. This lowers the calcium and phosphate ion concentration in the blood by inhibiting the release of these ions from bones and increasing their excretion by the kidneys.

The Parathyroid Glands, Their Hormone, and Some Disorders

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

2. Their secretory cells, called chief cells, secrete the hormone parathyroid hormone or parathormone (PTH).

3. PTH causes bone cells to release calcium and phosphate into the blood, causes the kidneys to conserve blood calcium, and causes the intestinal cells to absorb calcium from digested food.

4. Vitamin D also increases absorption of calcium by the intestines.

5. High levels of PTH or hyperparathyroidism cause breakdown of bone matrix, resulting in soft, deformed, and easily fractured bones. In addition, elevated calcium affects muscle and nerves, resulting in muscle weakness and fatigue. Excess calcium can cause kidney stones.

6. Low levels of PTH or hypoparathyroidism reduce osteoclast activity, resulting in reduced rates of bone breakdown and vitamin D formation. Bones remain strong but as the blood calcium level decreases, muscle and nerves become abnormally excitable, resulting in muscle cramps and tetanic contractions. This could result in respiratory failure.

The Adrenal Glands, Their Hormones, and Some Disorders

1. The adrenal glands, also known as the suprarenal glands, are found on top of each kidney.

2. Each gland is divided into an inner part called the adrenal medulla and an outer part called the adrenal cortex.

3. The adrenal medulla produces the hormone adrenaline, also called epinephrine, in large amounts, and noradrenaline or norepinephrine in small amounts in response to signals from the sympathetic division of the autonomic nervous system.

4. Epinephrine and norepinephrine are called the fight-or-flight hormones because they prepare the body for stressful situations.

5. They cause the release of glucose from the liver and fatty acids from fat cells as a source of energy. Heart rate and blood pressure increase. Blood flow to muscle cells increases and decreases to skin and internal organs. The lungs take in more oxygen.

6. The adrenal cortex is divided into three layers. The outer layer secretes the mineralocorticoid hormones, the most important of which is aldosterone, which regulates sodium reabsorption and potassium excretion by the kidney.

7. The middle layer of the adrenal cortex secretes cortisol, also known as hydrocortisone, a glucocorticoid hormone. It causes the liver to make glucose from circulating amino acids, causes protein to be broken down into amino acids, and causes fat cells to break down fat into fatty acids as sources of energy for body cells.

8. Cortisol also inhibits the inflammatory response. Cortisone, a steroid closely related to cortisol, is given to treat arthritis and to reduce inflammation.

9. The inner layer of the adrenal cortex produces androgens, the adrenal male sex hormones. Androgens stimulate male sex characteristics. In adult men, most androgens come from the testes. In adult women, they stimulate the female sex drive.

10. Addison's disease is caused by a lack of sufficient adrenal cortex hormones. Its symptoms include a bronzing of the skin, decreased blood sodium, low
blood glucose causing fatigue, dehydration, and low blood pressure.

11. Cushing’s syndrome is caused by too much secretion of the adrenal cortex. Its symptoms include high blood glucose levels and low tissue protein. Sodium retention causes tissue fluid increase, resulting in puffy skin. The patient is obese with a moon-shaped face.

The Pancreas, Its Hormones, and Some Disorders

1. The pancreatic islets or islets of Langerhans are the endocrine portion of the pancreas and produce two hormones, insulin and glucagon, which regulate blood glucose levels.

2. Beta cells of the pancreatic islets produce insulin after meals. Insulin causes excess blood glucose to be stored in the liver as animal starch or glycogen. Glucose is also moved to muscle cells and adipose tissue.

3. Alpha cells of the pancreatic islets produce glucagon between meals, when blood glucose levels are lower. Glucagon stimulates the liver to convert stored glycogen into glucose, to break down amino acids and convert them to glucose, and to break down fats in other tissues as another energy source.

4. Negative feedback mechanisms regulate the level of blood glucose concentrations.

5. A decline in blood glucose can cause nervous system malfunctions, because glucose is a main source of energy for nerve cells.

6. Low blood glucose levels cause the breakdown of fats releasing fatty acids and ketones in the blood, resulting in a lowering of blood pH, a condition called acidosis.

7. High levels of blood glucose cause the kidneys to produce large amounts of urine to dilute the excess glucose, resulting in dehydration.

8. Insufficient insulin production results in the disease diabetes mellitus.

The Testes and the Ovaries

1. The testes produce the principal male sex hormone testosterone.

2. Testosterone causes the development of the male reproductive structures and at puberty the enlargement of the testes and the penis.

3. Testosterone also causes the development of the secondary male sex characteristics like facial and chest hair, muscle development, low-pitched voice, broad shoulders, and narrow hips.

4. The ovaries produce the female sex hormones, estrogen and progesterone.

5. Estrogen and progesterone cause the development of the female reproductive organs. They also cause the development of the secondary female sexual characteristics like breast enlargement, high-pitched voice, broad hips, and fat deposits on the thighs, hips, and legs.

6. Female sex hormones also control the menstrual cycle.

The Thymus Gland and Its Hormone

1. The thymus gland produces the hormone thymosin, and the gland is crucial to the development of the immune system.

2. Thymosin causes the production of the T-lymphocyte white blood cells, which protect the body against foreign microbes.

The Pineal Gland and Its Hormone

1. The pineal gland is found in the brain near the thalamus and produces the hormone melatonin.

2. Melatonin inhibits the functions of the reproductive system and regulates body rhythms like wake and sleep patterns.


4. Low levels of melatonin in bright light make us feel good and increases fertility; high levels of melatonin in dim light causes us to feel tired and depressed.

5. The pineal gland also secretes serotonin, a neurotransmitter and vasoconstrictor.

REVIEW QUESTIONS

1. Explain how the hypothalamus of the brain controls the endocrine system.

2. Explain how a negative feedback system functions in maintaining hormonal levels in the body.

3. Name the three chemical categories for classifying hormones and give some examples.

4. Name the major endocrine glands and their hormones.

5. Name some effects that testosterone has on the male body.

Critical Thinking Questions
### MATCHING

Place the most appropriate number in the blank provided.

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<th>Thyroid</th>
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<td>Prolactin</td>
<td>2. Parathormone</td>
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<td>Adrenal medulla</td>
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<td>Anterior pituitary</td>
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<td>Adrenal cortex</td>
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### CASE STUDY

Sophia, a 58-year-old moderately obese woman, is seeing her primary health care provider. Sophia is concerned because she cut her foot two weeks ago and the wound is not healing. The health care provider notes that Sophia has lost 30 pounds since her last appointment. Despite her weight loss, she states that she has been very hungry lately, and is eating much more than usual. She also reports that she is constantly thirsty, and is experiencing frequent urination. Based on her symptoms and diagnostic studies performed by her health care provider, Sophia learns she has diabetes mellitus.

### Questions

1. What is the major characteristic of diabetes mellitus?
2. What type of diabetes mellitus do you think Sophia has?
3. What are the four classic symptoms of this disorder?
4. What measures will the health care provider take to control Sophia’s symptoms?
5. If Sophia eventually requires insulin, why must this medication be injected?
6. What complications can individuals with uncontrolled diabetes mellitus develop?
Take a practice quiz or play an one of the interactive games that reinforces the content in this chapter on your StudyWARE™ CD-ROM.

Go to your Study Guide for more practice questions, labeling and coloring exercises, and crossword puzzles to help you learn the content in this chapter.
LABORATORY EXERCISE:

THE ENDOCRINE SYSTEM

Materials needed: A dissecting kit, a fetal pig from a biologic supply company, and a dissecting pan

1. Place your fetal pig in a dissecting pan, ventral side up. Using your scalpel and pulling with your forceps, remove the skin from a square area from the middle of the lower jaw, where the ears attach, posteriorly to the chest near the sternum. Refer to Figure 12-9 cut number 2. Before you make your horizontal cut, feel for the larynx or voice box. Make your horizontal superior cut just above the larynx being careful not to cut too deeply. Then cut laterally on both sides, down to the thoracic region. As you make your horizontal posterior cut, the sternum

FIGURE 12-9. Fetal pig dissection guide. Perform cut number 2 to view the thymus and thyroid glands.

(continues)
THE ENDOCRINE SYSTEM (Continued)

will prevent your scalpel from damaging any tissues. Now remove the skin and muscle layer attached to the skin by gently pulling with your forceps and scraping with your scalpel.

2. When the skin is removed you will see exposed muscles and glands. Notice the large lengthwise muscles of the neck region. These can be removed to expose the thymus gland. Refer to Figure 12-10 of a fetal pig dissection for a view of this region. The thymus gland appears spongelike as opposed to the thick cords of muscle tissue.

3. In the pig, the thymus gland is two large lobes located just below the cartilaginous larynx or voice box. Now push the two lobes apart with a probe or forceps to expose the smaller, dark brown thyroid gland found on top of the trachea. While here, note the trachea with its cartilaginous rings.

4. Once you have found these glands of the endocrine system, return your fetal pig to its storage area. We will use it again in future dissections.

5. Your instructor may now show you a videotape or DVD on the endocrine system. There are a number to choose from. An excellent videotape is “Homeostasis: The Body in Balance” by Human Relations Media, 175 Tompkins Ave., Pleasantville, N.Y. 10570.