CHAPTER 13

The Endocrine System

Reflecting Questions

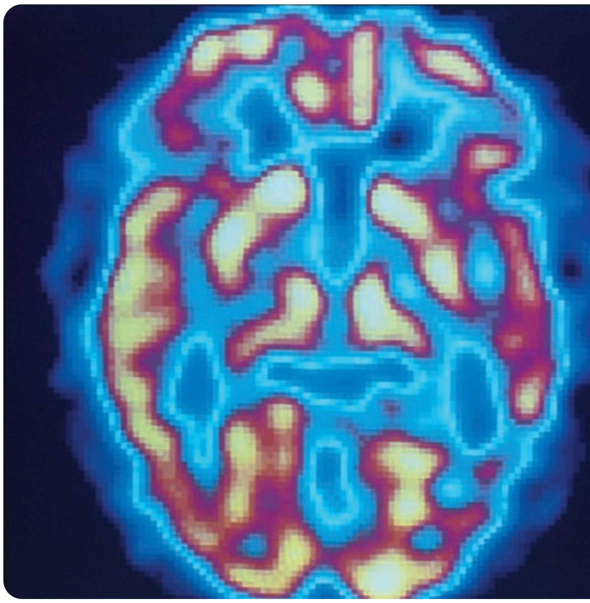
- How does the nervous system interact with and regulate endocrine activity?
- How do endocrine hormones maintain homeostasis in the body?
- What are some of the major treatable diseases of the human endocrine system?

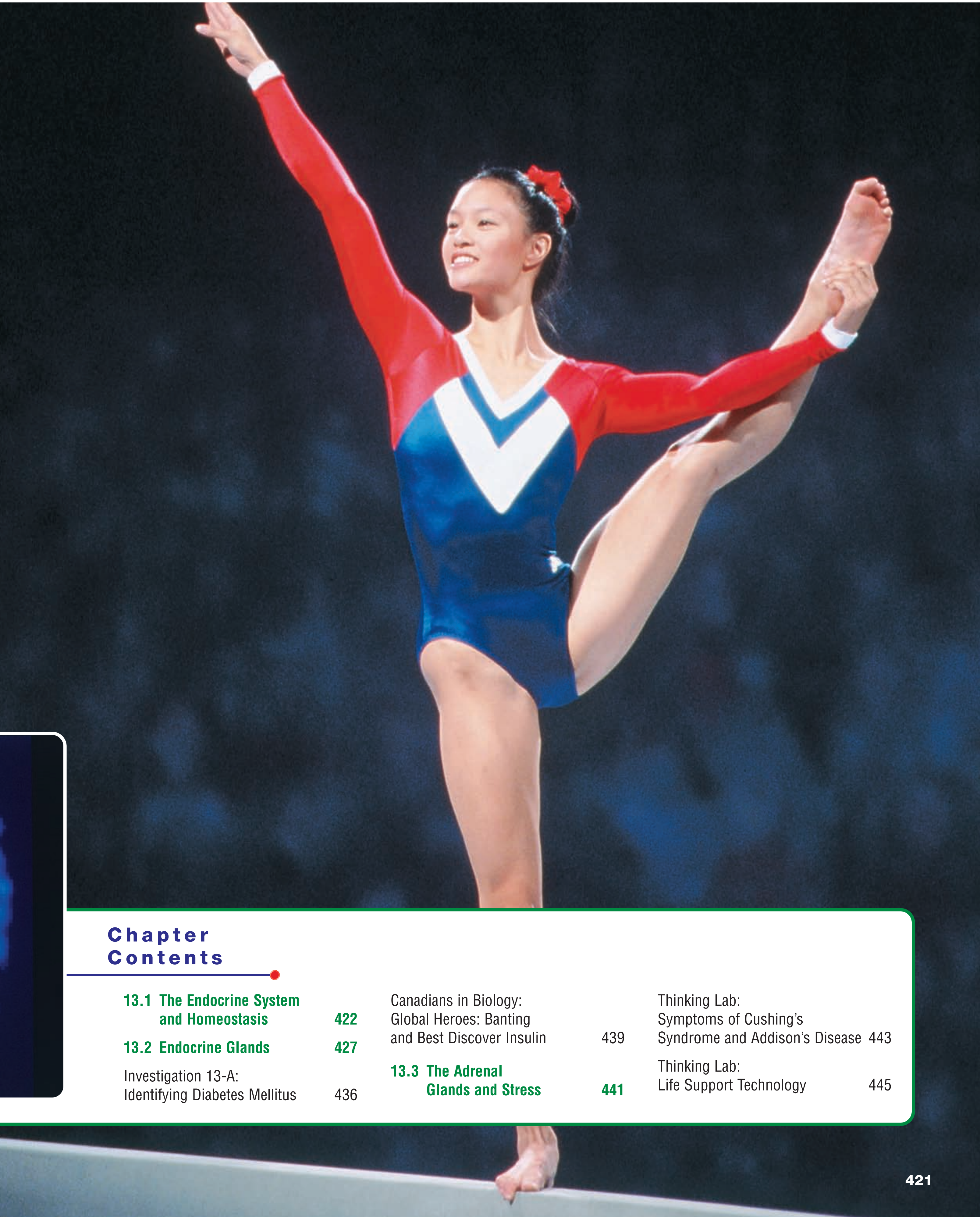
When a gymnastic performer entertains us with a display of prolonged, intense physical activity, the performer's body is being pushed to the limits of its capabilities. During the performance, homeostatic mechanisms work to maintain the body's internal environment within tolerance limits — the narrow range of conditions within which cellular processes are able to function at a normal level.

The endocrine system works in parallel with the nervous system to maintain homeostasis. It does so by releasing chemical substances — hormones – which in turn trigger actions in specific target cells. For example, vigorous exercise triggers endocrine glands in the brain and elsewhere to release several different hormones. These hormones regulate oxygen consumption, basal metabolic rate, and the metabolizing of carbohydrates and fat for energy. As a result, the rate and depth of breathing increase, as do heart rate and muscle contraction. In addition, energy stores are quickly mobilized. These changes ensure that fuel is readily available for an increase in skeletal muscle, heart, and brain activity, while at the same time maintaining normal physiological processes.

In this chapter, you will learn about the components of the endocrine system. You will examine how the nervous system and the endocrine system interact to regulate physiology, and how these systems affect each other's functions. You will also explore how, in addition to maintaining homeostasis, the endocrine system regulates a wide range of other biological processes. These processes include the control of blood sugar, metabolism, growth, reproductive development and function, and other physiological activities. You will discover how the body responds to stress, and how abnormal endocrine function can result in disease. Finally, you will see how some major endocrine disorders can be treated.

Endocrine glands within the brain secrete hormones to influence metabolism in other target glands. This positron emission tomography (PET) scan relies on a radioactive tracer, injected into the bloodstream, to reveal the brain's metabolic activity.





Chapter Contents

13.1 The Endocrine System and Homeostasis

OUTCOMES

- **Describe the anatomy and physiology of the endocrine system and explain its role in homeostasis.**
- **Identify and describe the structure and function of protein and steriod hormones.**

In Chapter 12, you studied the role of the human nervous system in maintaining homeostasis. This chapter focuses on the **endocrine system**, which comprises the hormone-producing glands and tissues of the body. As mentioned previously, **hormones** are chemical substances that circulate through the blood and exert some measure of control over virtually every organ and tissue in the body.

It is important to understand that hormones do not seek out particular organs, but rather organs await the arrival of the hormone. Cells that react to a particular hormone have specific receptors for that particular hormone. The receptors combine with the hormone in a lock-and-key fashion. An organ that contains receptors for a particular hormone is called a **target organ**.

In conjunction with the nervous system, the endocrine system acts as a complex internal communication network that continuously monitors and responds to the body's ever-changing internal environment. This system regulates critical physiological processes and plays a key role in homeostasis. Some of the regulatory functions of the endocrine system include the control of heart rate, blood pressure, immune response to infection, reproduction, emotional state, and the overall growth and development of the body. Hormone production and secretion fluctuate in response to nervous system activity, stimulation by other hormones, and changing concentrations of salt, glucose, and other essential constituents in the blood.

Abnormal endocrine function can seriously disrupt the body's normal metabolic functions. However, as you will see in this chapter, endrocrinology — the scientific study of the endocrine system — is a very active field of medical research. This field continually yields new and exciting discoveries about the unique functions of endocrine glands and the hormones they produce. New and effective medications and procedures are constantly being developed for many endocrine disorders.

Components of the Endocrine System

As Figure 13.1 illustrates, the endocrine system is composed of a number of glands and tissues. This system consists of the pituitary, thyroid, parathyroid, adrenal, thymus, and pineal glands, as well as the pancreas and reproductive tissues

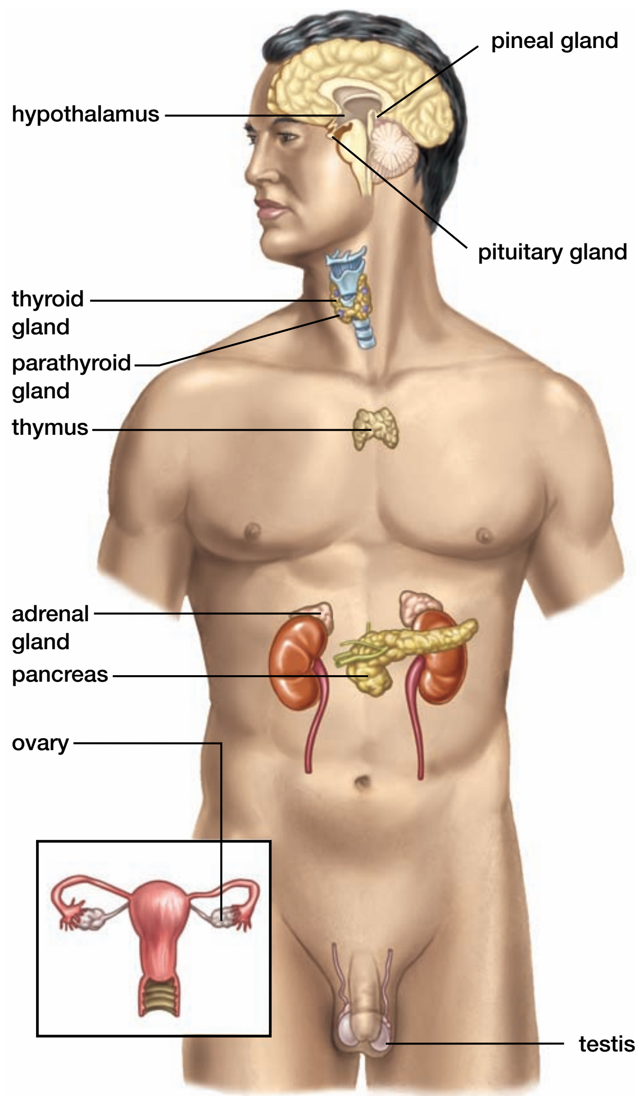


Figure 13.1 Anatomical location of major endocrine glands in the body

(ovaries and testes). Many other organs, such as the liver, skin, kidney, and parts of the digestive and circulatory systems, produce hormones in addition to their other physiological functions.

Endocrine glands are ductless glands that secrete hormones directly into the bloodstream, whereas **exocrine glands** release their secretions through ducts or tubes (as shown in Figure 13.2). Examples of exocrine glands are sweat glands, salivary glands, and tear (lacrimal) glands.

Hormones produced by the endocrine glands influence the activity of every organ and tissue in the body. The term "hormone" was introduced in 1908 by British physiologist Ernest Henry Starling. He identified hormones as "chemical messengers," substances that carry instructions or signals to one or more distant organs or tissues in the body. These signals instigate some type of specialized biochemical process in the target organ. For example, the pancreas produces hormones that can stimulate the liver to convert sugar to glycogen, or glycogen to sugar, depending on the body's immediate needs.

Very small quantities of each type of hormone are produced and secreted into the blood. The concentration of a hormone substance in blood may be no more than 10^{-12} mol/L (which can be compared to a drop of oil in a swimming pool full of water). However, the potency (or impact) of hormones is magnified many times by their ability to affect key metabolic processes in the target cells.

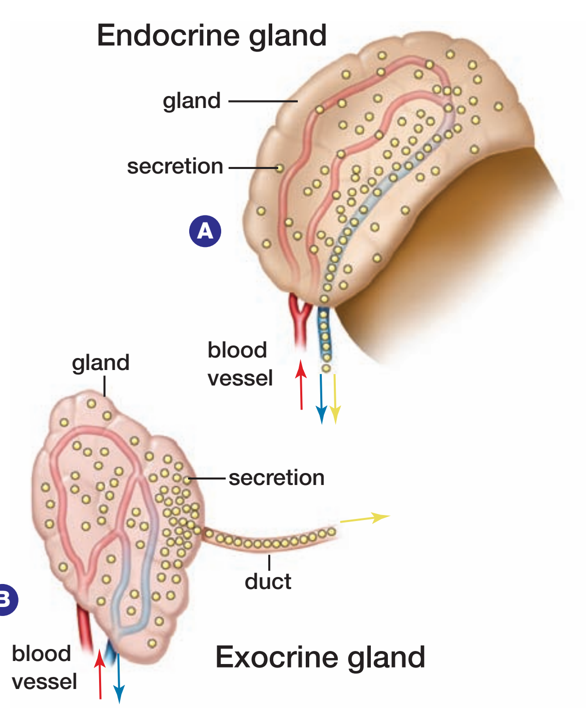


Figure 13.2 (A) Endocrine glands do not have ducts; they produce and secrete hormones directly into the bloodstream. (B) Exocrine glands have ducts and secrete sweat, milk, digestive enzymes, and other materials.

The adrenal gland has been the focus of many experimental breakthroughs in the field of endocrinology. One of the founders of endocrinology, a British country doctor named George Oliver, was among the first to demonstrate the physiological action of an extract of endocrine tissue. In 1894, he discovered that a preparation of tissue from the adrenal gland could raise blood pressure in test subjects.

In 1897, American scientist John Jacob Abel discovered adrenaline, the first hormone molecule to be isolated from an endocrine gland extract. Following Abel's discovery, Jokichi Takamine, a Japanese-born chemist working in the United States, independently isolated the same hormone molecule, which he named "adrenaline." With Takamine's assistance, a U.S. pharmaceutical company soon began to mass-produce and sell adrenaline as a treatment for a number of ailments. At the time, the company was unaware that their product was actually a mixture of two hormones, adrenaline and noradrenaline. Both hormones are produced by the adrenal gland.

Hormones such as adrenaline secreted by the adrenal gland come into contact with virtually all cells and tissues as they circulate throughout the body. However, they trigger a response only in cells (such as liver cells) that have specific receptor sites for the hormone. The combining of a hormone, such as adrenaline, with a specific receptor on the outer membrane of a liver cell sets off a cascade of chemical reactions, such as the conversion of glycogen to sugar.

Factors in Hormone Production and Function

In general, hormone production increases or decreases in response to changing metabolic needs of the body, such as fluid balance, and other factors such as infection, physical injury, and emotional stress. Hormone levels are also regulated by the activity of the nervous system and other endocrine glands. Hormone-secreting cells contain receptor molecules that are sensitive to regulatory hormones from other sources in the body. For example, thyroid-stimulating hormone molecules produced by the pituitary gland bind to receptors on cells of the thyroid gland. This action stimulates synthesis of a hormone called thyroxine, which you will study in greater detail later in this chapter.

The impact of a specific hormone on the activity of target tissues is a function of the rate of hormone production and secretion, hormone concentration in the blood, the rate of blood flow to a target organ or tissue, and the half-life of the hormone. The half-life refers to the length of time a hormone remains viable in the blood before it is degraded by the liver or other tissues. Half-life may range from several hours to several days.

Normal endocrine function can be disrupted by various medical problems such as tumours, infection, autoimmune diseases, and physical injury. Genetic disorders, industrial pollutants, and certain food additives have also been linked to abnormal endocrine function. Symptoms can range from mild discomfort to chronic, but manageable conditions, to more severe, potentially life-threatening complications.

The medical treatments for endocrine disorders include hormone replacement therapy, other medications that moderate endocrine activity, and changes in diet and other forms of behavioral modification. If required, treatment might involve more aggressive procedures such as surgery to remove the affected endocrine tissues or organs. Throughout this chapter, discussions of each type of endocrine gland will be followed by an overview of related hormonal disorders.

Types of Hormones

Hormones produced by the endocrine system also interact with each other. In addition to the regulation of endocrine activity through the action of negative feedback loops (as shown in Figure 13.3), hormone levels can also be controlled by the interaction of hormones that have opposing physiological properties. Such contrary hormonal substances are referred to as **antagonistic hormones**.

The endocrine system produces two main types of hormone product: steroid and non-steroid hormones. These hormone types can be differentiated by their chemical composition and their mode of action in target cells and tissues.

Steroid hormones, such as cortisol, are manufactured from cholesterol. Each type of steroid hormone is composed of a central structure of four carbon rings attached to distinctive side chains that determine the hormone's specific and unique properties (as shown in Figure 13.4).

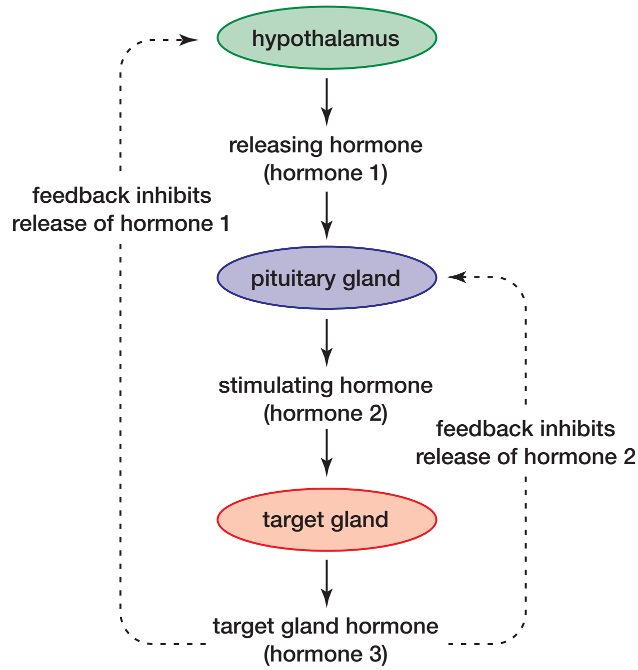


Figure 13.3 Hormones regulate endocrine activity by means of negative feedback loops.

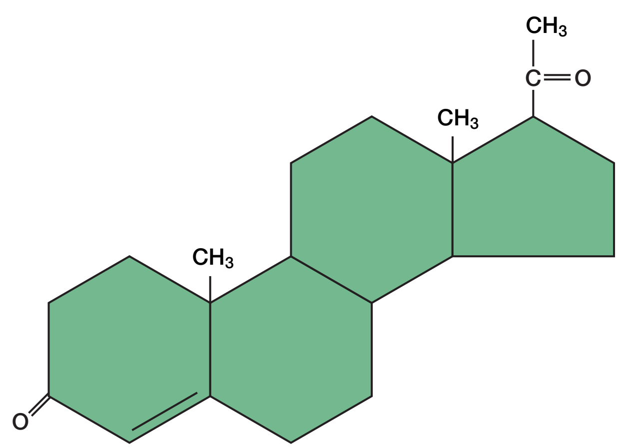


Figure 13.4 The structural formula of the steroid hormone progesterone.

Within the endocrine cells, steroid hormones are synthesized in the smooth ER. Most steroid hormones are secreted quickly into the blood by the endocrine organs that produce them. Since steroid hormones are hydrophobic, they combine with a protein carrier that transports them through the bloodstream.

Fat-soluble steroid hormones can pass through the membrane of a target cell. Once inside the target cell, steroid hormones attach to a protein receptor molecule in the cytoplasm.

This hormone-receptor complex then enters the nucleus, where it binds with and activates a specific gene on the cell's DNA molecule. The activated gene then produces an enzyme that initiates the desired chemical reaction within the cell. This process is illustrated in Figure 13.5.

Non-steroid hormones, such as adrenaline, are composed of either proteins, peptides, or amino acids. These hormone molecules are not fat-soluble, so they usually do not enter cells to exert their effect. Instead, they bind to receptors on the surface of target cells. This combination substance then triggers a specific chain of chemical reactions within the cell. The structure of a non-steroid hormone is illustrated in Figure 13.6.

In 1971, Edward W. Sutherland, Jr., received the Nobel Prize for his discovery of the biochemical mechanism by which adrenaline, and other hormones, influence target cell activity. Normally, adrenaline stimulates the conversion of stored glycogen to glucose in the liver. The liver then releases the glucose into the bloodstream.

Sutherland and his team of researchers investigated the mechanism by which adrenaline regulated glucose synthesis in liver tissue. Their procedure involved breaking open liver cells and separating the cell membranes from the rest of the cellular material. They observed that adrenaline had no effect on glucose production in liver cells when cell membranes were removed from the inner cell contents. However, when adrenaline was added to isolated cell membranes, they found that adrenaline molecules bound to receptor molecules located on the surface of the membranes (as shown in Figure 13.5). This hormone-receptor combination triggered the synthesis of yet another molecule, called a "second chemical messenger." Sutherland's team identified this substance as cyclic AMP (cAMP). In this process, the hormone was referred to as the "first messenger."

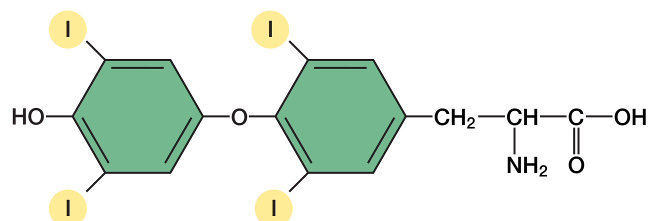


Figure 13.6 The structural formula of the non-steroid hormone thyroxine.

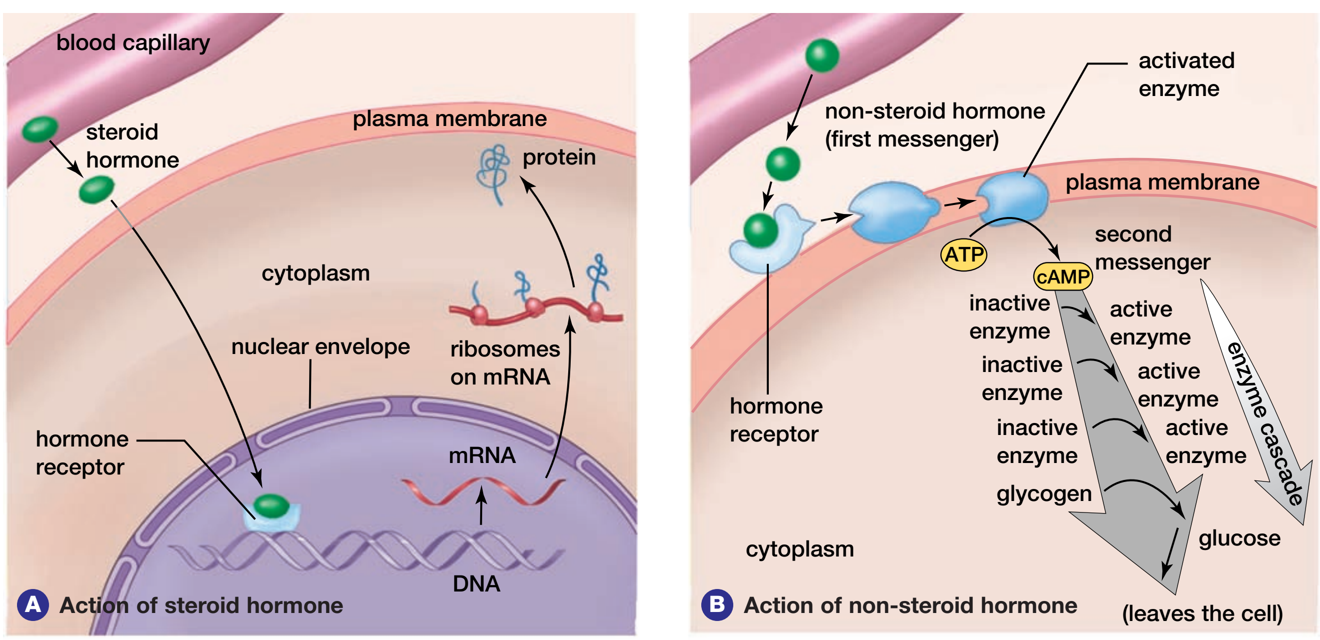


Figure 13.5 (A) After passing through the plasma membrane and nuclear envelope, a steroid hormone binds to a receptor protein inside the nucleus. The hormone-receptor complex then binds to DNA, and this leads to activation of certain genes and protein synthesis. (B) Non-steroid hormones, called first messengers, bind to a specific receptor protein in the plasma membrane. A protein relay ends when an enzyme converts ATP to cAMP (the second messenger), which activates an enzyme cascade.

Researchers discovered that the binding of the adrenaline to the receptor activated the enzyme portion of the receptor molecule. The activated enzyme then catalyzed the production of cyclic AMP from ATP inside the cell. This second messenger triggered a series of reactions that influenced the synthesis and reactivity of intracellular enzymatic proteins involved in the conversion of glycogen to glucose. This chain reaction acts as a kind of "biological amplifying system," in which relatively small amounts of hormone can substantially affect the biochemistry of target cells in the liver, heart, and other organs of the body.

Other hormones that exert their effect on cells through cyclic AMP-activating mechanisms include adrenocorticotropic hormone (ACTH), glucagon, luteinizing hormone (LH), follicle-stimulating hormone (FSH), and anti-diuretic hormone (ADH).

Sutherland and other researchers later discovered that similar biochemical pathways involving the formation of cyclic AMP were at work in many different types of cells in the body. Researchers also found that other cells used calcium, or an enzyme within the cell, as the second messenger.

The stimulating properties of caffeine for example, are the result of the way in which caffeine inhibits the breakdown of cyclic AMP in cells. This causes cyclic AMP to accumulate in the cell cytoplasm, which extends its amplifying effect on cell processes, such as the contraction of heart muscles. In this way, caffeine mimics the stimulating properties of hormones such as adrenaline. Due to its properties as a stimulant, caffeine is listed as a banned substance in the Olympic Movement Anti-Doping Code.

It is interesting to note that caffeine also acts as a diuretic, increasing urine production. This can result in increased calcium excretion, a contributing factor for osteoporosis. The physiological basis of caffeine's diuretic properties has yet to be determined. The regulation of calcium levels by the endocrine system and the symptoms of osteoporosis will be discussed in greater detail later in this chapter.

Another stimulant, nicotine, has a substantial impact on endocrine function. Nicotine stimulates the production of adrenaline, ACTH, cortisol, and ADH. In male smokers, nicotine also increases estrogen secretion.

SECTION REVIEW

1. Describe how hormones secreted by glands of the endocrine system regulate metabolic rate.
2. **(a)** How is an exocrine gland different from an endocrine gland?
   (b) Identify two organs in the body that act as both endocrine and exocrine glands.
3. In a chart, list the hormones produced in the human body. Divide the list into two sections: steroid and non-steroid hormones. Describe the substances used by the body to manufacture non-steroid hormones.
4. Compare the way steroid and non-steroid hormones affect cellular activity.
5. Explain why adequate lipid intake is essential for the normal function of some endocrine glands and hormones.
6. Identify the endocrine glands and hormones responsible for regulating blood pressure in the circulatory system.
7. Caffeine is not a controlled substance, and yet it can affect the body in many ways.
   (a) Review the various ways caffeine can affect the body.
   (b) Identify an endocrine system that may be affected by caffeine. Prepare a prediction.
   (c) Propose a research program to investigate your prediction.
8. Using the list below, make a chart with at least three pairs of antagonistic hormones. Describe the nature of their antagonistic functions.
   (a) insulin
   (b) thyroxine
   (c) calcitonin
   (d) glucagon
   (e) testosterone
   (f) aldosterone
   (g) PTH
   (h) cortisol
   (i) estrogen
9. Competitive events such as the Olympics test athletes for banned substances such as anabolic steroids. Some professional athletes, like Major League Baseball players, are not restricted by these rules. How does the use of these substances change the nature of the sporting event? Should these substances be banned? Explain your responses.

13.2 Endocrine Glands

OUTCOMES

- **Describe and explain homeostatic processes involved in maintaining equilibrium in response to both a changing environment and medical treatments (for example, describe the effect of disorders of the endocrine system).**
- **Identify the source and general effect of different hormones on the human organism.**

You should now be able to compare some of the essential features of the nervous system and the endocrine system. You have seen that the nervous system produces bioelectrical signals that travel along specialized nerve cells, while the endocrine system releases hormones into the bloodstream that circulates throughout the body. The nervous system elicits a rapid but short-lived response, illustrated by the body's reflex actions. Endocrine hormones produce a slower, but more sustained and enduring response in their target tissues.

The hypothalamus, a part of the brain connected to the pituitary gland, continuously monitors the state of the body's internal environment and regulates pituitary gland activity. Together, the hypothalamus and the pituitary gland control many critical physiological processes. These processes include metabolic rate, kidney function, appetite, mental alertness, reproduction, and growth and development. The hypothalamus and the pituitary gland secrete hormones that influence the activity of other hormone-producing glands. The constant interaction between the hypothalamus and the pituitary gland is a key factor in maintaining homeostasis.

An In-depth Look at the Pituitary Gland

Figure 13.7 shows how the pituitary gland is connected to the hypothalamus of the brain. A short but complex network of blood vessels, called a portal system, extends from the hypothalamus to the pituitary gland. This is the critical link by which the nervous system exerts its control over hormone production in the pituitary gland and other endocrine glands.

As noted above, the pituitary gland produces hormones that regulate the hormone production of many other endocrine glands in the body. Such substances are referred to as tropic hormones. For example, the thyroid-stimulating hormone (TSH) is a tropic hormone produced by the pituitary gland that stimulates — as its name implies — the thyroid gland to produce and secrete thyroid hormone. TSH regulates thyroid secretion through a negative feedback system.

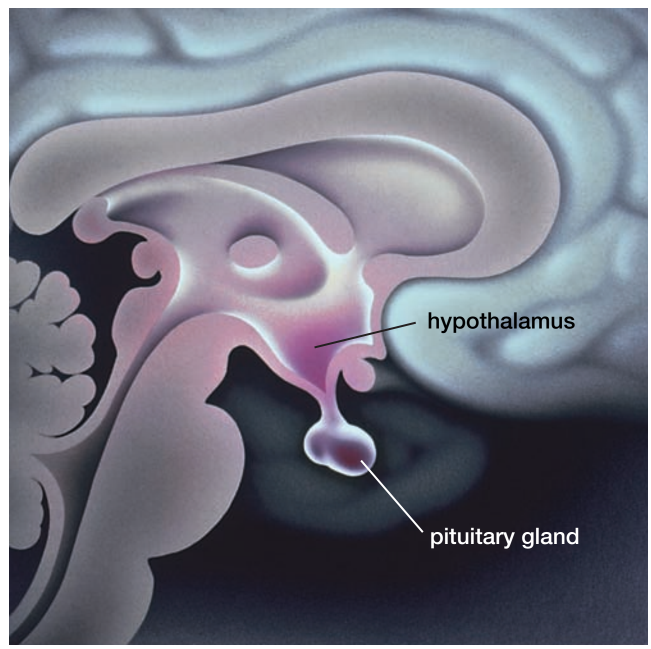


Figure 13.7 The pituitary gland regulates the hormone production of many of the body's endocrine glands.

The pituitary gland is typically referred to as the "master gland" of the endocrine system. This designation reflects the role of the pituitary gland in regulating the activity of the other hormone-producing glands of the endocrine system. The pituitary gland is actually composed of two glands – the anterior and posterior pituitary, as shown in Figure 13.8. As the human embryo develops, the anterior pituitary is formed from cells from the roof of the mouth that migrate toward the brain. The posterior pituitary is composed of neural tissue. The differing embryonic origins of the anterior and posterior lobes are reflected in their dissimilar functions.

The Anterior Pituitary

The anterior lobe of the pituitary gland produces six types of endocrine hormones, human growth hormone, and four tropic hormones.

Human growth hormone The anterior pituitary regulates growth and development of the body through the production and secretion of a non-steroid hormone called human growth hormone (HGH). Human growth hormone (sometimes referred to as somatotropin) is a small protein molecule. HGH spurs body growth by increasing intestinal absorption of calcium, increasing cell division and development (especially in bone and cartilage), and stimulating protein synthesis and lipid metabolism.

HGH has a half-life of about 20 hours after secretion, after which it is no longer chemically active. HGH, acting as a tropic hormone, triggers

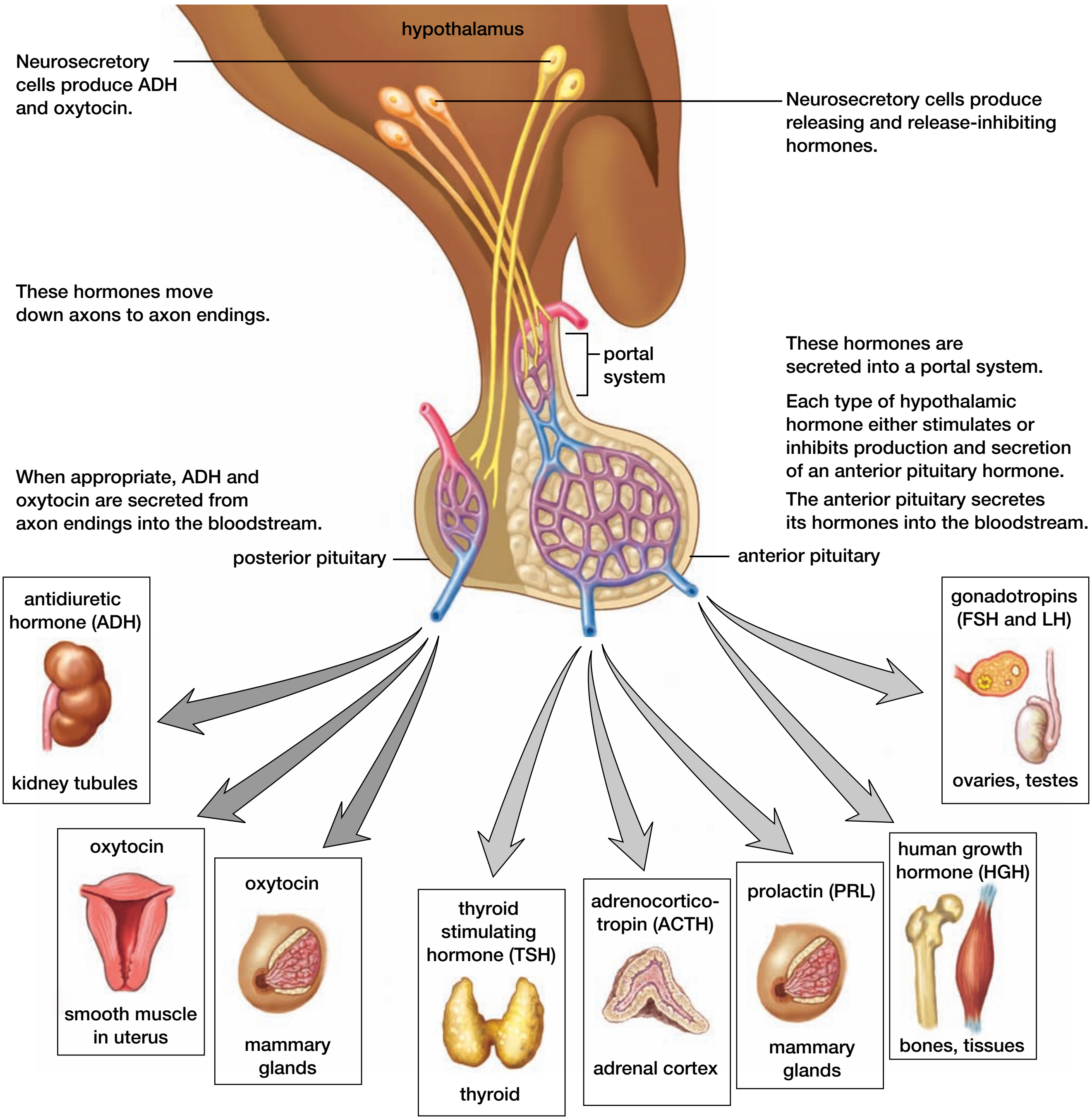


Figure 13.8 The hypothalamus produces two hormones, ADH and oxytocin, which are stored and secreted by the posterior pituitary. The hypothalamus controls the secretions of the anterior pituitary, and the anterior pituitary controls the secretions of the thyroid, adrenal cortex, and gonads (which are also endocrine glands).

the production of **growth factors** in the liver and other tissues. These growth factors (composed of protein molecules) prolong the effects of HGH on bone and cartilage tissues.

Levels of HGH tend to decrease with age. The resulting decline in protein synthesis may be responsible for some of the characteristic signs of aging, such as diminished muscle mass and wrinkles.

Insufficient HGH production during childhood results in a condition called **pituitary dwarfism**. This disorder results in abnormally short stature. But, unlike genetic dwarfism, body proportions (the length of arms and legs and the size of the head) are normal. Puberty may be delayed or not occur at all. Pituitary dwarfism may be the result of a pituitary tumour or the total absence of a pituitary gland. Measurement of growth hormone levels in the blood is used to confirm the diagnosis of pituitary dwarfism (see Figure 13.9).

Figure 13.9 The amount of human growth hormone produced during childhood affects the height of an individual. The symptoms of both inadequate and excessive growth hormone are readily treated today.

In the past, treatment of pituitary dwarfism required the extraction of growth hormone from the pituitary glands of human cadavers. However, this source yielded insufficient quantities of the hormone. In addition, growth hormones from animal sources were not suitable for human use. However, current biotechnology techniques now provide a much more reliable supply of this hormone. These procedures involve inserting sections of DNA that code for HGH into certain strains of bacteria. The altered, rapidly reproducing bacteria are thus transformed into biochemical factories that produce HGH as a "waste product."

An excess of HGH production prior to puberty causes a disorder known as **gigantism** (as illustrated in Figure 13.9). The symptoms of gigantism are primarily the result of abnormal growth of long bones in the skeleton. The disorder is easily treated by the microsurgical removal of a tumour from the pituitary gland, irradiation of gland tissue, or both. Excess HGH production during adult years produces **acromegaly**, symptoms of which include excessive thickening of bone tissue. This thickening causes abnormal growth of the head, hands, and feet as shown in Figure 13.10, as well as spinal deformities. Treatment of patients diagnosed with acromegaly involves surgical removal of the tumour, radiation therapy, injection of a growth hormone blocking drug, or a combination of these treatments. The development of a tumour within the pituitary gland is the most common cause of both gigantism and acromegaly.

HGH shares many structural and functional similarities with prolactin, the next pituitary hormone to be described in this section.

Prolactin This substance is a non-steroid hormone produced by the anterior pituitary and, in smaller quantities, by the immune system, the brain, and the pregnant uterus. Prolactin stimulates the development of mammary gland tissue and milk production (lactogenesis).

The hypothalamic regulation of prolactin production is somewhat unusual. The hypothalamus secretes the neurotransmitter dopamine, which inhibits rather than stimulates the production and secretion of prolactin by the pituitary. Severing the connection between the hypothalamus and the pituitary gland results in an increase in prolactin production. After birth, however, the stimulation of nerve endings in the nipples during infant feeding will trigger the release of prolactin-secreting hormones by the hypothalamus. This spinal reflex

Age 16 Age 33 Age 52

Figure 13.10 Acromegaly is caused by overproduction of HGH in the adult. It is characterized by an enlargement of the bones in the face, fingers, and toes of an adult. Today, various therapies are used to treat this disorder.

(known as a neuroendocrine reflex) stimulates the production of prolactin. Increasing estrogen levels also stimulate prolactin production in late pregnancy to prepare the mammary glands for lactation after the birth of a baby. Increased prolactin levels in pregnancy also inhibit ovulation by suppressing the production of LH. Figure 13.11 illustrates one common application of increasing prolactin levels, in milk-producing cows.

Figure 13.11 This milking machine stimulates prolactin release so milk production continues after the calf has been weaned.

BIO FACT

The neuroendocrine reflex is necessary for the production of milk in dairy cattle. A cow gives birth and produces milk for the calf. Milk production is maintained after the calf has been weaned by the use of milking machines that trigger an artificial sucking response to stimulate prolactin release.

The Posterior Pituitary

The posterior pituitary gland is composed of secretory nerve cells that originate in the hypothalamus. Two hormones, oxytocin and the anti-diuretic hormone (ADH), are produced by secretory nerve cells in the hypothalamus. These hormones migrate down their axons to the tissues of the posterior pituitary gland, where they are stored and then later released. When neurosecretory cells receive signals from other nerve cells, they are stimulated to release hormones rather than triggering a new nerve impulse.

Anti-diuretic hormone (ADH) This hormone is produced by the hypothalamus and released from the posterior pituitary gland. ADH regulates sodium levels in the bloodstream. Specialized cells in the hypothalamus, called osmoreceptor cells, monitor the concentration of sodium ions in blood. An increase in sodium levels triggers the secretion of ADH.

The pituitary also secretes ADH in response to decreased blood pressure resulting from loss of blood from torn or damaged blood vessels. ADH stimulates severed arteries to constrict (vasoconstriction), reducing blood loss and increasing blood pressure. These mechanisms help maintain adequate blood supply to the organs and tissues, reducing potential cell damage.

The secretion of ADH can be inhibited by many factors. These factors include head trauma (injury) that damages pituitary or hypothalamus tissue, the development of pituitary tumours (that destroy pituitary secretory cells), and inflammation due to infection or an autoimmune response.

Insufficient production of ADH can cause diabetes insipidus. Symptoms of this endocrine disorder include increased thirst and dehydration, production of abnormally high volumes of very dilute urine, and an enlarged urinary bladder. This loss of fluids and essential ions can cause a serious imbalance in concentration of body fluids and disrupt normal physiological processes. However, diabetes insipidus can be successfully treated with administration of the missing hormone (ADH). ADH also plays a critical role in the body's response to extreme blood loss. When this happens, massive quantities of ADH are released.

Conversely, abnormally high ADH levels prompt the kidneys to retain water and produce more concentrated urine. This increases blood volume and decreases sodium concentration in the blood. The loss of sodium can cause nerve fibres and muscle tissue to become "twitchy." This type of abnormal hormone production can be the product of a pituitary tumour or a depression of inhibitory signals from the hypothalamus.

Oxytocin In women, the hormone oxytocin plays an important role during and after childbirth triggering muscle contractions during childbirth and the release of milk from the breasts. Towards the end of pregnancy, the baby's head pushes against the opening of the uterus. Pressure receptors in the uterine wall send impulses to the hypothalamus. This triggers the release of oxytocin from the posterior pituitary.

Oxytocin stimulates the uterine muscles to contract more forcefully. Each contraction increases the stimulus on the pressure receptors and the release of more oxytocin. This positive feedback loop ends with the birth of the baby. The action of an infant feeding from the mother's breast initiates the "suckling" reflex. This reflex triggers oxytocin secretion. Oxytocin stimulates contractions in the smooth muscles of the mammary ducts, which causes the expulsion of milk from the mammary glands.

Some studies suggest that oxytocin secretion acts as an "affiliation hormone" by eliciting pleasurable emotions during intimate contact. For example, the release of oxytocin during infant feeding may stimulate maternal feelings and strengthen a mother's bonding with her newborn baby (as depicted in Figure 13.12). Oxytocin may also arouse feelings of strong affection that contribute to the creation of adult pair bonds. In the reproductive process, oxytocin may be a factor in male erection and female orgasm.

Figure 13.12 The release of the hormone oxytocin during infant feeding strengthens maternal bonding with a newborn.

You will now examine the other major endocrine structures in the body. These include the thyroid, parathyroid, pancreas, pineal, thymus, and adrenal glands.

The Thyroid and Parathyroid

The activity of the **thyroid gland** illustrates the role of negative feedback loops in controlling metabolism and maintaining homeostasis in the body. This gland, with its distinctive "butterfly" shape, is located above the trachea in the neck. Embedded in the thyroid glands are four small parathyroid glands. They produce a hormone called parathyroid hormone (PTH). The function of these small glands will be discussed in more detail later in this section.

The primary function of the thyroid gland is the production of the hormone thyroxine, a non-steroid peptide molecule made from the amino acid tyrosine. Each thyroxine molecule contains four atoms of iodine. Receptors for thyroxine are found on most cells in the body.

Thyroxine increases basal metabolic rate and oxygen consumption, especially in the heart, skeletal muscle, liver, and kidney. In comparison, metabolic activity of the brain, spleen, and reproductive organs is less affected by thyroxine. The increased oxygen demand is due to the stimulation of sodium potassium pump activity in the cell membranes of target cells. The additional oxygen is consumed in the production of ATP that is required to drive the sodium potassium pump. Heat is given off as a byproduct of this process.

Thyroxine secretion is governed by the anterior lobe of the pituitary gland, which produces thyroid-stimulating hormone (TSH). As you can see in Figure 13.13, the interaction between thyroxin and TSH takes the form of a negative feedback loop. The two hormones, thyroxine and TSH, interact to adjust the levels of thyroxine in response to the body's constantly changing needs. Caffeine in some beverages we consume reduces glucose metabolism in the cells of the body by inhibiting TSH production, which in turn suppresses thyroxine secretion.

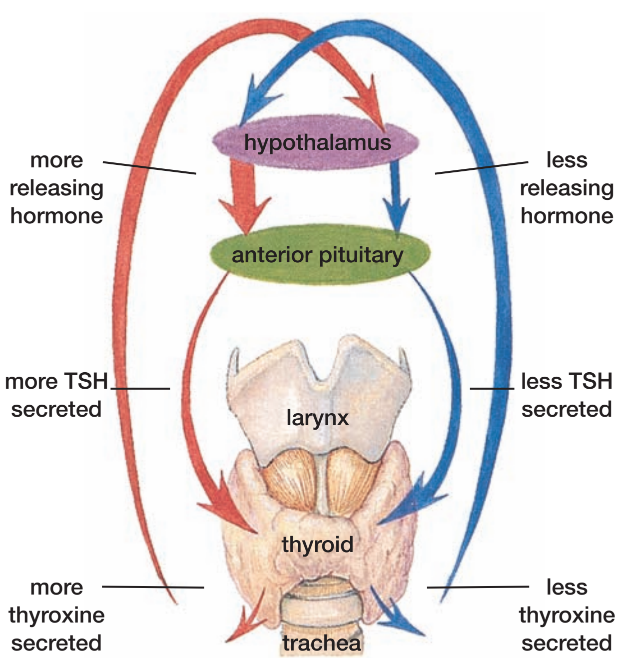


Figure 13.13 This diagram shows how negative feedback by hormones keeps the amount of thyroxine at a level suitable to the body's needs.

Thyroid hormones are carried through the blood by carrier proteins, as are steroid hormones. Thyroid hormones (circulating in the blood) then feed back to the pituitary gland, where they suppress the secretion of TSH. In the thyroid gland, TSH stimulates an increase in iodine uptake from the blood, and the synthesis and secretion of thyroxine hormone. About 30 percent of the iodine in blood is consumed by the thyroid gland to be used in the synthesis of thyroxine. The rest is eventually excreted from the body.

Hyperthyroidism and Hypothyroidism

Various medical complications can arise from the production of abnormally high (hyper) or low (hypo) levels of thyroxine.

Hyperthyroidism An excess of thyroxine production is referred to as hyperthyroidism, also known as Grave's disease. **Grave's disease** is an autoimmune disorder in which antibodies attach to TSH receptors on thyroid cells. This attachment puts receptors in a "perpetually on" mode that stimulates cell division and production of thyroid hormone. The excessive hormone production causes enlargement of the thyroid, muscle weakness, increased metabolic rate, excessive heat production, and sweating and warm skin due to dilation of blood vessels in the skin (vasodilation). Patients also experience increased appetite despite continued weight loss. Grave's disease also causes the eyes to bulge out or protrude, due to edema (the buildup of fluid) and the entry of lymphocytes into orbital tissues.

Treatment involves surgical removal of the thyroid gland, thyroid-blocking drugs, treatment with radioactive iodine that destroys overactive thyroid tissue, and injections of thyroid hormone. All these therapies are effective in eliminating the symptoms of this disease.

Hypothyroidism A deficiency in thyroxine production is referred to as hypothyroidism, or myxedema. A decrease in thyroxine output can be caused by an iodine deficiency. Decreased thyroxine levels disrupt the negative feedback loop to the pituitary, resulting in continued production of TSH. TSH continues to stimulate cell division in thyroid tissue. The symptoms of hypothyroidism are like a mirror-image of hyperthyroidism. Typically, a hypothyroid condition results in reduced basal metabolic rate (which decreases heat production), reduced tolerance of cold temperatures, decreased heart rate and output, and weight gain despite decreased appetite. Hypothyroidism is also characterized by decreased mental capacity, general weakness and fatigue, and poor physical development.

Failure of normal thyroid development in infants results in a related disorder referred to as congenital hypothyroidism. Since this disorder appears in about 1 out of 4,000 infants, screening for hypothyroidism is recommended for all newborns within one week after birth. Screening involves testing for the presence of thyroid hormone (using radioactive isotopes) in a drop of a baby's blood, as shown in Figure 13.14. Children with congenital hypothyroidism typically have a short, stocky stature and are developmentally delayed. Failure to diagnosis and treat this disorder before two months of age can result in life-long mental impairment.

Figure 13.14 Testing for the presence of thyroid hormone

Goiter

Figure 13.15 illustrates a condition referred to as a "goiter." A goiter is a swelling of the thyroid gland caused by insufficient levels of dietary iodine. While this disorder had been well documented for many years, its cause remained a mystery. Ultimately, the puzzle was solved by studying geographical disparities in the incidence of goiter around the world. These studies suggested that goiter was more prevalent in regions where the soil was lacking in iodine. Locally produced food crops in these regions typically had low levels of iodine. A diet low in iodine increased the risk of developing an enlarged thyroid gland.

Figure 13.15 An enlarged thyroid gland can result from a lack of iodine in the diet. Without iodine, the thyroid is unable to produce thyroid hormones, and continued anterior pituitary stimulation causes the gland to enlarge.

A lack of dietary iodine prevents the thyroid gland from producing sufficient thyroxine to meet the metabolic demands of the body. Reduced thyroxine levels lower the basal metabolic rate and stimulate the pituitary gland to increase TSH secretion. TSH stimulates cell division in the under-producing thyroid gland, causing the gland to expand. This swelling produces the characteristic bulge in the neck associated with a goiter. In more advanced cases, a goiter can become a disfiguring growth. A goiter can weigh as much as 200 g (a normal thyroid weighs approximately 20 g).

Early treatments for goiter involved the simple addition of small amounts of iodine to the diet. Later attempts to add iodine to drinking water were dropped in response to public opposition. The problem was finally dealt with by the addition of trace amounts of iodine to common table salt. In much of the world, the consumption of "iodized salt" has generally eliminated goiter as a public health problem.

Calcitonin and Parathyroid Hormone

Calcium is essential for healthy teeth and normal skeletal development. This mineral also plays a significant role in blood clotting, the formation of nerve impulses, and in muscle contraction. Calcium levels in the blood are regulated by **calcitonin**, a hormone which is produced by the thyroid gland,

and **parathyroid hormone** (PTH), which is made by the parathyroid glands. Calcitonin and parathyroid hormone are antagonistic hormones. They have opposite effects on blood calcium levels.

High levels of calcium, obtained from dietary sources, stimulate an increase in calcitonin secretion, which then increases the rate at which calcium in blood is deposited into bone tissue of the skeletal system. This results in a lowering of blood calcium levels. Calcitonin acts by increasing the rate of calcium excretion in the kidney.

As illustrated in Figure 13.16, a decrease in blood calcium prompts the parathyroids to produce more parathyroid hormone. When blood calcium falls below a critical threshold level, PTH secretion is stimulated by a negative feedback loop. Increased PTH stimulates bone tissue to release calcium into the blood and increases the rate of re-absorption of calcium from the kidneys and the duodenum of the digestive system.

In past generations, before they were recognized as distinct glands, one or more of the parathyroid glands might have been removed along with the surgical removal of the thyroid gland. In the absence of parathyroid glands, the amount of calcium in a patient's blood would fall to dangerously low levels. These patients were then at high risk of developing tetany, a potentially fatal condition characterized by uncontrollable, continuous muscular contraction sustained by the activity of hypersensitive nerve cells. Due to our current level of understanding of how these glands function, surgeons no longer use this procedure.

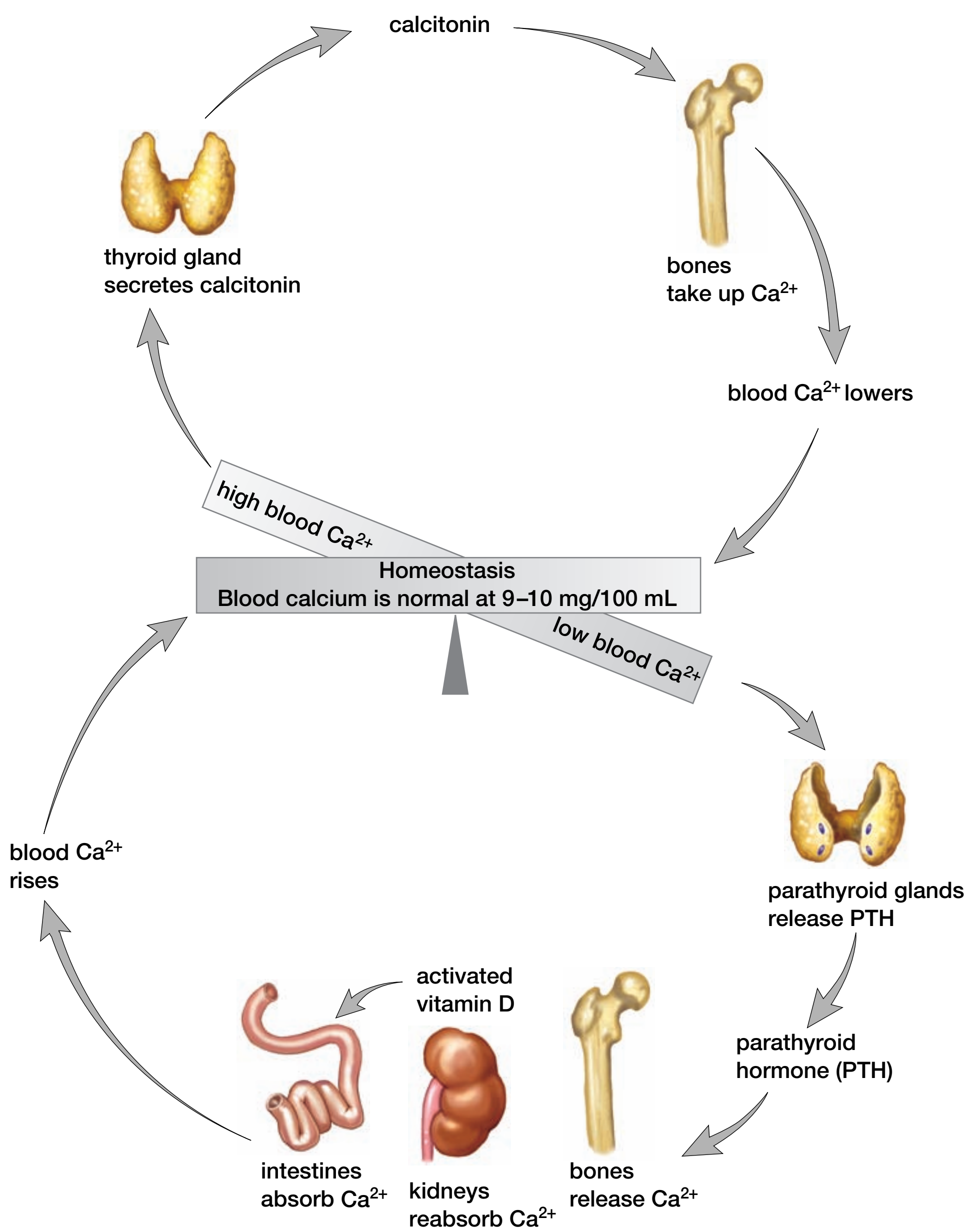


Figure 13.16 When the blood calcium (Ca^{2+}) level is high, the thyroid gland secretes calcitonin. Calcitonin promotes the uptake of Ca^{2+} by the bones, and therefore the blood Ca^{2+} level returns to normal. When the blood Ca^{2+} level is low, the parathyroid glands release parathyroid hormone (PTH). PTH causes the bones to release Ca^{2+}, the kidneys to re-absorb Ca^{2+}, and the intestines to absorb Ca^{2+}. As a result, the blood Ca^{2+} level returns to normal.

BIO FACT

Osteoporosis is the loss of bone mass that results in the bones becoming brittle and subject to fractures. At least 20 different hormones, growth factors, and vitamins affect bone formation, along with diet and activity level. Postmenopausal women are at greatest risk of osteoporosis because they have less bone mass than men and begin losing it earlier (starting around age 35). By age 70, the average woman has lost 30 percent of her bone mass, and some have lost as much as 50 percent. In men, bone loss begins around 60 years of age and seldom exceeds 25 percent. Bone mass is acquired primarily during puberty and adolescence, when high levels of growth hormone, estrogen, and testosterone stimulate bone formation. This makes proper diet and exercise critical during adolesence.

Vitamin D

Vitamin D is a steroid hormone involved in the regulation of blood calcium (as well as phosphate). Vitamin D is synthesized in a multi-step process starting in the skin and culminating in the kidney. An inactive precursor substance, vitamin D3, is first synthesized in the skin by the action of ultraviolet radiation on molecules of cholesterol. The liver converts this substance into an intermediate product, which the kidney then uses to produce the active form of vitamin D. This process is regulated by the parathyroid hormone.

PTH also promotes vitamin D synthesis in the proximal tubule of the kidney. The primary role of vitamin D is to maintain blood calcium levels. Vitamin D increases the release of calcium into the blood from bone tissue. In the kidney, it increases the retension of calcium.

In the small intestine, vitamin D increases the rate of calcium absorption by stimulating the growth of cells lining the intestine and by stimulating the synthesis of cellular proteins involved in calcium transport. Low levels of blood calcium due to a lack of vitamin D can impede mineralization of bone tissue. This problem can cause osteomalacia ("softness of bone") (in adults) or rickets (in infants). Symptoms include interruption of normal growth and development, skeletal deformities, and susceptibility to bone fractures. In adults, symptoms of osteomalacia also include skeletal pain and muscular weakness.

Lifestyle factors or geographical location may prevent sufficient production of vitamin D. In the past, rickets was sometimes described as a common disease of "smoky cities and cloudy skies." In developed countries, the addition of vitamin D to common foods such as dairy products has sharply reduced the incidence of this disease.

During pregnancy, adequate levels of vitamin D and dietary calcium are critical for normal bone development in the fetus. In the last few days of pregnancy, the fetus requires about 2 g of calcium per day. A vitamin D deficiency can result in the development of fetal rickets.

The Pancreas

The **pancreas** is a small gland located near the small intestine. It is made up of two kinds of tissues that independently function as exocrine and endocrine glands. As an exocrine organ, the pancreas secretes digestive enzymes into the duodenum.

The primary products of the endocrine portion of the pancreas are glucagon and insulin, two non-steroid protein hormones. These hormones regulate the body's metabolism of sugar and other carbohydrate molecules. They are produced by the islets of Langerhans, small groups of cells scattered throughout the pancreatic tissue.

Insulin is sometimes referred to as the "hormone of abundance" because it forces the body to store nutrients surplus to our immediate needs as glycogen in the liver, fat in adipose tissue, and protein in muscle tissue. Insulin and glucagon are antagonistic hormones. The secretion of glucagon, a catabolic hormone, triggers the cellular release of glucose, fatty acids, and amino acids into the bloodstream.

High levels of blood glucose stimulate the secretion of insulin, an anabolic hormone, by the beta cells. Insulin increases the intake of glucose, fatty acid, and amino acids by adipose (fat) and muscle cells and activates enzyme systems that convert glucose to glycogen in liver and muscle cells. In addition, insulin stimulates protein synthesis and tissue growth throughout the body, and suppresses the metabolism of glucose in liver and muscle cells.

Insulin receptors are found on the surface of most cells in the body. When insulin attaches to a receptor, the insulin-receptor combination migrates into the cell. Part of the receptor molecule has enzymatic properties. Insulin activates these enzymes by attaching to the enzyme molecule. These receptor enzymes then activate protein molecules (carriers) that transport glucose into the cell by facilitated diffusion. These activated carriers significantly increase the rate of glucose intake.

Once in the bloodstream, insulin is broken down in a few minutes by the liver and kidneys. The number of insulin receptors on any cell varies according to the current physiological state of the body. Starvation tends to induce the production of more receptors, while obesity decreases the number of cell receptors on cell surfaces.

Unfortunately, complications with this regulating system can arise. One major complication is diabetes (see Figure 13.17 on page 438). The World Health Organization has declared that a diabetes epidemic is underway. In 1985 it was estimated that there were 30 million cases of diabetes in the world; in 1995 there were 135 million cases; by 2025 it is predicted the number of cases will reach 300 million. Diabetes has many different forms, but the two main ones are Type 1 (insulin-dependent) diabetes and Type 2 (non-insulin-dependent) diabetes.

Investigation 13 • A

SKILL FOCUS

- Predicting
- Performing and recording
- Analyzing and interpreting
- Communicating results

Identifying Diabetes Mellitus

Diabetes is a malfunction of one of the major homeostatic systems in the body — the endocrine system. Two hormones, insulin and glucagon, control the level of sugar in the blood. The more glucose in the blood and surrounding fluid, the greater the amount of insulin that gets produced. If insulin levels fall and blood sugar becomes too high, glucose in the nephrons cannot be completely reabsorbed by the cells of your body, so glucose is released in the urine. One of the earliest tests for diagnosing diabetes was to taste the urine of a potential diabetic. If it was sweet, diabetes was a probable diagnosis. In this investigation, you will test solutions to determine if the solutions contain high levels of glucose.

Pre-Lab Questions

- What are the steps involved in balancing blood sugar in the body?
- How does Benedict's solution work to detect sugar?

Problem

How can you use different indicators to test for blood sugar in a solution (urine)?

Prediction

Predict how you can tell if sugar is present in a solution (urine).

CAUTION: Be careful when handling Benedict's solution as it is toxic. Clean up spills immediately and notify your teacher if a spill occurs.

Materials

- 4 samples of solution, labelled A, B, C, and D
- 10 mL graduated cylinder or small pipette with bulb
- 4 test tubes
- grease pencil
- test tube rack
- beaker clamp
- test tube clamp
- Benedict's solution
- 500 mL beaker
- hot plate
- medicine dropper

Type 1 Diabetes

The cause of Type 1 diabetes (or diabetes mellitus) is not well understood, but evidence shows that Type 1 diabetes is an autoimmune disorder, in common with lupus and some forms of arthritis. In this type of disease, the body's own immune system mounts an attack on parts of the body. In the case of Type 1 diabetes, the immune system attacks the pancreas, because it no longer recognizes certain cells of the pancreas as being "self." The immune system functions by knowing the difference between "self" and "non-self," as you shall see in the next section. The ability to detect "non-self" cells and other materials allows the body to recognize and attack infections and abnormal growths such as cancer. In Type 1 diabetes, the immune system seems to attack the insulin-producing beta cells without warning. Some scientists postulate that a viral infection of the beta cells may change them enough to trigger an attack by the immune system. Regardless, the body loses its ability to produce insulin almost overnight.

Type 2 Diabetes

Type 2 is a more common form of diabetes, affecting six percent of the population. It is also referred to as adult onset diabetes, as it typically occurs in adults

Procedure

1. Set up a hot water bath in the 500 mL beaker and maintain it a 37°C.
2. Using the grease pencil, label each of the test tubes A, B, C, and D.
3. Carefully measure 5 mL of Benedict's solution with the pipette or the 10 mL graduated cylinder and pour the solution into each of the labelled test tubes.
4. Add 6 drops of the solution A to the test tube labelled A. Follow this procedure for the other three solutions B, C, and D.
5. Place the test tubes in the hot water bath for 5 min. Carefully remove the test tubes and allow them to cool. Observe the test tubes for any changes.
6. If a reaction has occurred and the colour has changed, gently swirl the test tube to gain a uniform colour. Record any colour changes that you observe.
7. Use the following table to determine the glucose level in your sample:

Solution colour	Approximate glucose concentration (percentage of solution)
blue	negative
light green	0.15%–0.5%
olive green	0.5%–1.0%
yellow-green to green	1.0%–1.5%
orange	1.5%–2.0%
red brown	2.0% and greater

Post-Lab Questions

1. What were the sugar concentrations for each of the samples?
2. Describe the chemical reaction that was responsible for changing the colour of the Benedict's solution in the test samples.
3. Was this a controlled experiment? Explain your answer.
4. What other controls could be added to the procedure?

Conclude and Apply

5. One of the symptoms of diabetes mellitus is frequent and copious urination. Explain why this occurs.
6. When we eat a meal, our blood sugar level rises. How is homeostasis maintained in non-diabetic patients? How do diabetic patients deal with the increase in blood sugar?
7. What other tests would need to be performed to conclusively diagnose an individual with diabetes? Would these tests be adequate?

Exploring Further

8. Diabetes mellitus is also called Type 1 diabetes. Another form of diabetes, Type 2 diabetes or adult onset diabetes is more common. Describe the differences between Type 1 and Type 2 diabetes.
9. Explain why Type 2 diabetes can be controlled with lifestyle modification, but Type 1 diabetes cannot.

over the age of 40. Ninety percent of diabetics are Type 2. In these cases, while the body produces insulin, it is either in insufficient quantities or the body cells neither recognize nor respond to the insulin. This form of diabetes is often successfully treated by means of changes in diet and exercise. However, patients may require medication or even insulin shots to control increased blood sugar levels. Both forms of diabetes can cause rapid weight loss, blindness, and/or circulatory disorders that may have serious consequences.

The Pineal Gland

As you have seen, human physiological processes are generally in a constant state of flux, as the body adjusts to changes in the external and internal environment. For example, a stressful situation may trigger the release of hormones that cause a sudden increase in blood pressure and breathing rate. Similar effects may result from excessive exercise.

However, some hormone levels and physiological processes in the body seem to rise and fall in a regular pattern. Some of these biological cycles correlate with the seasons. Other processes follow a regular 24-hour cycle. Such daily cycles are referred to as **circadian rhythms**. Cortisol is one hormone that fluctuates in a circadian rhythm.

Cortisol levels tend to increase at night, peaking just before a person awakes. These levels then decrease sharply during the daytime. Another hormone that is subject to circadian rhythm is melatonin, a non-steroid hormone composed of a modified amino acid. Melatonin is produced by the **pineal gland**, a small, pine cone-shaped structure

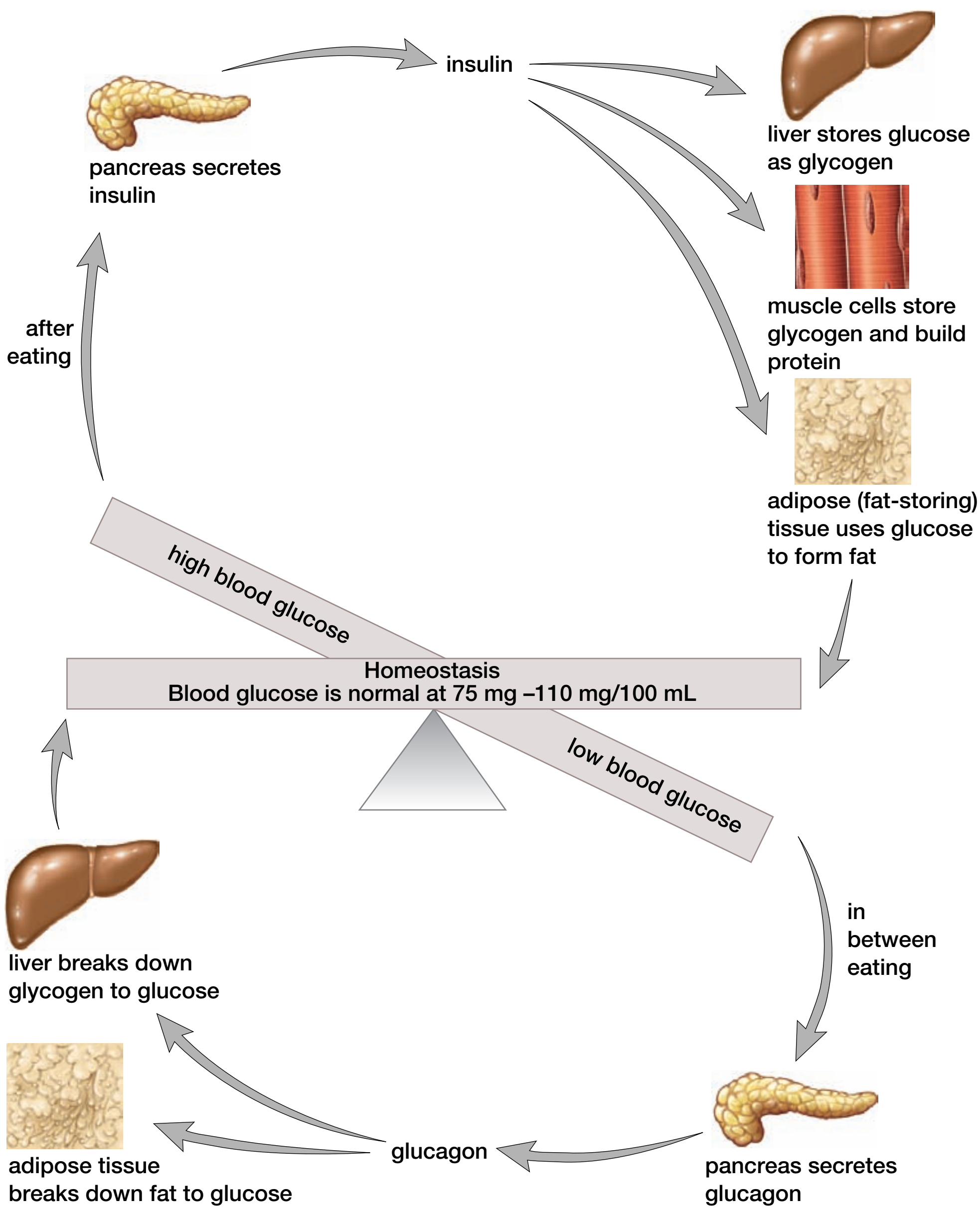


Figure 13.17 When blood glucose levels are high, the pancreas secretes insulin. Insulin promotes the storage of glucose as glycogen and the synthesis of proteins and fats (as opposed to their use as energy sources). Therefore, insulin lowers blood glucose levels to normal. When blood glucose levels are low, the pancreas secretes glucagon. Glucagon acts in a way opposite to insulin; therefore, glucagon raises blood glucose levels to normal.

Canadians in Biology

Global Heroes: Banting and Best Discover Insulin

Frederick Banting, right, and Charles Best, left, discovered a life-saving treatment for diabetes: insulin.

A diabetic's blood contains high levels of glucose, but very little of it enters the cells. This means that an untreated patient can literally starve to death while eating what should be adequate meals. A diagnosis of diabetes meant almost certain death until 1922, when the discovery of its cause and treatment thrust two young Canadian researchers into the international spotlight. Frederick Banting and Charles Best seemed unlikely heroes, and neither had any special research qualifications.

Unexpected Insight

Banting had obtained a medical degree at the University of Toronto and trained in orthopedic surgery. On October 30, 1920, he read a medical journal article about an apparent link between the pancreas and diabetes. He learned that (1) dogs which had their pancreas' removed developed symptoms of diabetes; (2) a healthy pancreas contains background cells and a small scattering of distinctive cell clusters called the islets of Langerhans; (3) if the main duct of the pancreas is deliberately blocked, the background tissue usually shrivels up but the islets often persist; (4) if the islet cells remain healthy, diabetes does not develop. Apparently, the islets held the key that allowed glucose to enter the body's cells.

At about two the next morning, Banting suddenly awoke with an exciting research idea that would eventually save the lives of millions of diabetics around the world and dramatically change his own.

Banting's Bold Idea

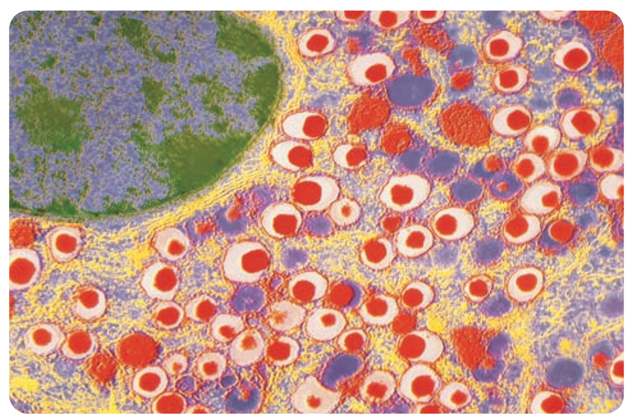
Banting's idea involved the following procedure: block the pancreatic duct to isolate islets cells from the pancreas of a dog, chemically extract the islet secretions, and administer the purified extract to another dog made diabetic by removing its pancreas. He hypothesized that the islets extract would normalize the second dog's blood sugar levels.

Banting presented his hypothesis to Dr. J.J.R. Macleod, a diabetes expert at the University of Toronto. Intrigued, Macleod offered Banting a small lab, a supply of dogs, and a 21-year-old assistant, Charles Best. Best was in medical school, and his excellent laboratory skills in biochemistry complemented Banting's surgical experience.

The first exhilarating results supporting their hypothesis came on July 30, 1921, when a diabetic dog's blood sugar did normalize as expected. By November, they had duplicated this result many times over.

Breakthrough

Banting's and Best's extract was given to a human diabetic patient for the first time on January 11, 1922, but with disappointing results. Fortunately, J.B. Collip, a biochemist from the University of Alberta, had joined the team late in December. After much "bathtub chemistry," as he later described it, Collip discovered that alcohol in a 90% concentration precipitated the active ingredient out of the raw extract. On January 23, Collip's purer extract was given to the same patient with much greater success.



The membrane-bound secretory granules (vesicles) in this islets cell contain insulin (red dots).

Macleod named the extract insulin, after the Latin word for "island." The University of Toronto's Connaught Laboratories immediately began developing large-scale production methods. The outcome was dramatic: within months, insulin was saving lives all around the world.

The media spotlight shone with its brightest intensity in 1923 when Banting and Macleod were awarded the Nobel Prize for medicine. Shocked that Macleod was named and not Best, Banting immediately split his award with his young assistant. Macleod followed suit by sharing his award with Collip.

located deep in the centre of the brain. Melatonin production is highest during nighttime hours and diminishes considerably during the day.

As daylight fades, melatonin levels rise, producing the familiar feeling of sleepiness. Some studies indicate a connection between abnormal melatonin production and sleep disorders. In addition, medical research suggests that abnormal melatonin production could be a factor in the development of mood disorders and depression.

One example is seasonal affective disorder (SAD), a condition that typically produces symptoms of depression and an overwhelming desire for sleep. These symptoms generally appear at the onset of winter and are believed to affect about 20 percent of residents of northern countries. This disorder is much less prevalent in southern regions. For example, SAD appears in only about 2.5 percent of the population of Florida.

Above-normal levels of melatonin enhance SAD symptoms. Some researchers suggest that exposure to bright lights for two to three hours each day can diminish the symptoms of this disorder.

The secretion of thyroxine is another process that follows a seasonal pattern. Thyroxine levels tend to increase during winter months, boosting metabolic rate. This may explain why a 15°C day may feel cool in the fall but warm in the spring.

Research efforts continue to refine our understanding of the role of these cycles in maintaining homeostasis in the body. The many rhythmic patterns discussed in this section are a daily reminder that despite our technologically advanced way of life, our close association with the natural environment continues to be strong and pervasive.

The Thymus Gland

The **thymus gland** is located between the lobes of the lungs in the upper chest cavity. This part of the immune system is especially active in young children. The thymus gland produces **thymosin**, a hormone that stimulates the production and maturation of lymphocytes into T cells. The thymus gland normally disappears after puberty. (In adults, lymphocytes continue to be produced by the spleen and lymph glands.) The pituitary gland regulates hormone production in the thymus gland. If the pituitary gland is surgically removed, the thymus gland will atrophy (shrink).

In this section, you learned that the pituitary gland is aptly named the master gland. You saw that the pituitary gland is the essential link between the nervous system and the endocrine system. This gland regulates the activities of other endocrine organs in the body. The next section examines the adrenal glands and their role in managing the body's physiological response to stressful situations.

WEB LINK

www.mcgrawhill.ca/links/atlbiology

Nicotine, alcohol, and caffeine are considered to be drugs that can alter the production and effectiveness of hormones secreted by endocrine organs. To access information about how these substances act on the endocrine system, go to the web site above, and click on **Web Links**. Compare the effects of nicotine, alcohol, and caffeine on the production and secretion of the following hormones: thyroxine; cortisol; ACTH; and insulin. How do these changes in hormone function affect metabolic activity (for example, heart rate, absorption of nutrients, and basal metabolic rate)?

SECTION REVIEW

1. Describe the difference between hyperthyroidism and hypothyroidism.
2. Design a study to investigate how medications that inhibit the normal metabolism of iodine in the body can be used to treat hyperthyroidism.
3. Make an outline diagram of the human body. In the diagram, draw the approximate shape of each endocrine gland (to scale) in its correct location within the body. Label the hormones produced by each gland and use arrows to show the target organs and tissues of each hormone.
4. Some studies indicate that normal endocrine function in people and other animals can be disrupted by exposure to industrial toxins, such as dioxins and PCBs, at the prenatal or infant stage of development. These toxins interfere with growth or lead to neurological disorders, including learning difficulties. Identify hazardous substances in your area. List strategies to minimize exposure to these substances. What long-term changes are needed to radically reduce the degradation of the environment?
5. Explain how calcitonin can influence the development of osteoporosis.

13.3

The Adrenal Glands and Stress

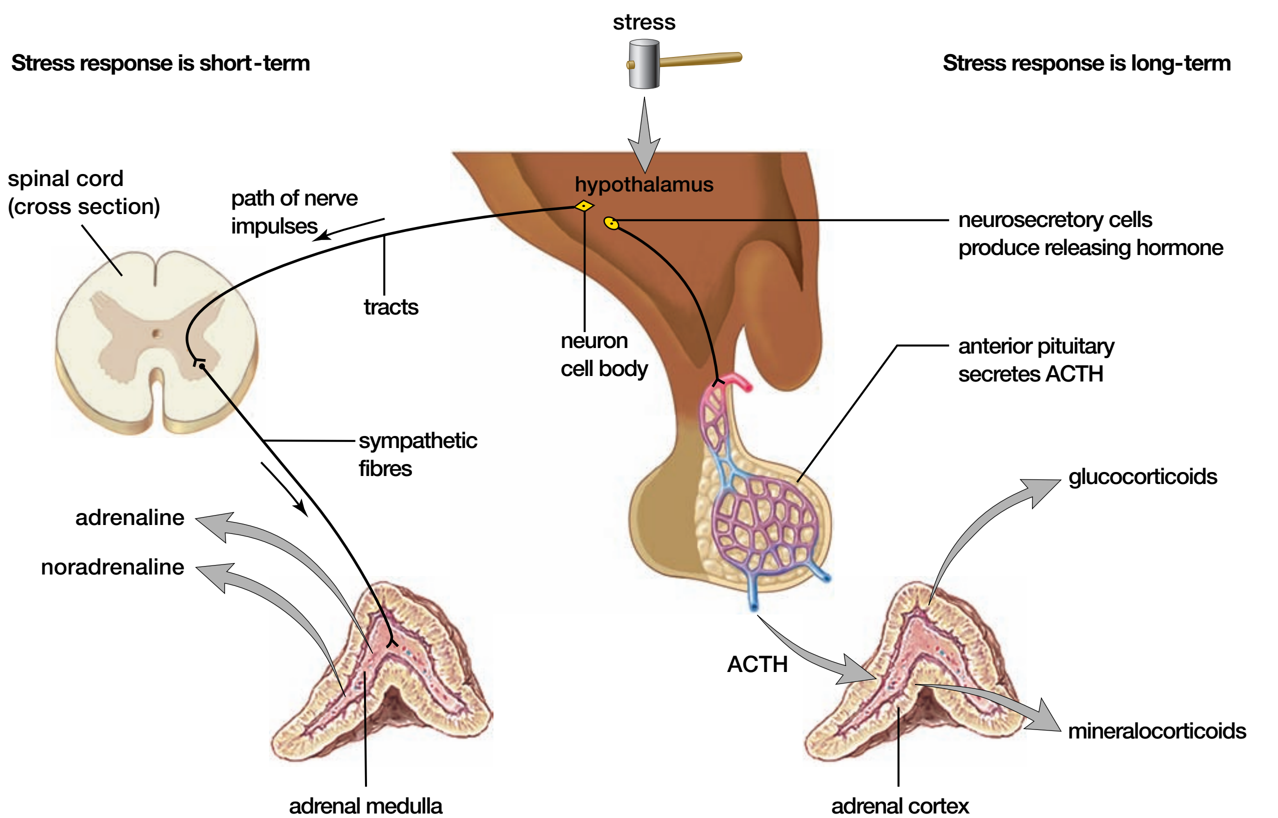
OUTCOMES

- **Describe the anatomy and physiology of the endocrine system and explain its role in homeostasis.**
- **Describe some Canadian contributions to knowledge and technology in the field of homeostasis.**

The body has two adrenal glands, one on top of each kidney. As shown in Figure 13.18, the **adrenal gland** is composed of two layers: an outer cortex and an inner medulla. Each layer produces different hormones and functions as an independent organ. While the cortex and the medulla do not interact, they are both regulated by the hypothalamus. In addition to many other functions, the adrenal gland produces adrenaline, noradrenaline, and cortisol as part of the body's response to stress.

The Adrenal Cortex

The **adrenal cortex** produces two types of steroid hormones — the glucocorticoids (cortisol) and the mineralcorticoids (aldosterone). Cortisol stimulates carbohydrate synthesis and related metabolic



Stress response:
- heartbeat and blood pressure increase
- blood glucose level rises
- breathing rate increases
- muscles become energized
- digestive system shuts down

Stress response:
- protein and fat metabolism occur instead of glucose breakdown
- reduction of inflammation; immune cells are suppressed
- sodium ions and water are re-absorbed by kidney
- blood volume and pressure increase

Figure 13.18 Both the adrenal medulla and the adrenal cortex are under the control of the hypothalamus when they respond to stress. The adrenal medulla provides a rapid but short-lived emergency response, while the adrenal cortex provides a sustained stress response.

functions. Aldosterone regulates salt and water balance, which in turn affects blood pressure. Both types of hormones contribute to the long-term stimulation of the immune system when the body is under stress. The adrenal cortex also produces male sex hormones (androgens) and female sex hormones (estrogens).

The production of cortisol and aldosterone is regulated by the **adrenocorticotropic hormone (ACTH)**, a polypeptide molecule synthesized by the anterior pituitary gland. ACTH production, in turn, is stimulated by a peptide substance, corticotropin-releasing factor (CRF), which is produced by the hypothalamus.

Increased aldosterone and cortisol levels exert a negative feedback effect on the hypothalamus and anterior pituitary, which suppresses ACTH production. However, the synthesis of aldosterone is primarily controlled by changes in blood pressure and the production of angiotensin in the kidney (discussed below).

In healthy individuals, the secretion of CRF in the hypothalamus exhibits a diurnal pattern, reaching its lowest levels late at night (around midnight) and rising to a peak in early morning hours before awakening. This pattern is also reflected in the production of ACTH, aldosterone, and cortisol. Changing sleep patterns, caused by shift work, for example, will cause a corresponding change in this pattern of hormone production.

Cortisol

Cortisol secretion causes a dramatic rise (6 to 10 times normal levels) in the process of gluconeogenesis, the synthesis of carbohydrates from amino acids and other substances in the liver. As you may recall, metabolic reactions such as glucogenesis need enzymes in order to proceed. Enzymes are proteins that accelerate chemical reactions without actually going through any change themselves. Without enzymes, metabolic reactions would proceed much too slowly to maintain normal cellular functions.

Cortisol triggers the conversion of protein to amino acids in muscle tissues, and the release of amino acids into the blood. In the liver, cortisol triggers the uptake of amino acids and stimulates the production of enzymes active in glucogenesis. This increase in glucose synthesis leads to increased glycogen stores in the liver. Subsequently, under the influence of other hormones such as glucagon and adrenaline, this stored carbohydrate can then be converted back to glucose when needed (such as between meals). In addition, cortisol prompts the breakdown of lipids in fat tissues (for use as an alternative energy source in other tissues), inhibits metabolism, and suppresses protein synthesis in most organs in the body (with the exception of the brain and muscles).

Cortisol also has strong anti-inflammatory properties. In general, cortisol decreases the buildup of fluids in the region of inflammation by decreasing the permeability of capillaries in affected tissues. This hormone also suppresses production of T cells and antibodies, as well as other immune system responses that might cause further inflammation. It is therefore often used to treat and reduce inflammation caused by skin injuries, autoimmune disorders such as rheumatoid arthritis (which causes inflammation of the joints of the skeletal system), and asthma. As an asthma medication, corticosteroids are most effective when inhaled. They help alleviate inflammation of bronchial tissues during an asthmatic attack.

Physiological Response to Stress

The hypothalamus plays a key role in the body's physiological response to stress. Any form of physical or emotional stress stimulates a very rapid response in the hypothalamus. For example, during times of mental stress, increased signals from the brain stimulate the hypothalamus to produce more CRF. This increased production, in turn, prompts ACTH secretion in the anterior pituitary (as illustrated in Figure 13.19). ACTH then triggers higher levels of cortisol production by the adrenal cortex. The extra cortisol may help to relieve some of the possible negative physiological effects of stress. As described above, higher levels of cortisol speed up gluconeogenesis and other metabolic functions that may provide additional energy sources for cell functions. Note that the precise role of cortisol in mediating the body's response to stress is still the subject of much speculation and research.

WEB LINK

www.mcgrawhill.ca/links/atlbiology

Think about how you react to situations that generate stress, such as preparing for a driver's test or watching a suspenseful movie. To access a stress test and supporting articles that will help you gauge your own reactions to stress, go to the web site above, and click on **Web Links**. Please note that this is not a medical diagnostic test. Consult your family health professional to discuss personal concerns about stress.

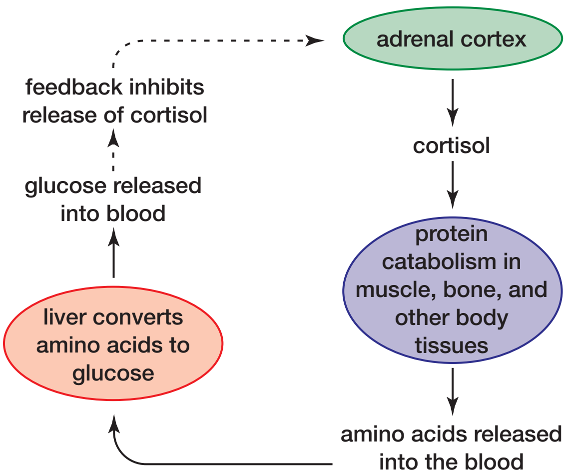


Figure 13.19 Cortisol appears to play a major role in the body's physiological response to stress.

During extended periods of stress, cortisol can interact with insulin to increase food intake and redistribute stored energy from muscle to fat tissues, primarily in the abdominal region. Abdominal obesity is a strong risk factor for Type 2 diabetes, coronary heart disease (such as arteriosclerosis), and stroke. Excessive cortisol production in times of stress may also depress immune function by reducing the availability of proteins needed for synthesis of antibodies and other substances produced by the immune system. Over time, depressed immune system function may increase the body's susceptibility to infection and the onset of some forms of cancer. The connection between cortisol and other adrenal secretions in times of stress will be discussed later in this chapter, in "Fight or Flight Syndrome."

Aldosterone

Two primary (and related) functions of aldosterone are osmoregulation (the process of regulating the amounts of water and mineral salts in the blood) and regulation of blood pressure. In the kidneys, aldosterone acts to increase sodium ion absorption and secretion of potassium ions, primarily in the collecting ducts of nephrons in the kidneys. Aldosterone also stimulates sodium re-absorption in the colon. This process raises sodium concentration in the blood and triggers the hypothalamus to release ADH, which in turn increases the absorption of water, leading to an increase in blood pressure.

Aldosterone production is primarily controlled by changes in blood pressure. A decrease in blood pressure will stimulate the kidneys to secrete the enzyme rennin. This enzyme secretion, in turn, triggers the activation of the protein angiotensin (which the kidney produces from blood proteins). Angiotensin raises blood pressure by triggering the constriction of arterioles and by stimulating the release of aldosterone from the adrenal cortex.

Abnormal secretion of mineralcorticoids or glucocorticoids can cause ailments such as Cushing's

THINKING LAB

Symptoms of Cushing's Syndrome and Addison's Disease

Background

Cushing's syndrome is caused by an excess of glucocorticoids (hypersecretion) due to either elevated levels of ACTH or a tumour on the adrenal gland. The disease is characterized by high blood pressure, high blood sugar, muscle weakness, and edema (the accumulation of fluid in the tissues). These symptoms can also appear if someone is treated with cortisone over a long period of time.

Addison's disease is the result of a hyposecretion (deficient secretion) of glucocorticoids and mineralocorticoids. The symptoms are the reverse of those for Cushing's syndrome. Addison's disease sufferers have low blood pressure and low blood sugar. They also tend to suffer from weight loss, weakness, and a loss of resistance to stress.

You Try It

1. Based on what you have learned in this chapter, explain each of the symptoms of these diseases.
2. What treatment(s) do you think should be provided?

Cushing's syndrome can result from hormonal hypersecretion due to an adrenal cortex tumour. (A) First diagnosed with Cushing's syndrome. (B) Four months later, after therapy.

syndrome and Addison's disease. Addison's disease is caused by the autoimmune destruction of the adrenal cortex tissue, resulting in decreased cortisol and aldosterone production. Loss of cortisol typically leads to hypoglycemia, weight loss, and feelings of nausea. Depressed aldosterone levels result in lowered blood pressure due to decreased volume of body fluids. The loss of adrenal androgens also contributes to a reduced sex drive. In addition, Addison's disease sufferers may develop a "perpetual tan" appearance (hyperpigmentation) as a result of increased ACTH secretion.

BIO FACT

U.S. President John F. Kennedy, assassinated in 1963, was likely the most famous Addison's patient. Doctors controlled his disease with hormone replacement therapy, involving injections of glucocorticoids and mineralcorticoids.

Cushing's syndrome is the result of a spontaneous and chronic production of glucocorticoids by the adrenal cortex. Treatment for this disorder involves the administration of drugs that block the synthesis of glucocorticoids. Cushing's disease, a related disorder, is a condition in which a pituitary tumour results in the over-secretion of ACTH and the subsequent increase in cortisol production. This disease is generally treated by surgically removing the pituitary tumour. Both diseases cause increased protein breakdown and muscle wasting, as well as excessive fat buildup in the abdomen and elsewhere in the body.

In the Thinking Lab on the previous page, you can consider these conditions in greater detail.

Sex Hormones

The adrenal cortex also produces small amounts of male sex hormones (androgens) and female sex hormones (estrogens). These hormones are found in both sexes, but males produce higher levels of androgens while females synthesize more estrogens. Because the testes in males produces high levels of androgens, the amount of this hormone secreted by adrenal glands have only a slight effect on body functions. The androgen hormones produced by the adrenal glands account for 50 percent of the total androgen output in females.

Androgens promote muscle and skeletal development in both males and females. The estrogen production by the adrenal glands remains insignificant until after menopause, when the ovaries cease production of these hormones.

The Adrenal Medulla

The adrenal gland secretes adrenaline (also called epinephrine) and noradrenaline (also called norepinephrine), two non-steroid hormones. Adrenaline, the first hormone discovered (in 1894) is often called the "stress hormone" because it is the major hormone secreted in response to stress.

The adrenal medulla is another example of the overlapping functionality of the nervous and endocrine systems. The **adrenal medulla** is composed of modified neurons of the sympathetic nervous system. The production of adrenaline and noradrenaline is under the control of the hypothalamus via this direct connection with the sympathetic nervous system. The hormones adrenaline and noradrenaline also serve as excitatory neurotransmitters in the sympathetic nervous system. When adrenaline and noradrenaline act as neurotransmitters, their effect on the body is limited and of short duration.

The adrenal medulla secretes a mixture of 85 percent adrenaline and 15 percent noradrenaline. Despite minor differences in molecular structure, these hormones produce very similar effects on target tissues.

Adrenaline and noradrenaline act to increase heart rate and blood pressure, and cause vasodilation (widening) of blood vessels in the heart and respiratory system. These hormones also stimulate the liver to break down stored glycogen and release glucose into the blood. When the body is "at rest," these two hormones sufficiently stimulate cardiovascular function to maintain adequate blood pressure without additional input by the sympathetic nervous system.

Adrenaline and Anaphylactic Shock

Some people suffer severe allergic reactions, called anaphylactic shock, to antigens from bee stings, peanuts or other foods, latex gloves, or intravenous medications such as penicillin. If these antigens enter the bloodstream, they can trigger a life-threatening chain reaction called "anaphylactic shock." Once in the circulatory system, the antigen stimulates the widespread release of histamine, an anti-inflammatory substance produced by the immune system. Histamine stimulates vasodilation of arterioles throughout the cardiovascular system, and leakage of fluid and proteins out of the capillaries. This precipitates a rapid decline in blood pressure and reduced flow of blood (and oxygen) to the organs and tissues of the body.

Without immediate treatment, this situation can result in death within minutes. Emergency treatment involves injections of adrenaline hormone. Adrenaline mimics the action of the sympathetic nervous system, increasing heart rate and the strength of heart contractions. This action helps to restore blood pressure.

Figure 13.20 An EpiPen™ is used to counteract anaphylactic shock.

People at risk for anaphylactic shock usually carry a syringe-like device called an EpiPen™ (as shown in Figure 13.20). This device can be used to quickly self-administer (if necessary) a life-saving dosage of adrenaline. Doctors recommend that at-risk individuals also wear emergency identification bracelets.

Fight or Flight Syndrome

In Chapter 12, the "fight or flight" syndrome was discussed in the context of nervous system function. The fight or flight reaction is the way in which the body responds to a sudden, unexpected stressful stimulus, such as a physical threat or some other perceived emergency situation. This reaction is produced by the rapid release of adrenaline and noradrenaline by the adrenal gland (which reinforces the action of the sympathetic nervous system).

For example, if you were to notice that you were in the path of a rapidly oncoming car or if you came face to face with a bear in the woods, your breathing

THINKING LAB

Life Support Technology

Background

As you have seen throughout this chapter, maintaining homeostasis in the human body is an intricate and complex interaction of our body systems with the external world. It is possible for homeostasis to be upset fairly easily if one system fails or is injured. In many cases when this happens, medical advances and improved technologies are able to bring back homeostasis artificially. Machines take over for the system that is not working properly.

Life can be extended beyond its natural limits by means of technology, such as those that breathe for an individual who cannot breathe for themselves, or that balance hormones at safe levels. This technology also creates moral and ethical issues for individuals and medical personnel. In this lab, you will determine what some of these issues are and debate them. You will also determine how you feel about life support for yourself.

You Try It

1. Do research in your library or on the Internet about life support technology. Create a list of three different situations in which life support has been used.
2. Combine your list of situations with the lists of your classmates, creating a master list for the class.
3. In small groups of three or four students, categorize the cases on the class list based on whether the patients are on life support temporarily or permanently.

4. In your group, discuss whether you feel there is a difference between temporary or permanent life-support use. For example, should life-support keep an individual alive if they have no chance of recovery? How does that situation differ from using life-support if it is a temporary measure?
5. Individually, research the concept of a living will. What types of decisions would you have to make in order to write a proper living will? Would you create a living will for yourself? Explain your answer.

rate and heart rate would quickly increase. You would also experience a rapid elevation in blood sugar level.

In our human ancestors, this reaction would have been induced primarily by a perception of physical danger. However, stress can also be triggered by feelings of excitement, anxiety, psychological conflicts, environmental extremes (such as severe heat or cold), or a lack of sleep.

The phrase "fight or flight response" was coined by Walter B. Cannon and Hans Selye, a Canadian doctor, in the 1930s. The phrase defines the pattern of physiological responses that prepares the body for emergency situations. Cannon studied the effect of stress on dogs, observing that stress depressed digestive function. His work led him to develop the concept of homeostasis. Much of Selye's research focussed on how the adrenal gland affects the body's immune and inflammatory responses during times of stress.

In this section, you learned how hormones of the adrenal gland regulate metabolism and control the body's response to stressful situations. You also examined the negative effects of chronic stress on the immune system and other body functions.

SECTION REVIEW

1. Describe how two different information pathways control hormone secretion in the adrenal glands.
2. Compare the functions of the hormones produced by the adrenal medulla and the adrenal cortex.
3. Make a concept map to describe the typical physiological symptoms of stress, the systems and tissues involved, and possible factors that may trigger a stress response in an individual.
4. Refer back to the stress test you performed in the Web Link on page 442. What are some coping strategies that might help you deal with stressful situations in the future?
5. Compare the functions of adrenaline and noradrenaline in the nervous and endocrine systems.
6. The body's response to stress involves different hormones. Is this a negative feedback loop or a positive feedback loop? Explain your answer.
7. Describe how adrenal gland activity would be affected by the consumption of food with a high salt content.
8. Explain why ACTH is sometimes used to treat problems associated with the adrenal gland.
9. Make a chart listing the physical impact of too much or too little corticoid secretion.
10. Create a flowchart showing the sequence of steps that lead to anaphylactic shock.
11. Describe the "fight-or-flight response."
12. How did Hans Selye contribute to our understanding of stress? Do research to provide details for your answer.
13. Does caffeine contribute to stress or decrease stress? How could you determine this? Develop a testable hypothesis for this problem.
14. Studies with rats suggest that overcrowding causes behaviour changes.
    - **(a)** Describe the impact of overcrowding in terms of stress.
    - **(b)** Can you find evidence that people living in cities are more prone to stress than people living in less crowded environments?
    - **(c)** If city dwellers are found to be more prone to stress, can you conclusively link this to population density, or are there other factors that may be more relevant?
15. Current news stories from around the world claim that more people now have an unhealthy body size. Many factors contribute to this problem, making it difficult to correct.
    - **(a)** Outline how a high level of stress may be a factor.
    - **(b)** Suggest preventative strategies.
    - **(c)** Briefly describe a research plan to test the relationship between stress using mice as the subjects.

Chapter Summary

Briefly explain each of the following points.

- The endocrine glands produce hormones that influence the activity of every organ and tissue in the body. (13.1)
- Endocrine hormones are secreted directly into the bloodstream, whereas exocrine hormones are secreted through ducts or tubes. (13.1)
- Steroid hormones are fat-soluble and can pass through the membranes of target cells; non-steroid hormones are not fat-soluble, so they bind to receptors on the surface of target cells. (13.1)
- The nervous system produces bioelectrical signals that travel along specialized nerve cells, while the endocrine system releases hormones into the bloodstream. (13.1, 13.2)
- Abnormal endocrine function can upset a number of metabolic processes in the body. (13.1, 13.2)
- Hormones of the adrenal gland control the body's response to stress in several ways. (13.3)

Language of Biology

Write a sentence using each of the following words or terms. Use any six terms in a concept map to show your understanding of how they are related.

- endocrine system
- hormones
- target organ
- endocrine glands
- exocrine glands
- antagonistic hormones
- steroid hormones
- non-steroid hormones
- human growth hormone
- growth factors
- pituitary dwarfism
- gigantism
- acromegaly
- prolactin
- anti-diuretic hormone
- oxytocin
- thyroid gland
- hyperthyroidism
- Grave's disease
- hypothyroidism
- calcitonin
- parathyroid hormone
- pancreas
- circadian rhythms
- pineal gland
- thymus gland
- thymosin
- adrenal gland
- adrenal cortex
- adrenocorticotropic hormone (ACTH)
- adrenal medulla

UNDERSTANDING CONCEPTS

1. Describe the relationship between the endocrine system and each of the following.
(a) nervous system
(b) immune system
(c) reproductive system

2. Some disease conditions are due to abnormal endocrine function. Name the glands and hormones associated with each of the following conditions. Describe the symptoms associated with each problem.
(a) acromegaly
(b) SAD
(c) diabetes
(d) hypothyroidism
(e) goiter
(f) gigantism

3. Why is caffeine banned for Olympic athletes? What hormones would you expect would be banned? Explain your answer.

4. Explain how hormones regulate the level of calcium in the blood.

5. Explain why, in most regions of the world, goiter is less common today than in past generations.

6. How do levels of HGH change as we age? How do these changes in hormone level affect our bodies?

7. Give some examples of hormone levels changing in response to:
(a) the nervous system
(b) other hormones
(c) changes in body chemistry

8. Explain and give an example of a negative feedback loop in the human body.

9. Compare the general roles of the nervous system and the endocrine system in maintaining homeostasis in the body.

10. Explain the difference between steroid and non-steroid hormones in terms of their chemical structure and how they alter the chemistry of a cell.

11. Compare how cortisol and insulin affect blood sugar levels.

12. How does the body maintain an internal clock?

13. What are the causes and symptoms of SAD?

14. Explain why the side effects associated with prolonged use of cortisone medications are similar to the symptoms of Cushing's syndrome.

15. Describe how the levels of various hormones in your body might change during a typical day — from the time you wake until you fall asleep.

16. Explain how impaired adrenal function can lead to hypotension (low blood pressure).

17. What hormones are involved in the "fight or flight" syndrome and what hormones adapt the body to long-term stress?

18. Describe anaphylactic shock and the conditions that can trigger it.

19. Immediately after the Chernobyl nuclear disaster, people in Sweden began to buy and consume iodine. Explain why.

20. Many athletes "psych" themselves up before a competition by visualizing themselves in competition. Do you think this strategy might enhance their performance? Explain your answer.

INQUIRY

21. Describe procedures or tests that could be used to evaluate stress levels in an individual. Think about and evaluate how you respond to stressful situations. Discuss with others in your class the types of situations that cause short-term stress and various methods of dealing with stress.

22. Human growth hormone, thyroid hormones, and reproductive hormones that are produced during puberty are all important in human growth at various ages. Together, these hormones stimulate the growth of bone and cartilage, protein synthesis, and the addition of muscle mass. Because the reproductive hormones are involved in human growth, perhaps there is a difference in the growth rate between males and females. Use the table on the right to answer the following questions.
    (a) Construct a graph that plots mass on the vertical axis and age on the horizontal axis.
    (b) Plot the data in the table for the average female growth in mass from ages 8 to 18. Connect the points with a red line.
    (c) On the same graph, plot the data for the average male growth in mass from ages 8 to 18. Connect the points with a blue line.
    (d) Construct a separate graph that plots height on the vertical axis and age on the horizontal axis.
    (e) Plot the data for the average female growth in height from ages 8 to 18. Connect the points with a red line. Plot the data for the average male growth in height from ages eight to 18. Connect the points with a blue line.
    (f) During what ages do females and males increase the most in mass? in height?
    (g) How can you explain the differences in growth between males and females?
    (h) Interpret the data to find if the average growth rate is the same in males and females.

Averages for Growth in Humans

Age	Mass (kg)		Height (cm)	
	Female	Male	Female	Male
8	25	25	123	124
9	28	28	129	130
10	31	31	135	135
11	35	37	140	140
12	40	38	147	145
13	47	43	155	152
14	50	50	159	161
15	54	57	160	167
16	57	62	163	172
17	58	65	163	174
18	58	68	163	178

23. Scientists in Western countries have been searching for a chemical that will curb an alcoholic's need for alcohol. Recently, some scientists have taken a look at a treatment used in China for over two thousand years. Chinese healers have given alcoholics an extract from the root of the kudzu vine, which they claim is about 80 percent effective in patients who have been treated with it for two to four weeks. Dr. Wing-Ming Keung of Harvard Medical School in Boston visited China to find out what modern researchers thought of the herbal remedy. He spoke to physicians who claimed to have treated 300 alcohol abusers with the extract. They were convinced that the chemicals in the extract effectively suppressed the appetite for alcohol.

After returning to Harvard, Dr. Keung and Dr. Bert L. Vallee decided to try the drug on Syrian golden hamsters in their laboratory. These hamsters were specifically selected because they are known to drink large amounts of alcohol when it is available to them. Imagine you are a member of the research team. Your job is to design an experiment that will prove the effectiveness of the extract from the root of the kudzu vine in suppressing the hamsters' craving for alcohol.

(a) Dr. Keung and Dr. Vallee discovered two active ingredients in the root extract. They found that each extract alone had the effect of lessening alcohol use in the hamsters by 50 percent. The two compounds appeared to affect enzymes involved in alcohol metabolism. Hypothesize how this discovery might help people overcome alcohol dependency.

(b) How would you follow up on your experiment?

(c) Predict the results of the experiment.

(d) What will be the variable in the experiment?

(e) What will you use as your control in the experiment?

COMMUNICATING

24. Acupuncture, an ancient and important part of Eastern medical practice, has only recently come under serious scrutiny by Western doctors and scientists. Investigate how this method of treatment is used in Chinese medicine. Research the current understanding of the possible physiological processes that might explain the apparent pain-relieving effects of acupuncture treatment.

25. Create a pamphlet that explains how cortisone medications can be used to treat some forms of skin inflammations and injuries.

26. Current research studies suggest a link between the levels of various hormones in the body, such as ACTH from the pituitary gland, and certain forms of depression. By consulting print resources, the Internet, or a medical expert, summarize the latest research findings on how hormone production may be connected to depression.

MAKING CONNECTIONS

27. Some students use anabolic steroids to enhance athletic performance and improve their appearance. What risks are associated with the use of these hormones?

28. Hormones are sometimes used to increase the productivity of cattle, chickens, and/or pigs. Do you think that the labels on food products should include information on the use of supplements such as hormones? What would be the advantages and disadvantages of this type of labelling?

29. Many types of animals (such as mice, rats, and monkeys) are used in some scientific and medical research studies that investigate diseases of the endocrine system, such as abnormal thyroid or pituitary function. How do such studies benefit human life? In your opinion, should animals be used for such research studies? Are there effective alternative research protocols that could replace research procedures involving laboratory animals?

30. Canada's pharmaceutical companies submit a steady stream of new prescription medications to Health Canada for approval each year. However, only 10 percent of these applications receive government approval. The other 90 percent are rejected, mostly because of safety concerns.

Suppose you were responsible for developing the regulations regarding control of prescription drugs in Canada. Some of the major issues concerning prescription drug use and safety involve providing timely information about new medications to Canadian doctors and the reporting of adverse reactions to new medications. What changes would you make to current legislation to address these issues?

UNIT 4 REVIEW

UNDERSTANDING CONCEPTS

True-False

In your notebook, indicate whether each statement is true or false. Correct each false statement.

1. In order for gas exchange to take place in the alveoli of the lungs, the gases must be dissolved.
2. The volume of the lungs is the most important factor in determining their efficiency.
3. Hemoglobin has a greater affinity for carbon monoxide than for oxygen.
4. The more active an organism is, the more it needs a circulatory system.
5. A closed circulatory system is more efficient than an open one.
6. A four-chambered heart ensures the separation of oxygenated and deoxygenated blood.
7. High blood pressure indicates that you are very physically active.
8. Both nerves and hormones regulate the secretion of enzymes.
9. The most important site for the absorption of nutrients is the large intestine.
10. It is important to eat representative foods from the four food groups every week.
11. Cholesterol is an unsaturated fat.

Multiple Choice

In your notebook, write the letter of the best answer(s) for each of the following questions. (You may select more than one item per question.)

12. Which of the following substances are not normally found in urine?
    (a) sodium
    (b) water
    (c) glucose
    (d) urea
    (e) uric acid
13. Which of the following is/are normally not part of the fight-or-flight reflex?
    (a) increase in blood glucose level
    (b) increase in oxygen level in blood
    (c) increase in thyroid hormone level in blood
    (d) increase in testosterone level in blood
    (e) increase in pH of blood
14. Which of the following structures is/are not part of the peripheral nervous system?
    (a) sensory receptors in skin
    (b) spinal cord
    (c) sensory neuron
    (d) motor neuron
    (e) hypothalamus
15. Which of the following structures, if any, could be considered part of both the peripheral and central nervous systems?
    (a) sensory receptors in skin
    (b) spinal cord
    (c) sensory neuron
    (d) motor neuron
    (e) hypothalamus
16. Which of the following organ(s) act(s) as both an exocrine and endocrine gland?
    (a) pituitary
    (b) thyroid gland
    (c) pancreas
    (d) parathyroid gland
    (e) hypothalamus
17. Which of the following organs secrete(s) pairs of antagonistic hormones?
    (a) pituitary
    (b) thyroid gland
    (c) pancreas
    (d) parathyroid gland
    (e) hypothalamus
18. Which of the following substances is/are used by the body to make hormones?
    (a) proteins
    (b) glucose
    (c) cholesterol
    (d) polypeptides
    (e) vitamins
19. Which of the following illnesses are not initially caused by an endocrine disorder?
    (a) osteoporosis
    (b) cancer
    (c) high blood pressure
    (d) arthritis
    (e) Type 1 diabetes
20. The process that uses oxygen to break down glucose to produce energy takes place
    (a) only in the lungs
    (b) in the lungs and in cells
    (c) when the diaphragm contracts
    (d) in alveoli
    (e) within cells

21. One thing that does not occur during inspiration is
  (a) the intercostal muscles of the rib cage contract
  (b) the rib cage rises
  (c) the rib cage extends out from the body
  (d) the diaphragm relaxes
  (e) air moves into the lungs

22. Cardiopulmonary circulation does not involve
  (a) the pulmonary veins
  (b) the right ventricle
  (c) the left atrium
  (d) the carotid artery
  (e) the pulmonary arteries

23. The release of food from the stomach to the small intestine is controlled by the
  (a) villus
  (b) larynx
  (c) epiglottis
  (d) uvula
  (e) pyloric sphincter

24. The duodenum is
  (a) the middle section of the colon
  (b) the bottom part of the stomach
  (c) the first section of the small intestine
  (d) 10 fingers wide
  (e) located in the appendix

25. The body's preferred energy source is
  (a) carbohydrates
  (b) fats
  (c) vitamins
  (d) proteins
  (e) minerals

26. Vitamins
  (a) provide energy to the body
  (b) regulate processes in the body
  (c) remove wastes
  (d) supply building materials
  (e) digest proteins

27. The surface area of the small intestine is greatly increased by
  (a) villi
  (b) chemical digestion
  (c) peristalsis
  (d) rhythmical segmentation
  (e) lacteals

28. A balanced diet contains
  (a) water and vitamins
  (b) proteins
  (c) fats and carbohydrates
  (d) minerals
  (e) all of the above in the correct proportions

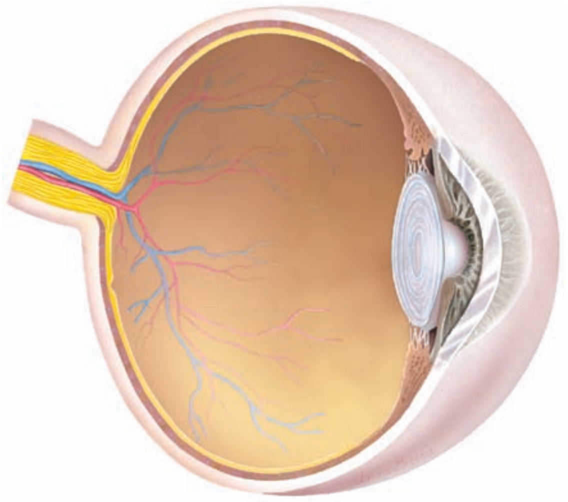
29. Unsaturated fats
  (a) will make you sick
  (b) are the "bad" fats
  (c) are cholesterol
  (d) are the "good" fats
  (e) contain extra vitamins

Short Answer

In your notebook, write a sentence or a short paragraph to answer each of the following questions.

30. Which system plays the dominant role in managing the body's response to stress: the central nervous system or the endocrine system? Explain your answer.

31. What part of the eye is referred to in each of the following descriptions (the diagram below may help you identify the parts)?
  (a) regulates the amount of light entering the pupil of the eye
  (b) the pigmented inner layer made up of photoreceptor cells
  (c) a protective layer that extends over the lens
  (d) the photoreceptor cells that function in colour vision
  (e) the part of the retina that is the centre of the visual field and is made up of cones
  (f) adjusts the shape of the lens
  (g) the photoreceptor cells most active in low light conditions



32. Which is more common in the human body: steroid or non-steroid hormones? In general, what are the major differences in the way each type of hormone interacts with target cells?

33. How does the body restore and maintain a normal homeostatic state after exposure to extreme environmental temperatures?

34. How would the following processes in the kidney respond to serious dehydration in the body due to excessive sweating on a hot day?
   (a) glomerular filtration
   (b) tubular re-absorption
   (c) tubular secretion

35. Describe the primary functions of each of the following sections of a human kidney.
   (a) cortex
   (b) medulla
   (c) collecting duct

36. Describe the type of stimulus that would trigger the following homeostatic reactions.
   (a) constriction of blood vessels in the skin
   (b) increase in shivering activity
   (c) increase in breathing rate
   (d) increase in sweating

37. Identify the endocrine glands, hormones, and symptoms associated with the following diseases or disorders. (Remember that more than one type of gland or hormone may be involved with a single type of ailment.)
   (a) gigantism
   (b) seasonal affective disorder
   (c) Cushing's syndrome
   (d) congenital hypothyroidism
   (e) diabetes
   (f) acromegaly
   (g) goiter
   (h) Addison's disease
   (i) Graves' disease

38. Construct a chart of the following components of the human immune system. Match each component with one or more of the following types of immune function: non-specific immunity, specific immunity, cellular immunity, antibody immunity.
   (a) the epidermis of the skin
   (b) memory B cells
   (c) neutrophils
   (d) lining of the respiratory tract
   (e) monocytes
   (f) T lymphocytes
   (g) lining of the digestive tract
   (h) memory T cells
   (i) macrophages

39. Describe how the volume of the chest cavity increases during inhalation.

40. Explain how the respiratory system prevents most of the foreign matter in the air from reaching our lungs.

41. Describe the effects that smoking has on the lungs of a smoker.

42. Distinguish between blood serum and blood plasma.

43. Explain how a pacemaker sets the heart rate of its user.

44. Distinguish between systolic and diastolic pressure.

45. Over time, arteriosclerosis reduces blood flow through the arteries to the brain. Explain how this might affect a patient with this condition.

46. When a person has pneumonia, their alveoli become inflamed and the air spaces within them become clogged. Describe some of the effects these symptoms will have on a pneumonia patient.

47. Identify the means by which the liver ensures that the body has a constant supply of energy.

48. Describe what is meant by someone having a fast metabolic rate.

49. Describe what happens to a hamburger as it goes through the digestive system.

50. Explain how hormones secreted by the small intestine affect digestion in both the stomach and the small intestine.

51. Identify the uses of proteins in the body.

52. Explain the role of insulin.

53. Explain the role of glucagon. What controls the release of this hormone?

54. A person suffering from diarrhea may become dehydrated. Predict how might this might cause a problem in the body.

55. Describe the major components of a healthy vegetarian diet.

INQUIRY

56. Investigate the types of performance-enhancing substances that are banned in major athletic competitions, such as the Olympics. Distinguish between hormone and non-hormone products. Describe the physiological effects of each substance on the body. How do they disrupt normal homeostatic function? Which effects are temporary or transitory and which can result in permanent alteration of a body structure or function?

57. As you have learned, people with Type 1 diabetes must self-administer insulin injections daily. There are various types of insulin (such as short-acting, intermediate-acting, and long-acting) that patients may need to use to manage their blood sugar. Some examples of these medications are listed below. Investigate the properties of each type of insulin, and describe how each is used in the treatment and management of Type 1 diabetes.

(a) Ultralente insulin **(c)** NPH insulin
(b) Lente insulin **(d)** regular insulin

58. Anaphylaxis is a general term that refers to life-threatening allergic reactions to various types of environmental triggers, such as peanuts or other foods, insect stings, and latex. Investigate four examples of specific stimuli that trigger anaphylactic shock and the recommended treatments for each type of reaction.

59. Most types of living cells, from bacteria to human cells, secrete a substance called "heat shock protein" when they are under stress. The chemical structures of all heat shock proteins are quite similar, regardless of their origin. In humans, T cells may respond to the presence of this protein by destroying the cells that produced it, whether these cells are infectious agents or actually part of the body. Medical researchers believe this action may be part of what causes auto-immune diseases such as diabetes and arthritis. Investigate the latest findings of current research into the potential use of heat shock proteins to treat or even prevent some types of auto-immune diseases in humans. Describe how vaccines containing these proteins may some day be able to inhibit destructive auto-immune activity associated with Type 1 diabetes and other diseases.

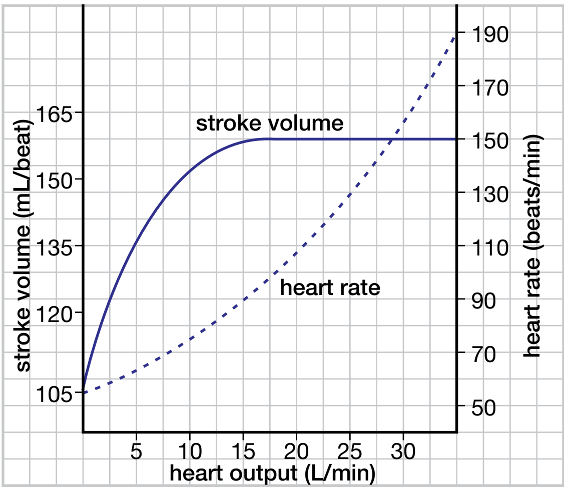
60. Investigate the type of lifestyle factors that can contribute to the onset of Type 2 diabetes in individuals who previously had no visible symptoms of this disease. Investigate how oral hypoglycemic drugs can manage some symptoms of Type 2 diabetes.

61. What is the difference between analgesic and anesthetic medications? How are they used to manage pain? Investigate the differences in the way analgesic and anesthetic medications affect the function of the central and peripheral nervous systems.

62. Narcolepsy, one of many sleep disorders, is a condition in which individuals experience an overwhelming need to sleep at any time during a 24-hour day. People with narcolepsy may also experience abnormal "dreaming sleep" patterns. Investigate the specific causes, symptoms, and management programs associated with this illness.

63. Cyclosporine is the medication most often used in kidney transplant procedures to help prevent rejection of the new organ by the host's immune system. Investigate the physiological action of cyclosporine. How does this medication interact with the immune system to protect a transplanted organ such as a kidney? Also, find out why (in transplant cases) organs from living donors are preferred to cadaver organs.

64. Olympic swimmers can increase the amount of blood pumped by their hearts (heart output) from a resting rate of 5 L/min to over 30 L/min during competition. As shown in the graph, their heart rates, measured in beats/min, and stroke volumes, measured in mL/beat, also increase. Based on the graph, which would you conclude has the greater effect on heart output, stroke volume or heart rate? Justify your answer.



65. Investigate how artificial kidneys filter blood in patients suffering from reduced kidney function or kidney failure. Specifically, compare how the process is carried out by dialysis machines (artificial kidneys) and real human kidneys.

66. Colony stimulating factors (CSFs) are proteins that stimulate the immune system to produce more white blood cells. They are sometimes given to cancer patients to help their immune systems recover from the destructive effects of chemotherapy. Investigate how CSFs help boost immune system activity in cancer patients.

67. You are a scientist on a team in the search of extraterrestrial life. Part of your team has found an organism that cannot be classified as any known species. These teammates believe that this creature is starving, and they ask you to determine what to feed it. Using your knowledge of digestion and nutrition, detail the steps you would take to ensure this creature, possibly from another world, does not starve.

COMMUNICATING

68. Draw a flowchart that illustrates the sequence of changes in the internal concentrations of sodium and potassium in neurons during depolarization and repolarization of a neuron.

69. Starting at the Bowman's capsule, draw a flowchart that illustrates the sequence of changes in the composition of the nephric filtrate as it travels through a nephron.

70. Make an outline drawing of the human body and draw in the organs and tissues that are part of the immune system. Indicate which parts of the immune system create the symptoms associated with an allergic reaction to an environmental allergen, such as plant pollen.

71. Draw a flowchart that illustrates the sequence of events that make up an allergic response to an environmental allergen, such as pollen from flowering plants.

72. Construct a series of feedback loops that illustrate: (a) normal thyroid gland activity; (b) activity of the thyroid gland in individuals with hypothyroidism; and (c) activity of the thyroid gland in individuals with hyperthyroidism. Include the following components in each feedback loop: effector, receptor, integrator. Describe any differences and similarities among these feedback loops.

73. Draw a feedback loop that illustrates how the buffer carbonic acid regulates the pH level of blood (normally about 7.4) as it circulates through the kidney.

74. Draw a reflex arc that involves reflexively removing your foot after stepping on a sharp object, such as a tack. Label each part of the diagram and use arrows to show the direction of nerve impulses along each nerve in the reflex arc.

75. Summarize clearly the relationship between cardiovascular fitness and diet.

76. Controversy stills surrounds the topic of smoking and its effects on both smokers and non-smokers. You are given the responsibility of preparing a case to a parliamentary committee that outlines the impact of smoking on the health, lifestyle, and economics of Canadians. As you prepare your speech and accompanying report, consider how you will address questions and arguments that may be raised by those who support smoking.

77. Being overweight is a concern for many North Americans. A weight-loss consultant claims the problem can easily be solved by surgically removing sections of obese people's digestive systems. You wish to demonstrate to your friends that such a solution could prove dangerous. Prepare a chart that lists the components of the human digestive system in one column and the consequences of removing (a) part of and (b) the entire component in a second column.

78. Cystic fibrosis I is a serious condition of the respiratory system that can lead to death. You are given the responsibility of preparing literature for a new campaign to raise public awareness of this disease. What information would you include in your material?

79. In a chart, list the endocrine glands found in the human body, describe their location, identify the hormones produced by each gland, and describe the hormones' function.

80. Draw a negative feedback loop to illustrate the control of water levels in the human body.

81. Make a sketch that illustrates the structural and functional relationships between the hypothalamus and the two lobes of the pituitary gland.

82. Draw a rough line graph of the changes in a person's blood sugar level over a 24-h day. Show the effects of meals, exercise, sleep, and so on. Label the time of each event on the horizontal axis.

MAKING CONNECTIONS

83. Some common over-the-counter medications, such as various types of analgesics, come with warnings that their use by people with diabetes should be restricted and monitored by a health professional. Why should people with diabetes, or others at risk for kidney disease, be especially cautious about regular or repeated consumption of such products? Should these products be available by prescription only?

84. Many people obtain flu shots each year. What are flu vaccines composed of and what type of immunity do they provide to the recipient? Why can't a single flu vaccine injection provide lifetime immunity? What are the health risks associated with flu vaccinations? Currently, flu vaccines are free for everyone in some provinces, but in other provinces some people have to pay. Find out what the eligibility rules are in a province that does not provide free flu shots to everyone. Should the flu vaccine be made available free to all Canadians?

85. Explain how your knowledge of cells and cell metabolism could be applied to your study of digestion and nutrition.

86. Evaluate how training for a sport requiring strength would differ from training for a sport requiring cardiovascular fitness.

87. The laboratory where you work wants to invent a blood vessel substitute. After evaluating both synthetic and natural materials, which would you recommend to be most suitable? Why?

88. Decide why an individual with an inflammation of the gall bladder might also develop an inflammation of the pancreas.

89. The Canadian government is funding a special five-year study to help determine the causes of heart disease and heart attacks in Canadians. The citizens of a small Labrador town have agreed to participate. You are in charge of designing the study. What will your plan be? What data will you need to collect? How will you obtain the data? What will your hypotheses be? Give reasons for your choices and proposed course of action.

90. Funding medical research often involves funding research in basic science, such as zoology. In this situation, the researcher usually has no medical training, but is a specialist in his or her own field of study. For one hormonal or neurological disorder, identify how research in basic science has helped develop understanding of the medical condition.

91. When conducting drug trials, a test group of people is divided into two groups. One group receives the new drug, and the other group receives a placebo, a treatment that has no active ingredients. While testing a new asthma medication, a test subject claims that she is using the new drug. She is pleased with the product and agrees to be interviewed on television to promote it. Has this person compromised the study? Justify your response.

92. People have easier access to diet supplements such as vitamins, minerals and various plant extracts such as *Echinacea* than to prescription drugs. *Echinacea* is promoted as an immune-system boost. Some proponents claim that it should be used daily, while others suggest that people add it to their diets only when they are most at risk, such as during flu season. Since *Echinacea* is an uncontrolled substance, might it be abused, thus creating problems for our health care system and society in general? Explain your response.