CHAPTER

13

Hormonal Regulation of Homeostasis

Chapter Concepts

13.1 The Glands and Hormones of the Endocrine System

- The endocrine system functions with the nervous system to regulate other body systems and maintain homeostasis.
- The endocrine glands secrete hormones directly into the bloodstream.
- Hormone secretion is regulated by the nervous system, other hormones, or negative feedback mechanisms.

13.2 Hormonal Regulation of Growth, Development, and Metabolism

- The hypothalamus regulates the pituitary gland, which secretes tropic hormones that affect various endocrine glands.
- Human growth hormone mainly affects bone and muscle growth. The thyroid hormones stimulate metabolism.

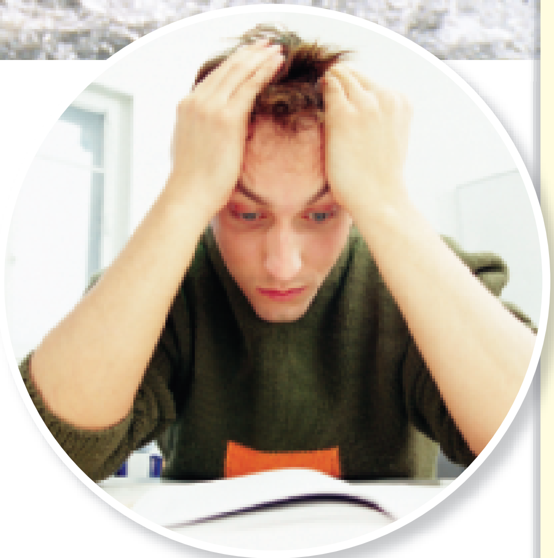
13.3 Hormonal Regulation of the Stress Response

- The hormones of the adrenal glands regulate the short-term and long-term stress responses.

13.4 Hormonal Regulation of Blood Sugar

- The hormones of the pancreas act antagonistically to maintain blood glucose levels within a narrow range. Diabetes results from improper regulation of blood glucose.

The bear moves cautiously toward the stream. For his body to maintain homeostasis, he must drink. But before he does, he is surprised by a growl from behind him. Terror pulses through his body and he whirls to face his attacker. It is another Kodiak bear (*Ursus arctos middendorffi*), the giant Alaskan grizzly. This could be the final challenge of his life. In this instant between survival and death, his body's endocrine system will ready him to fight or run away to safety. In humans and other animals, the endocrine system produces chemical messengers called hormones that regulate various systems of the body, including the response to perceived danger. When you are facing a threat, what physiological processes occur in your body? Which of these processes do hormones control? Chapter 13 explores the role of hormones in responding to danger and in regulating human systems.



Launch Lab

Modern Stress!

Exams, deadlines, and bills can all trigger a person's stress response. These stressors are not life threatening. Nevertheless, the body often responds as if they were, and produces the same physiological changes that would occur in a truly dangerous situation. In this activity, you will monitor one of the changes that occur in the body in response to a stressful, although not life-threatening, situation.

Safety

Do not take the role of the subject in this activity if you have an underlying medical condition, such as high or low blood pressure, that is made worse by stress.

Materials

- test questions
- stopwatch

Procedure

1. Work with a partner. One person will be the subject, and the other partner will be the tester.
2. The tester will obtain a stopwatch from your teacher. The subject will sit at a desk for 1 min with eyes closed and taking deep, relaxing breaths.
3. At the end of the relaxation period, the tester will take and record the subject's pulse over 1 min.
4. The tester will obtain a test from your teacher. The tester will give the test to the subject, who will have 2 min to complete the test.
5. Start the stopwatch when the subject starts the test.
6. At the end of the 2 min, shout "time's up!" and immediately take and record the subject's pulse over 1 min.

Analysis

1. Calculate the subject's pulse rate (beats per min) before and after writing the test.
2. List the main physiological changes that occurred in the subject while writing the test. (**Hint:** See Chapter 11, page 397.)
3. How would the physiological changes that you listed in question 2 be useful responses to a life-threatening situation?
4. List ten or more stressful situations that people in modern societies may experience. Which of these are truly dangerous? Which, if any, might be considered positive?

SECTION 13.1

The Glands and Hormones of the Endocrine System

Section Outcomes

In this section, you will
- **explain** how the endocrine system contributes to homeostasis
- **compare** the nervous system with the endocrine system
- **identify** the principal endocrine glands in the human body and the hormones they secrete
- **explain** how the endocrine system allows the body to sense and respond to the internal environment
- **explain** the relationship between negative feedback and hormonal regulation in the body
- **explain** how the endocrine system is involved in seasonal affective disorder (SAD) and the sleep-wake cycle

Key Terms

endocrine glands
hormones
endocrine system
negative feedback mechanisms
antidiuretic hormone (ADH)
tropic hormones

Figure 13.1 This synchronized swimmer relies on various body systems in order to perform her routine. The organs of her body's systems are composed of trillions of cells, some of which help to carry oxygen, remove wastes, move muscles, and hear sounds. Some cells communicate critical information from one area of the body to another.

The synchronized swimmer in Figure 13.1 relies on complex internal systems in order to hold her breath and swim in time to the music, while continuing to maintain homeostasis. Her respiratory, metabolic, and muscular-skeletal systems, for example, are regulated and co-ordinated. This means that the functioning of the over 100 trillion diverse cells making up the tissues and organs of her body must also be regulated and co-ordinated, and, therefore, the cells must be able to communicate with one another. The body systems that facilitate cellular communication and control are the nervous and endocrine systems (Figure 13.2).

Nervous system messages tend to be transmitted rapidly to precise locations in the body, such as the reflex arc that causes you to withdraw your hand from a hot stove. In addition to cellular communication through neurons, the body secretes chemical messengers from glands. **Endocrine glands** secrete chemical messengers called **hormones** directly into the bloodstream, which transports the hormones throughout the body. The original Greek meaning of the word *hormone* is "to excite" or "set in motion." As shown in Figure 13.3, when hormones reach their target cells, their interaction with these cells sets in motion specific regulatory responses. The action of the pancreas is an example

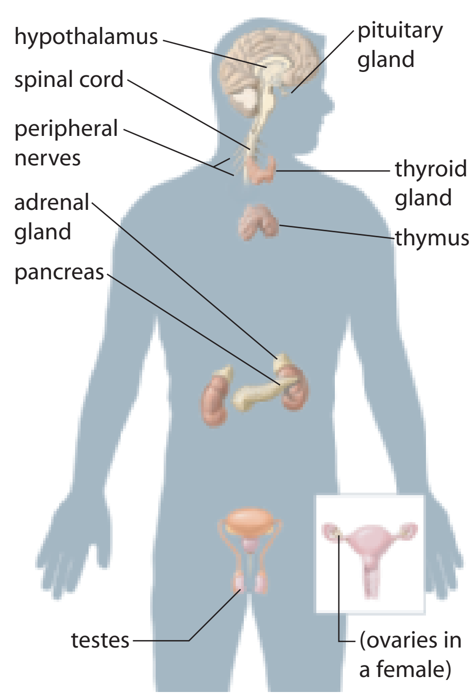


Figure 13.2 Some of the key glands of the endocrine system superimposed on the nervous system. How do the two systems work together to regulate homeostasis?

of this. Figure 13.4 shows the pancreas, an endocrine gland that secretes the hormone insulin into the bloodstream. Insulin affects its target cells by making them more permeable to glucose.

The endocrine glands and the hormones that they secrete make up the **endocrine system**. Compared to the rapid actions of the nervous system, the endocrine system typically has slower and longer acting effects, and affects a broader range of cell types.

Homeostasis depends on the close relationship between the nervous system and the endocrine system. Note, however, that the distinction between these two systems is often arbitrary. For example:

- Some nervous system tissues secrete hormones, such as cells in the hypothalamus, pituitary gland, and adrenal glands.
- Several chemicals function as both neurotransmitters and hormones, depending on their location in the body. An example is epinephrine, which acts as a neurotransmitter between certain neurons in the nervous system, and as a hormone released by the adrenal glands in the fight-or-flight response.
- The endocrine and nervous systems both include responses that are regulated by negative feedback loops.
- The regulation of several physiological processes involves both the nervous and endocrine systems acting in conjunction with each other. For example, when a mother breast-feeds her baby, the baby's suckling initiates a sensory message in the mother's neurons that travel to the hypothalamus, which in turn triggers the pituitary to release a hormone called oxytocin. Oxytocin travels in the bloodstream to the mammary glands of the breast, causing the secretion of milk.

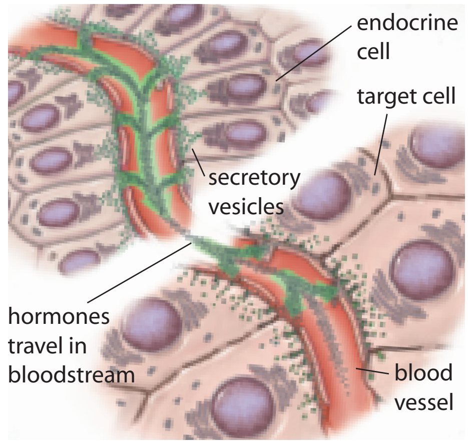


Figure 13.3 Endocrine gland secretion of hormones. How are the actions of the endocrine system different from the actions of the nervous system?

1. Why do nervous system responses tend to be more rapid than endocrine system responses?
2. Define the term *hormone* using a specific example.
3. Provide four reasons why the distinction between the nervous and endocrine systems is sometimes blurred.

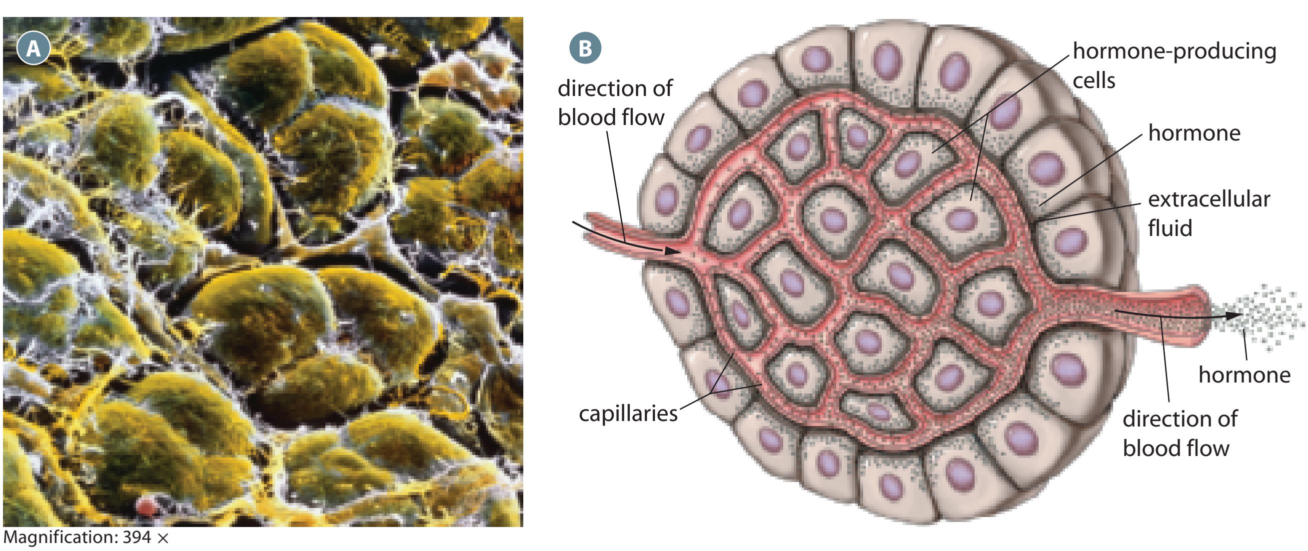
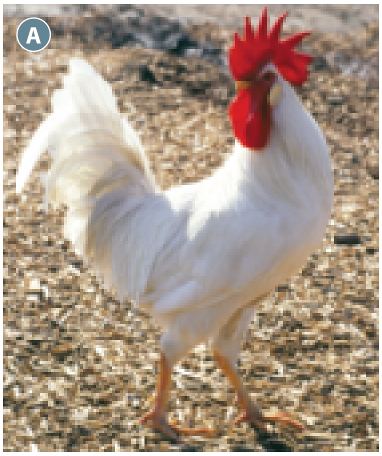


Figure 13.4 **(A)** A false-colour scanning electron micrograph and **(B)** a drawing of pancreas tissue. The hormone-producing cells are surrounded by blood vessels.



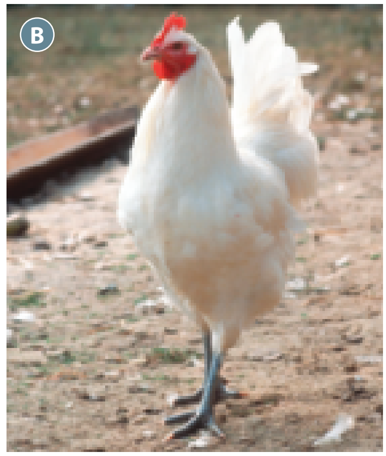


Figure 13.5 (A) An intact male rooster and **(B)** a castrated rooster (called a capon). What differences can you note between the capon and the other rooster?

From Hypothesis to Evidence

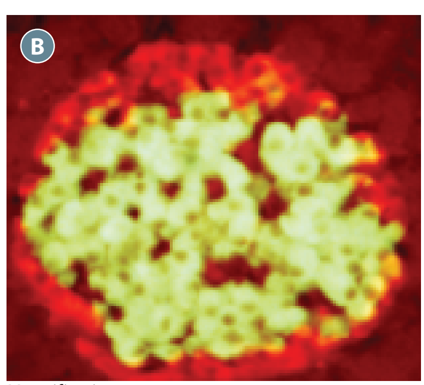
The first experiment to establish the link between hormones and the activity of their target organs is credited to Arnold Adolph Berthold of Göttingen University, in Germany. In 1849, Berthold experimented with roosters by removing their testes and observing the effects on the birds, now called *capons*. Unlike the intact roosters, the capons did not crow, fight with other roosters, or try to mate. The capons did not grow very large or develop the typical male rooster plumage (Figure 13.5). When Berthold replaced the testes into the capons, they began to look and behave like typical male roosters. Since the replaced organs were not connected to any nerves, Berthold concluded that the testes were releasing something into the bloodstream that caused the developmental changes in the male birds. Scientists later identified this substance as the hormone testosterone.

Researchers went on to study the function of other endocrine glands by removing them from test animals and observing the effects. These early techniques did not always provide useful results, however, because different hormones often work together, and in fact, another gland or hormone can compensate for one that is missing. Also, some glands produce more than one hormone. For example, the parathyroid glands are embedded in the thyroid tissue. Both tissues produce different hormones, however, which have different effects on the body.

Another complication is that the concentration of most hormones in the bloodstream is extremely low (10^{-8} to 10^{-12} mol/L). This is comparable to one drop of water in a swimming pool. Furthermore, they are not released continuously. Their release can be triggered by environmental factors, or may follow a pattern that repeats over hours, weeks, or every year.

More recently, nuclear scanning devices (such as PET) and high-powered microscopes have allowed scientists to visualize glands, hormones, and target cell

Magnification: 3720 ×



Magnification: 304.5 ×

Figure 13.6 (A) A scanning electron micrograph of thyroid tissue. The image has been coloured using a computer so that the hormone (in yellow) can be seen being secreted from chambers in the thyroid (in pink), which are nourished by blood capillaries (in grey). **(B)** Stained hormone-secreting cells of the pancreas as seen using a fluorescence microscope. The different hormones of the pancreas are stained with different colours, which are attached to hormone-specific antibodies. **(C)** Nuclear scan of a thyroid gland. Radioactive iodide makes the thyroid highly visible. The orange and red areas indicate the most active areas of the tissue.

membranes in great detail. Figure 13.6A shows a portion of the thyroid gland and the capillary network that nourishes it. At a magnification of 3720 ×, this image also shows a hormone that is being secreted by the thyroid. In another technique, fluorescent stains are used to colour the different hormones in a tissue sample. To view endocrine glands in the living body, doctors can have patients ingest capsules containing a small amount of radioactive material—effectively the same amount of radiation someone would receive from a standard X ray. The radioactive material, or tracer, accumulates in specific glands, which makes them easy to distinguish in PET scans or by other nuclear scanning techniques.

Q4 How did Adolph Berthold's experiment with roosters demonstrate the function of an endocrine gland?

Q5 What are some of the challenges for researchers studying the endocrine system?

Q6 Briefly describe two technologies used to study hormones and endocrine glands.

Hormone Action on Target Cells

Scientists have identified over 200 hormones or hormone-like chemicals in the human body. Some regulate growth and development, others speed up or slow down the body's metabolism, while others regulate blood pressure or the immune response. Figure 13.7 shows the location in the body of the major and best studied endocrine glands: the hypothalamus, and pituitary, pineal, thyroid, parathyroid, and adrenal glands, as well as the pancreas, the testes, and the ovaries. Table 13.1 on page 440 provides an overview of some of these glands, the hormones they release, and their effects on target tissues and organs.

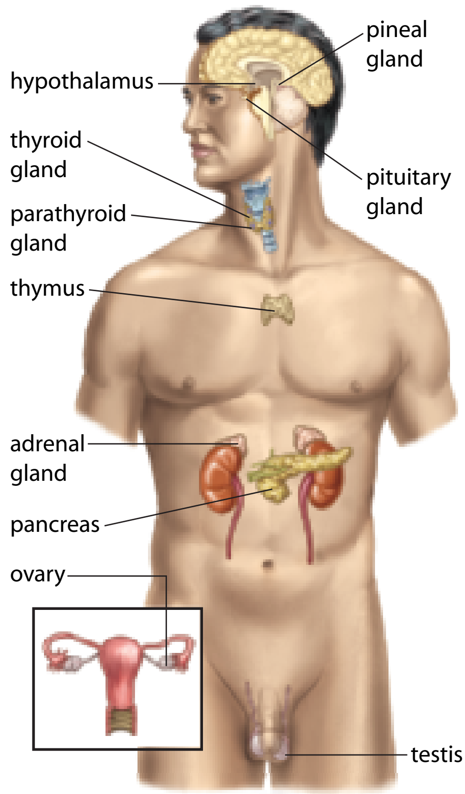


Figure 13.7 The anatomical location of the major endocrine glands of the body. The role of the thymus gland in the immune system is noted in Chapter 8.

When hormones encounter their target cells, how do they affect them? Each target cell contains *receptor proteins*. Circulating hormones bind to their specific receptor proteins, much like a key fits into a lock. For example, human growth hormone (hGH) circulates in the bloodstream and interacts with liver, muscle, and bone cells. Each of these cell types contains receptor proteins specifically shaped to bind with hGH (Figure 13.8). When the hormone binds to its receptor, this triggers other reactions in the target cell. In other words, the target cell receives and responds to the chemical message sent by the hormone.

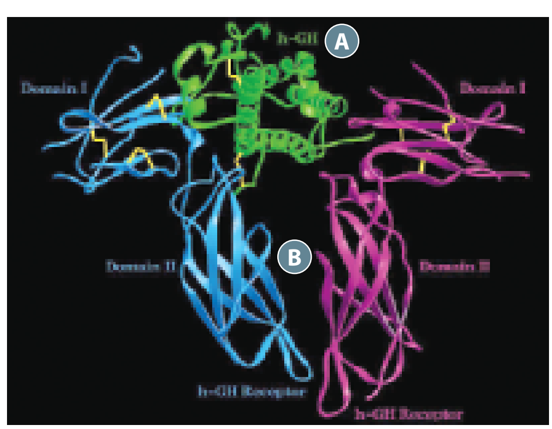


Figure 13.8 A model of **(A)** hGH (in green) bound to **(B)** its protein receptor (in blue and purple). Each hormone of the endocrine system has a unique molecular shape, which fits into a specific receptor protein on its target cells.

Table 13.1 The Principal Endocrine Glands and Some of their Hormones

Endocrine Gland	Hormone Secreted	Effects of Hormone on Target Tissues/Organs
hypothalamus	hypothalamic releasing- and inhibiting-hormones	regulates anterior pituitary hormones
anterior pituitary	human growth hormone (hGH)	stimulates cell division, bone and muscle growth, and metabolic functions
	thyroid-stimulating hormone (TSH)	stimulates the thyroid gland
	adrenocorticotropic hormone (ACTH)	stimulates the adrenal cortex to secrete glucocorticoids
	follicle-stimulating hormone (FSH)	stimulates production of ova and sperm from the ovaries and testes
	luteinizing hormone (LH)	stimulates sex hormone production from the ovaries and testes
	prolactin (PRL)	stimulates milk production from the mammary glands
posterior pituitary	antidiuretic hormone (ADH)	promotes the retention of water by the kidneys
	oxytocin (OCT)	stimulates uterine muscle contractions and release of milk by the mammary glands
thyroid	thyroxine (T_4)	affects all tissues increases metabolic rate and regulates growth and development
	calcitonin	targets bones and kidneys to lower blood calcium by inhibiting release of calcium from bone and reabsorption of calcium by kidneys
parathyroid	parathyroid hormone (PTH)	raises blood calcium levels by stimulating the bone cells to release calcium, the intestine to absorb calcium from food, and the kidneys to reabsorb calcium
adrenal cortex	glucocorticoids (e.g., cortisol)	stimulate tissues to raise blood glucose and break down protein
	mineralocorticoids (e.g., aldosterone)	promote reabsorption of sodium and water by the kidneys
	gonadocorticoids	promote secondary sexual characteristics
adrenal medulla	epinephrine and norepinephrine	fight-or-flight hormones raise blood glucose levels
pancreas	insulin	lowers blood glucose levels and promotes the formation of glycogen in the liver
	glucagon	raises blood glucose levels by converting glycogen to glucose
ovaries	estrogen	stimulates uterine lining growth and promotes development of the female secondary sexual characteristics
	progesterone	promotes growth of the uterine lining and prevents uterine muscle contractions
testes	testosterone	promotes sperm formation and development of the male secondary sexual characteristics

Lipid-Soluble and Water-Soluble Hormones

Hormones are composed of either lipids or amino acids. Steroid hormones, such as testosterone, estrogen, and cortisol, are lipid-based. Therefore, these hormones can easily diffuse through the lipid bilayer of cell membranes. Inside the target cell, steroid hormones bind to their receptor proteins. This interaction activates specific genes, causing changes in the cell. For example, estrogen can trigger cell growth.

Epinephrine, human growth hormone, thyroxine, and insulin are water-soluble hormones. Water-soluble hormones, such as amino-acid based hormones, cannot diffuse across the cell membrane. Typically, a water-soluble hormone will bind to a receptor protein on the surface of the target cell. This starts a cascade of reactions inside the target cell. Much like a phone fan-out in which everyone on a list phones several other people, each reaction that occurs in the target cell triggers many other reactions. As a result of this process, the impact of the hormone is greatly amplified. This is why a single molecule of epinephrine in the liver can trigger the conversion of available glycogen into about one million molecules of glucose. Once a hormone's message has been delivered, enzymes inactivate the hormone, since any lingering effect could potentially be very disruptive.

7. What are the two major groups of hormones? How do they interact with their target cells?
8. How does a hormone stimulate a response in a target cell?
9. Identify which glands secrete the following hormones: thyroxine, human growth hormone, cortisol, insulin, and glucagon.

Regulating the Regulators

Many hormones are regulated by **negative feedback mechanisms**, or loops. When a certain blood concentration of hormone is reached, or when target cells have responded to a specific hormone, the endocrine gland releasing the hormone is inhibited. Thus, the release of the hormone slows.

In Chapter 9, you learned how **antidiuretic hormone (ADH)** and aldosterone regulate water reabsorption by the kidneys (Figure 13.9). When the blood plasma becomes too concentrated, receptors in the hypothalamus detect this and send a neural signal to the posterior pituitary gland to release ADH. ADH targets the nephrons of the kidneys, causing the tubules to become more permeable to water. As a result, more water is reabsorbed, the body excretes less (but more concentrated) urine, and blood pressure increases. The hypothalamus detects this and sends a signal to the posterior pituitary to stop secreting ADH.

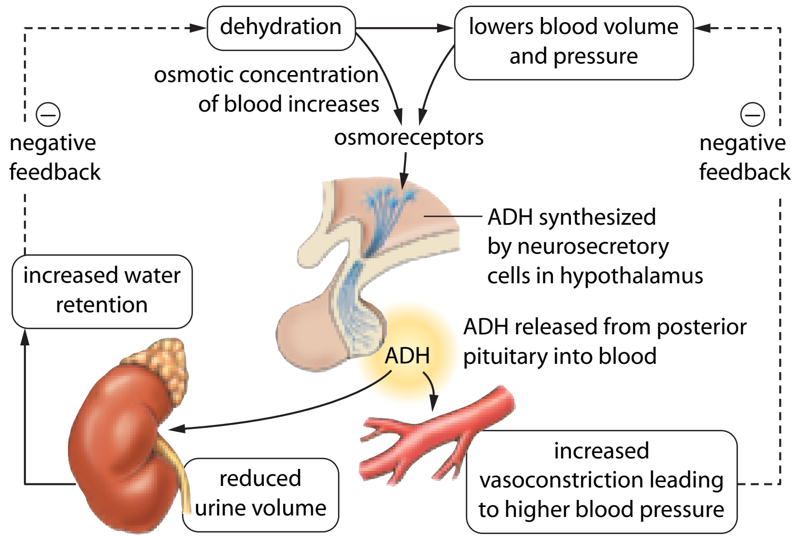


Figure 13.9 A negative feedback mechanism controls the secretion of ADH from the hypothalamus.

The inability to produce ADH causes diabetes insipidus—a condition in which a person produces large volumes of urine with a resulting loss of ions from the blood. The condition can be corrected by administering ADH.

Many of the hormones released from the anterior pituitary and the hypothalamus are called **tropic hormones**, which means that their targets are other endocrine glands. Tropic hormones stimulate endocrine glands to release other hormones. Figure 13.10 shows the general mechanism of action of tropic hormones. Typically the hypothalamus secretes a releasing hormone into the anterior pituitary. This causes the anterior pituitary to release a tropic hormone into the bloodstream. The tropic hormone then stimulates the

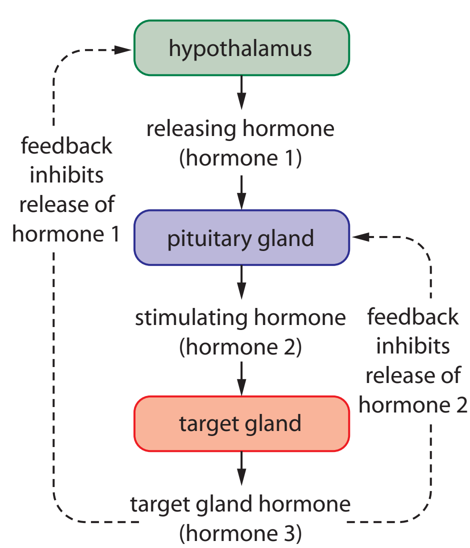


Figure 13.10 The generalized regulatory pathway of tropic hormones. The target gland hormone will affect other tissues in the body, such as the bones and muscles. How are tropic hormones regulated by negative feedback?

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FYI
Bedwetting is not always a matter of weak self-control. Some children wet their beds because their bodies do not produce enough ADH. In this case, an ADH nasal spray can be used to address the situation.

target gland to release a third hormone into the blood. This hormone travels to another target tissue and produces an effect. This system is also controlled by a negative feedback loop in which the third hormone prevents further release of the first two hormones in the pathway.

10. Describe how the secretion of ADH is regulated by negative feedback.

11. What is a tropic hormone?

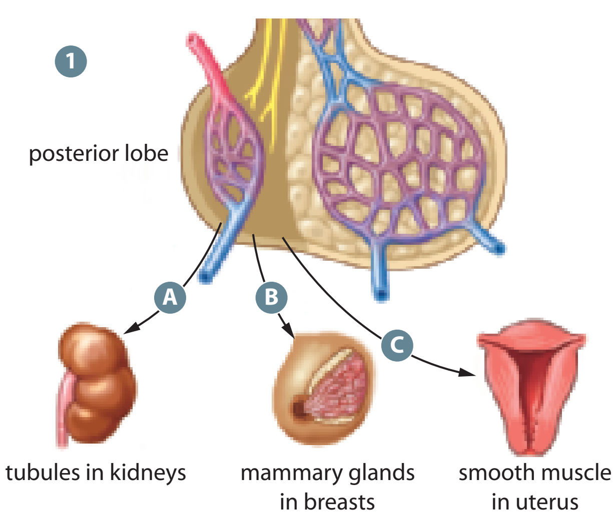
12. How is the secretion of tropic hormones from the pituitary gland regulated?

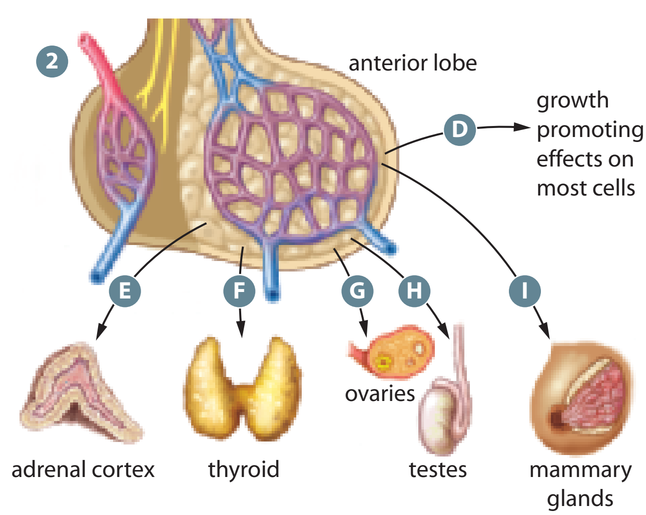
Section 13.1 Summary

- The nervous and endocrine systems are self-regulating, and help regulate other body systems, thereby maintaining homeostasis.
- The nervous system rapidly affects specific tissues, to which it is directly connected by neurons. The endocrine system relies on chemical messengers called hormones, which circulate in the blood, and have broad, long-lasting effects.
- The endocrine glands have no ducts, and secrete hormones directly into the bloodstream.
- Hormones trigger changes in their target cells when they bind to receptor proteins on or within the cells.
- Tropic hormones stimulate endocrine glands to produce other hormones.
- Many hormones are regulated by negative feedback mechanisms. For example, ADH is released when the blood plasma concentration is high (and blood pressure is low). ADH stimulates the kidneys to absorb more water, which dilutes the blood plasma (and increases blood pressure).

Section 13.1 Review

1. Define homeostasis and explain how the endocrine system helps to maintain homeostasis in the body.
2. Use an example to explain how the nervous and endocrine systems work together to regulate a response in the body.
3. Use the following diagrams to answer this question. For each diagram (1 and 2), in your notebook, list the hormones that are released by the pituitary and indicated by letters (A) through (I). List a major effect that each hormone has on its target organ.
4. Draw and describe a negative feedback mechanism for a thermostat. How is this feedback mechanism similar to how some hormones are regulated in the body? ICT
5. Suppose a scientist has discovered a new hormone. It is not clear what gland produces the hormone, but people who produce above average amounts of this hormone also produce very high levels of insulin. Based on your knowledge of how tropic hormones function, provide a possible explanation for the observation.





Light up Your Life!

During our northern winters, daylight hours are few. One out of every four people living in North America has difficulty adjusting to this shortage of sunlight and may experience symptoms of Seasonal Affective Disorder (SAD). SAD can cause fatigue, poor concentration, irritability, carbohydrate cravings, weight gain, social withdrawal, and a low sex drive. These problems generally disappear in the spring when the days start becoming longer.

Melatonin: The SAD Hormone

Melatonin is a naturally produced hormone that lets the body know when it is time to sleep and when to wake up. Darkness stimulates the secretion of melatonin and light inhibits its secretion. It is made at night by the pineal gland, a pea-sized endocrine gland located in the middle of the brain. When light hits the retina, the eye sends a message to the hypothalamus. The hypothalamus then signals the pineal gland to stop producing melatonin. When people are not exposed to enough light to turn off melatonin secretion, they may experience the symptoms of SAD.

Consider how you feel on a bright summer day compared to a cloudy winter day. Since light plays a key role in melatonin secretion, some doctors use light therapy to treat people with SAD. The person is exposed to a bright light source for 15–60 min every day. The light source is usually a light board that produces a colour of light optimal for melatonin suppression. Light therapy also stimulates the body's production of serotonin, a hormone and neurotransmitter that makes people feel energized. The treatment provides benefit to about 80 percent of people who are experiencing SAD.

The Circadian Rhythm

Recently, light therapy has been used to help people overcome the fatigue associated with loss of sleep, shift work, and jet leg. Larry Pederson of Medicine Hat, Alberta, has been a long time user of light therapy for SAD. Along with a team of industrial design students from the University of Calgary, Pederson has developed the Litebook®, a small, portable light board. Standard light boards are fairly large, and people cannot travel with them. The Litebook®, however, makes it much easier for people to receive light therapy. Some libraries and airports now have Litebook® stations, and many gyms have installed the light board on exercise equipment.

Light therapy could even help you and other teens. Have you ever wondered why you just cannot stay awake in class, no matter how hard you try? Each day, your internal clock tells your body when to be sleepy and awake. This is called your *circadian rhythm*. Starting at puberty, in most people the circadian rhythm slows down by several hours. This can make you feel wide-awake at night, but sleepy in the morning. This shift in the circadian rhythm often lasts into the early twenties, which makes it difficult for many teens to be in learning mode before noon.

But there may be a way to help teenagers wake up in the morning. Clinical research confirms that light therapy administered to teens for 30–40 min in the morning reduces melatonin production. This helps teens to feel more alert in the morning, and allows them to fall asleep sooner at night. Maybe someday your desk at school will be equipped with a Litebook®, but unfortunately you will no longer have an excuse for dozing in class!

• • •

1. Explain why people living in Canada may be more susceptible to Seasonal Affective Disorder (SAD) compared to people who live farther south.
2. How do innovative technologies such as the Litebook® contribute to society?

SECTION 13.2

Hormonal Regulation of Growth, Development, and Metabolism

Section Outcomes

In this section, you will
- **describe** the structure of the anterior and posterior pituitary and **explain** how they are regulated
- **explain** how human growth hormone (hGH) contributes to healthy growth and development
- **evaluate** the use of hormone therapy
- **describe** the structure and regulation of the thyroid gland, and its role in homeostasis
- **describe** the physiological effects of hormonal imbalances
- **formulate** a hypothesis about an environmental factor to which the endocrine system responds

Key Terms

pituitary gland
posterior pituitary
anterior pituitary
human growth hormone (hGH)
thyroid gland
thyroxine (T_4)
hypothyroidism
hyperthyroidism
thyroid-stimulating hormone (TSH)
goitre

BiologyFile

FYI
The hormones of the pituitary are released in such small quantities that when researchers were originally searching for them, four tonnes of hypothalamic tissue from animal subjects were needed to extract 1 mg of hormone.

The **pituitary gland** is an endocrine gland that has two lobes and is about one centimetre in diameter—about the size of a pea. It sits in a bony cavity attached by a thin stalk to the hypothalamus at the base of the brain (Figure 13.11). If you point a finger right between your eyes, and point another finger towards your auditory canal, you will be pointing at your pituitary gland, which is located at the spot where the imaginary lines cross. Despite its small size, this gland releases at least eight hormones involved in the body's metabolism, growth, development, reproduction, and other critical life functions. In fact, it has been called "the master gland" because it releases several tropic hormones. The pituitary gland is controlled by the hypothalamus via releasing hormones and neurons that run through the connecting stalk. Together, the hypothalamus and pituitary gland control many physiological processes that maintain homeostasis.

The anterior pituitary and posterior pituitary make up the two lobes of the pituitary gland. Each lobe is really a separate gland, and they release different hormones. The **posterior pituitary** is considered part of the nervous system. The posterior pituitary does not produce any hormones; instead, it stores and releases the hormones, ADH and oxytocin, which are produced in the hypothalamus and transferred to the posterior pituitary by neuronal axons (Figure 13.12).

The **anterior pituitary** is a true hormone-synthesizing gland. Its cells produce and release six major hormones: human growth hormone (hGH), prolactin (PRL), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), and leutinizing hormone (LH). A series of blood vessels called a portal system carries releasing hormones from the hypothalamus to the anterior pituitary, and these hormones either stimulate or inhibit the release of hormones from this gland.

The hormones of the pituitary will be studied in detail in the remainder of this chapter and in the next unit on human reproduction.

Human Growth Hormone

The anterior pituitary regulates growth, development, and metabolism through the production and secretion of **human growth hormone (hGH)**. This hormone ultimately affects almost every body tissue. It can affect some tissues by direct stimulation, but the majority of the effects are tropic. Figure 13.11 shows how hGH stimulates the liver to secrete hormones called growth factors. Together, hGH and the growth factors influence many physiological processes. For example, they increase:
- protein synthesis
- cell division and growth, especially the growth of cartilage, bone, and muscle
- metabolic breakdown and release of fats stored in adipose (fat) tissue

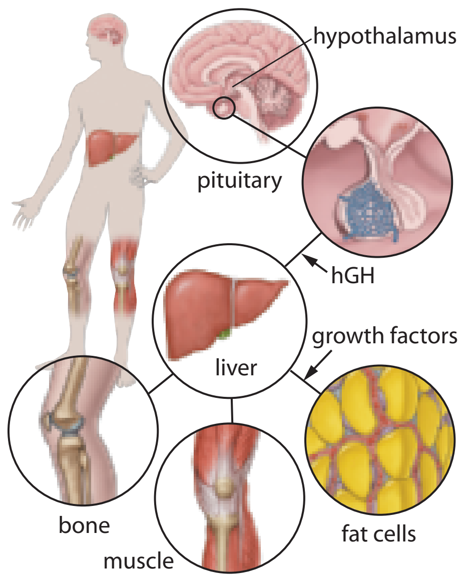


Figure 13.11 The targets of hGH in the body. Why is hGH considered a tropic hormone?

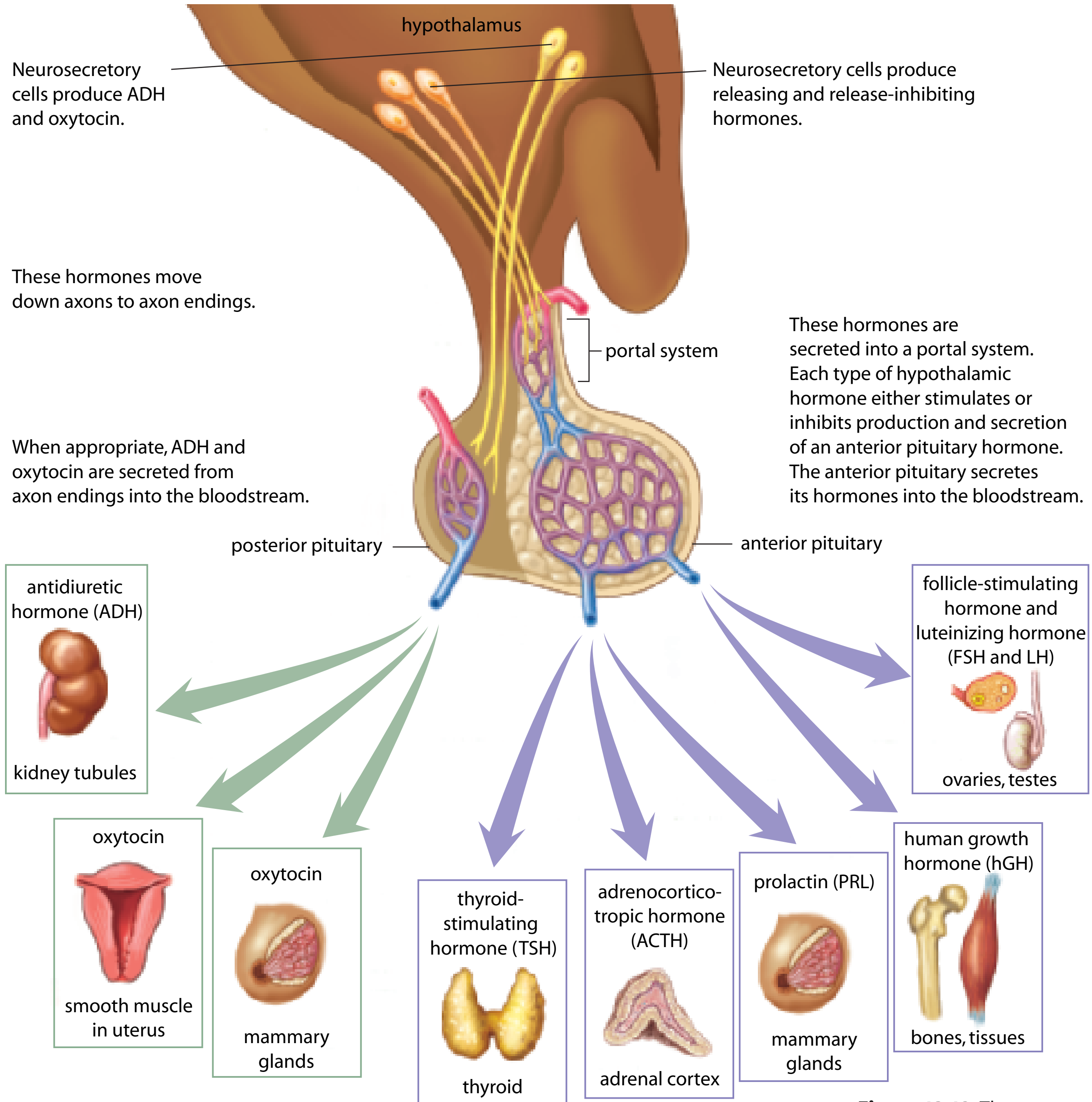


Figure 13.12 The hormones of the pituitary gland. The hypothalamus regulates the release of hormones from the anterior pituitary and posterior pituitary.

hGH stimulates the growth of muscles, connective tissue, and the growth plates at the end of the long bones, which causes elongation of these bones. If the pituitary gland secretes excessive amounts of hGH during childhood, it can result in a condition called gigantism (Figure 13.13 on page 446). Insufficient hGH production during childhood results in pituitary dwarfism. In this case, an affected person will be of extremely small stature as an adult but will have typical body proportions (Figure 13.14 on page 446).

When someone reaches adulthood and skeletal growth is completed, overproduction of hGH can lead to a condition called acromegaly. The excess hGH can no longer cause an increase in height, and so the bones and soft tissues of the body widen. Thus, over time, the face widens, the ribs thicken, and the feet and hands enlarge. The condition not only affects a person's appearance. As Figure 13.15 shows, some of the effects of untreated acromegaly include cardiovascular diseases, sugar intolerance

Figure 13.13 Robert Wadlow, the tallest human being ever known, had an anterior pituitary tumour, which caused the overproduction of hGH and his resulting growth. He stood 2.7 m tall and was growing taller when he died at 22 years. This photograph shows him with his brother and father.

Figure 13.14 Pituitary dwarfism results in short stature, but does not otherwise affect physical growth, or mental or sexual development.

leading to diabetes, breathing problems, muscle weakness, and colon cancer.

Scientists first began to understand the function of hGH by studying and treating children with insufficient hGH production, leading to dwarfism. Researchers found that by injecting the children with material from pituitary gland tissue from human cadavers, the children often grew taller. Sadly, some of the children who received hGH treatment were infected by a form of Creutzfeldt-Jakob disease and died. In addition to the risk of infection with this procedure, it is difficult to obtain sufficient quantities of hGH from organ donations. Since 1985, however, genetic engineering has been used to produce synthetic hGH. The gene that codes for hGH is inserted into bacteria. The altered and rapidly producing bacteria are biological factories that make hGH. You will explore the issues surrounding the use of synthetic hGH in the next investigation.

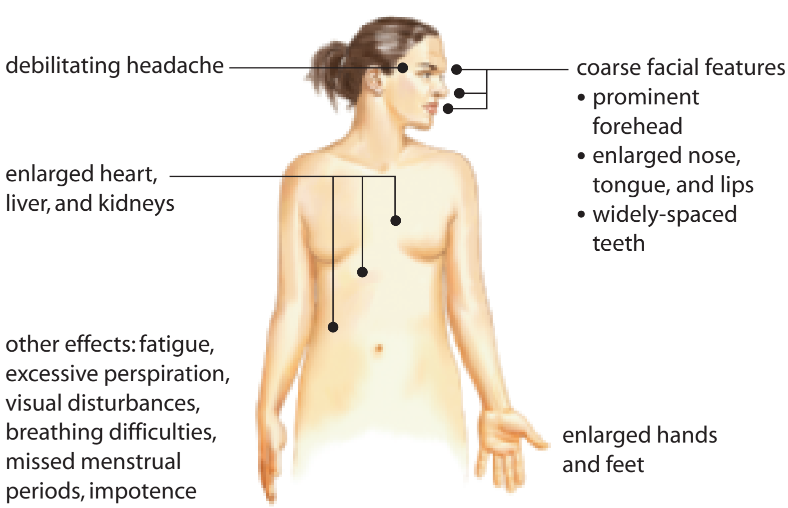


Figure 13.15 Acromegaly results from excessive production of hGH during adulthood. It may be difficult to diagnose the condition in the early stages before a person's appearance noticeably changes.

13 Compare the anterior and posterior pituitary.

14 List three effects of hGH on the body.

The Thyroid Gland: A Metabolic Thermostat

Do you know someone who can eat anything, without ever gaining weight? You might have heard that this person has a high metabolism (burns stored energy very quickly). Is it biologically possible to have a high or low metabolism? How do the thyroid hormones influence the metabolic rate? What happens when there is an imbalance of thyroid hormones or a nutrient deficiency?

As shown in Figure 13.16 on page 448, the **thyroid gland** lies directly below the larynx (voice box). It has two lobes, one on either side of the trachea (windpipe), which are joined by a narrow band of tissue. Millions of cells within the thyroid secrete immature thyroid hormones into the chambers between the cells. Here, one of these hormones, **thyroxine** (T_4), will become functional and be released into the bloodstream. The primary effect of thyroxine is to increase the rate at which the body metabolizes fats, proteins, and carbohydrates for energy. Thyroxine does not have one specific target organ, but especially stimulates the cells of the heart, skeletal muscles, liver, and kidney to

INVESTIGATION 13.A

Target Skills

Evaluating the use of synthetic hGH treatment of humans

Working with a team in addressing an issue and **communicating** findings

Evaluating Potential Uses for Human Growth Hormone

Issue

Since the approval of the restricted use of synthetic hGH, concerns have arisen about its use and potential abuse. Health Canada has approved extremely limited use of the hormone, which is very expensive ($25 000 or more per year) and is associated with several negative health effects. Should Health Canada approve the widespread use of synthetic hGH for Canadians?

Gathering Data and Information

1. Suppose Health Canada is re-evaluating its regulations for the use of synthetic hGH and is asking for input on the matter. Your group will address one of the issues described in the table. Read the description of the issue. You may wish to research it further using library or Internet resources. As a group, you will write a list of questions that you think should be addressed before Health Canada takes action on this issue. Your questions should address ethical and safety concerns, and possibly specific guidelines for any new regulations.

Issue 1
Until recently, the use of synthetic hGH was approved only for those children who had malfunctioning pituitary glands and could not produce adequate amounts of the hormone themselves. Recently, the use of synthetic hGH has been approved for children who are genetically of short stature. Should people have the option to take synthetic hGH just to increase their genetically predetermined height?
Issue 2
In adults, the production of natural hGH declines with age. This makes it increasingly difficult to reduce one's body fat as one ages. Given that obesity has reached epidemic levels in the North American population, and one of the functions of hGH in the body is to reduce cellular fat, should synthetic hGH be approved as a diet treatment for obesity?
Issue 3
Because one of the functions of hGH in the body is to build lean muscle mass, its use has become widespread among various athletes. In fact, many athletes at the 1996 summer Olympic games in Atlanta, Georgia, referred to the event as the "hGH Games." Despite its expense, many athletes from baseball players to weightlifters are acquiring synthetic hGH because it is difficult for drug testers to detect. Should competitive athletes be allowed legal access to synthetic hGH?

Organizing Findings

2. Suppose you are attending a forum on hGH use held by Health Canada. Your group has 5 min to present your list of questions to the delegates (your class). You may use visual aids such as computer generated slides, overheads, or a poster. You will have another 5 min to respond to questions from the audience.

Opinions and Recommendations

3. Listen to the other presentations, and then answer the following questions:
   a) What are the main questions that Health Canada should investigate before changing its regulations on the use of synthetic hGH?
   b) Why might parents want synthetic hGH for their children? What should parents be aware of before deciding to obtain hGH for their children?
   c) Should athletes be allowed to use synthetic hGH? Why or why not?
   d) Should health insurance cover the use of synthetic hGH, and if so, in which circumstances?
4. Create a table in your notebook to record the major societal risks and benefits of approving the use of synthetic hGH in the three situations discussed in the forum. As a class, discuss the arguments for both sides of the issues.

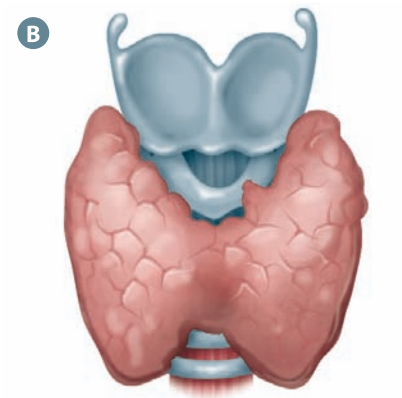


Figure 13.16 **(A)** Silhouette of the human body showing the location of the thyroid gland. **(B)** A close up illustration of the thyroid gland. **(C)** Micrograph of the cells that make up the thyroid, which produce the hormone thyroxine, also called T_4.

BiologyFile

FYI

Hypothyroidism can be treated with daily doses of thyroxine. Traditionally, pills were made from desiccated cow, sheep, or pig thyroid. Ground-up extracts could contain varying levels of hormone. Current treatments usually use a pure synthetic form of thyroxine produced in a laboratory.

Hyperthyroidism can be treated with drugs that interfere with the efficiency of the thyroid gland in producing hormones. Radioactive iodine can also be used to selectively damage or kill thyroid cells.

increase the rate of cellular respiration. Thyroxine also plays an important role in the growth and development of children by influencing the organization of various cells into tissues and organs.

If the thyroid fails to develop properly during childhood, a condition called cretinism can result. In this case, the thyroid produces extremely low quantities of thyroxine, and the person is said to have severe **hypothyroidism**. Individuals with *cretinism* are stocky and shorter than average, and without hormonal injections early on in life, they will have mental developmental delays.

Adults with hypothyroidism tend to feel tired much of the time, have a slow pulse rate and puffy skin, and experience hair loss and weight gain. This explains why someone with a slow metabolism due to an underactive thyroid may eat very little, but still gain weight. Hypothyroidism is rare, however. For most people, diet and activity are the main factors in weight gain.

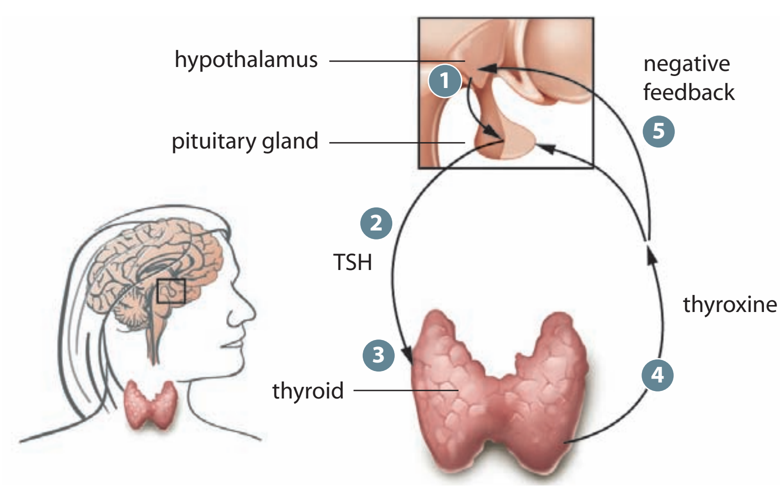


Figure 13.17 The regulation of the thyroid gland by negative feedback. **(1)** The hypothalamus secretes a releasing hormone that stimulates the anterior pituitary gland. **(2)** The anterior pituitary releases TSH into the bloodstream. **(3)** TSH targets the thyroid gland, **(4)** causing it to secrete thyroxine into the bloodstream. Thyroxine stimulates increased cellular respiration in target cells throughout the body. **(5)** High levels of thyroxine cause negative feedback on the pituitary and hypothalamus, shutting down production of TSH.

Overproduction of thyroxine is called **hyperthyroidism**. Since thyroxine stimulates metabolism, which releases stored energy as ATP, the symptoms of hyperthyroidism include anxiety, insomnia, heat intolerance, an irregular heartbeat, and weight loss. *Graves' disease* is a severe state of hyperthyroidism that results when the body's immune system attacks the thyroid. In addition to the other symptoms of hyperthyroidism, Graves' disease produces swelling of the muscles around the eyes, which causes them to protrude and interferes with vision. Hyperthyroidism can be treated by medications, or removal or irradiation of part of the thyroid.

Thyroxine secretion is controlled by negative feedback. The anterior pituitary releases a hormone called **thyroid-stimulating hormone** (**TSH**), which causes the thyroid gland to secrete thyroxine. As thyroxine levels rise in the blood, thyroxine itself feeds back to the hypothalamus and anterior pituitary, which suppresses the secretion of TSH and, therefore, thyroxine (Figure 13.17). When the body is healthy, the amount of thyroxine in the bloodstream remains relatively constant.

The thyroid requires iodine in order to make the thyroid hormones. (The short form for thyroxine, T_4, refers to the four iodine molecules in the hormone.) If there is insufficient iodine in the diet, thyroxine cannot be made, and there will be no signal to stop the secretion of TSH by the anterior pituitary. The relentless stimulation of the thyroid gland by TSH causes a **goitre** (an enlargement of the thyroid gland). In some places, such as the Great Lakes region in Canada, iodine is lacking in the soil and, therefore, in the drinking water. In Canada it is uncommon for people to have goitres, however, because salt refiners add iodine to salt, making it iodized.

15. Explain how the thyroid gland is like a metabolic thermostat.

16. Explain the role of thyroxine.

17. Why does hypothyroidism cause a goitre to develop?

The Thyroid Gland and Calcitonin

Calcium (Ca^{2+}) is essential for healthy teeth and skeletal development. This mineral also plays a crucial role in blood clotting, nerve conduction, and muscle contraction. Calcium levels in the blood are regulated, in part, by a hormone called *calcitonin*. When the concentration of calcium in the blood rises too high, calcitonin stimulates the uptake of calcium into bones, which lowers its concentration in the blood.

The role of calcitonin in regulating blood calcium levels is significant in some vertebrates such as fish and rodents. In humans, on the other hand, calcitonin appears to play a minor regulatory role. A different hormone, secreted by the parathyroid glands, plays a much more significant role in calcium homeostasis.

The Parathyroid Glands and Calcium Homeostasis

The parathyroid glands are four small glands attached to the thyroid. The parathyroid glands produce a hormone called *parathyroid hormone (PTH)*. The body synthesizes and releases PTH in response to falling concentrations of calcium in the blood. PTH stimulates bone cells to break down bone material (calcium phosphate) and reabsorb calcium into the blood. PTH also stimulates the kidneys to reabsorb calcium from the urine, activating vitamin D in the process. Vitamin D, in turn, stimulates the absorption of calcium from food in the intestine. These effects, outlined in Figure 13.18, bring the concentration of calcium in the blood back within a normal range so that the parathyroid glands no longer secrete PTH.

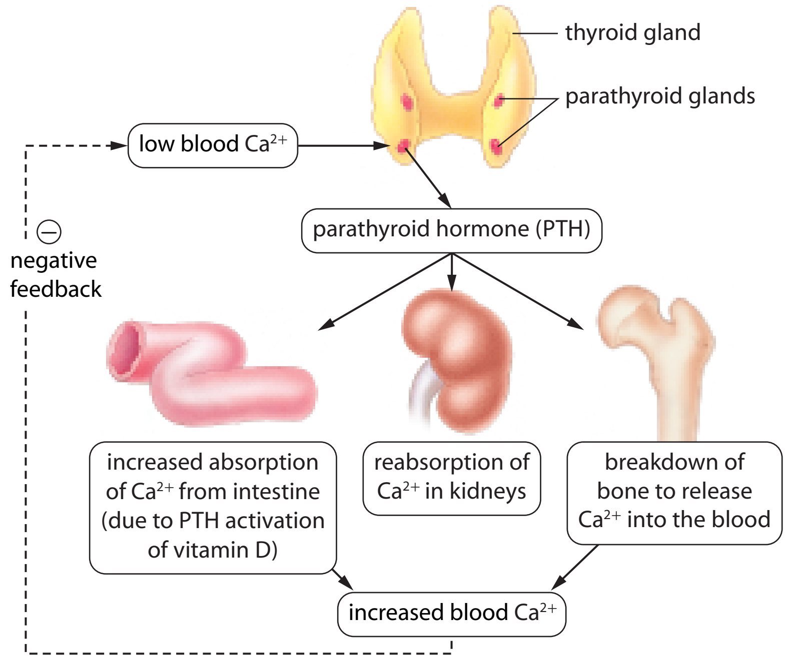


Figure 13.18 Negative feedback mechanisms regulate the concentration of calcium in the blood by parathyroid hormone (PTH). When blood concentration of calcium (Ca^{2+}) is low, PTH is released by the parathyroid glands. PTH directly stimulates the breakdown of bone and the reabsorption of Ca^{2+} by the kidneys. It indirectly promotes the absorption of Ca^{2+} in the intestine by stimulating the production of vitamin D.

Section 13.2 Summary

- The hypothalamus controls the pituitary gland. The pituitary gland has two lobes that store and release tropic hormones, which are regulated by negative feedback mechanisms.
- The anterior pituitary gland releases human growth hormone (hGH), which stimulates fat metabolism, and targets the liver to release hormones that

BiologyFile

FYI

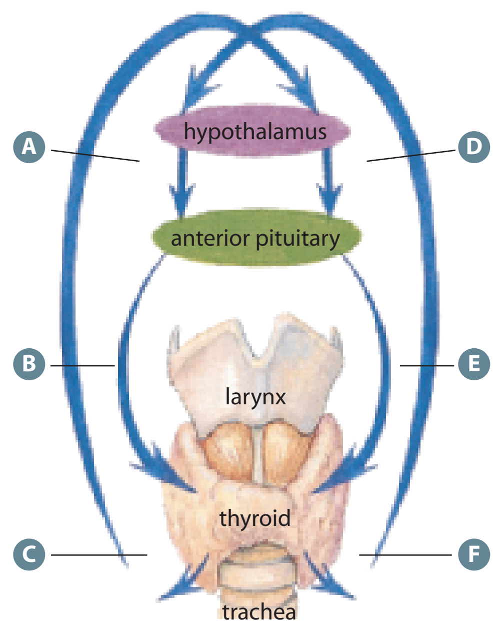
Yoda, the world's oldest known mouse, lived for over four years—or about the equivalent of 136 human years! Richard Miller, a scientist at the University of Michigan Geriatrics Center in the United States found that Yoda's pituitary gland secreted unusually low levels of growth hormone. Miller hypothesizes that having low levels of hGH could increase a person's lifespan.

stimulate protein synthesis, and muscle and bone growth.

- The thyroid gland secretes hormones that regulate cell metabolism, growth, and development.
- Thyroxine (T_4) is required for healthy mental and physical development during childhood, and an active metabolism throughout life. Thyroxine contains iodine, and thus people require iodine in the diet.
- Thyroxine secretion is regulated by the release of thyroid-stimulating hormone (TSH) from the anterior pituitary. TSH is regulated by negative feedback by thyroxine on the hypothalamus and pituitary.
- The thyroid gland also produces calcitonin, which helps lower blood calcium levels.
- The parathyroid glands secrete parathyroid hormone (PTH), which raises blood calcium levels.

Section 13.2 Review

1. In what way could hGH be considered a tropic hormone?
2. Construct a table or Venn diagram to compare and contrast hyperthyroidism with hypothyroidism. ICT
3. What causes the different effects seen in gigantism and acromegaly?
4. The diagram on the right shows feedback mechanisms associated with the thyroid gland. In your notebook, identify what is occurring at the labels (A) through (F), and name the hormones involved at each point.



5. Why might having an overactive thyroid make someone feel jittery and hungry?
6. A young child with cretinism is not growing and her parents would like her to take synthetic hGH. Will this treatment help the child? Explain your answer.
7. There has been research on the use of hGH to counteract the effects of aging. Some scientists claim that use of hGH has effects such as an increase in muscle mass, a decrease in body fat, and an increase in energy levels. Some of the known side-effects include heart problems, organ failure, and overgrowth of muscle and bone. Based on what you learned in Investigation 13.A, evaluate the advantages and disadvantages of using hGH for this purpose.

SECTION 13.3

Hormonal Regulation of the Stress Response

Section Outcomes

In this section, you will
- **explain** how the nervous and endocrine systems act together to regulate the stress responses
- **identify** and **describe** the actions of epinephrine and norepinephrine in the human body
- **describe** the effects of cortisol and aldosterone on the human body during the long-term stress response
- **describe** the physiological effects of chronic stress or an imbalance in the stress hormones

Key Terms

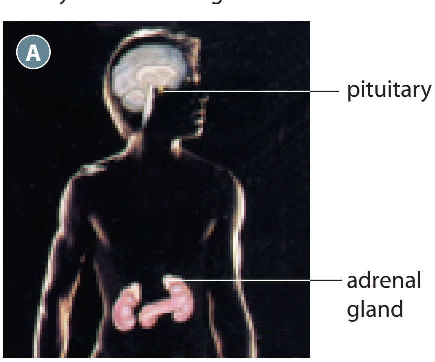
adrenal glands
adrenal medulla
epinephrine
norepinephrine
short-term stress response
fight-or-flight response
adrenal cortex
long-term stress response
cortisol
adrenocorticotropic hormone (ACTH)
aldosterone

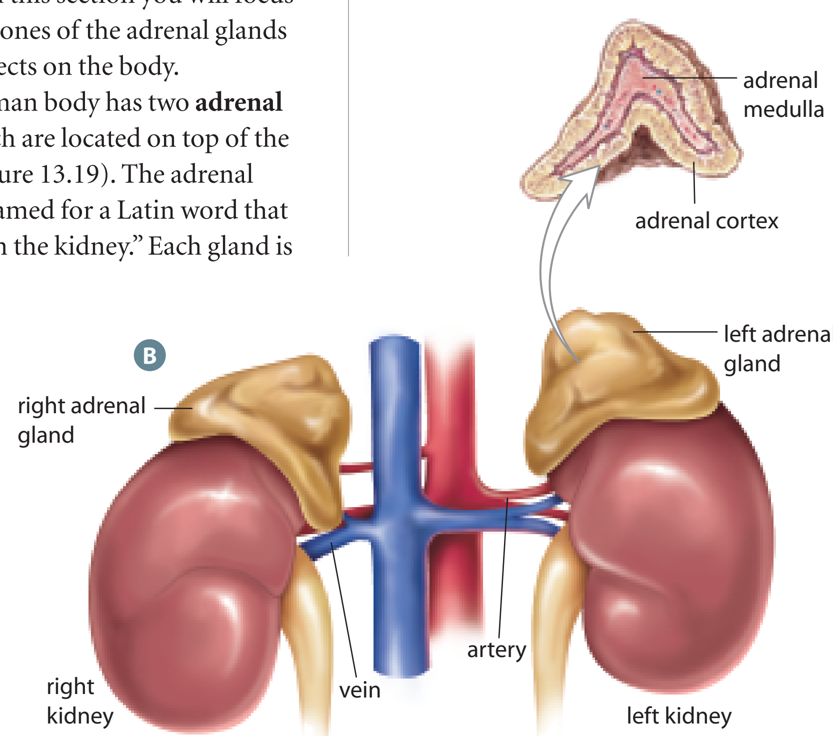
Figure 13.18 What happens to your body when you experience stress? How does the endocrine system help you cope with stressful situations?

Imagine yourself on the roller coaster in Figure 13.18. What physiological changes would be occurring in your body? The stress response involves many interacting hormone pathways, including those that regulate metabolism, heart rate, and breathing. In this section you will focus on the hormones of the adrenal glands and their effects on the body.

The human body has two **adrenal glands**, which are located on top of the kidneys (Figure 13.19). The adrenal glands are named for a Latin word that means "upon the kidney." Each gland is composed of an inner layer (the adrenal medulla) and an outer layer (the adrenal cortex). The adrenal cortex produces hormones that are different in structure and function from the hormones produced by the adrenal medulla.

Figure 13.19 **(A)** The location of the adrenal glands in the human body. **(B)** A close up view of the kidneys and adrenal glands.





The Adrenal Medulla: Regulating the Short-Term Stress Response

The **adrenal medulla** produces two closely related hormones: **epinephrine** and **norepinephrine**. (These hormones are also called adrenaline and noradrenaline, respectively.) These hormones regulate a **short-term stress response** that is commonly referred to as the **fight-or-flight response**. The effects of these hormones on the body are similar to those caused by stimulation of the sympathetic nervous system. In fact, in the developing embryo, sympathetic neurons and adrenal medulla cells are both formed from nervous system tissue, which is why the adrenal medulla is considered a neuroendocrine structure.

Like the sympathetic nervous system, the hormones of the adrenal medulla prepare the body for fight-or-flight by increasing metabolism. In response to a stressor, neurons of the sympathetic nervous system carry a signal from the hypothalamus directly to the adrenal medulla. These neurons (rather than hormones) stimulate the adrenal medulla to secrete epinephrine and a small amount of norepinephrine. These hormones trigger an increase in breathing rate, heart rate, blood pressure, blood flow to the heart and muscles, and the conversion of glycogen to glucose in the liver. At the same time, the pupils of the eyes dilate, and blood flow to the extremities decreases. Epinephrine acts quickly. This is why epinephrine injections can be used to treat different life-threatening conditions. For example, it can be used to stimulate the heart to start beating in someone with cardiac arrest. In cases of anaphylactic shock caused by severe allergies, injected epinephrine will open up the air passages and restore breathing (Figure 13.20).

The release of epinephrine and norepinephrine is rapid because it is under nervous system control. Although the hormonal effects are similar to those of the sympathetic nervous system, their influence on the body lasts about 10 times longer. Figure 13.21 shows some of the interactions between the sympathetic

Figure 13.20 Some people are extremely allergic to nuts, bee sting venom, or certain medications, and exposure to these substances will cause the air passages to constrict. Epinephrine injections can be used to restore breathing. An EpiPen®, for example, is an automatic epinephrine injector that is easy to use in an emergency.

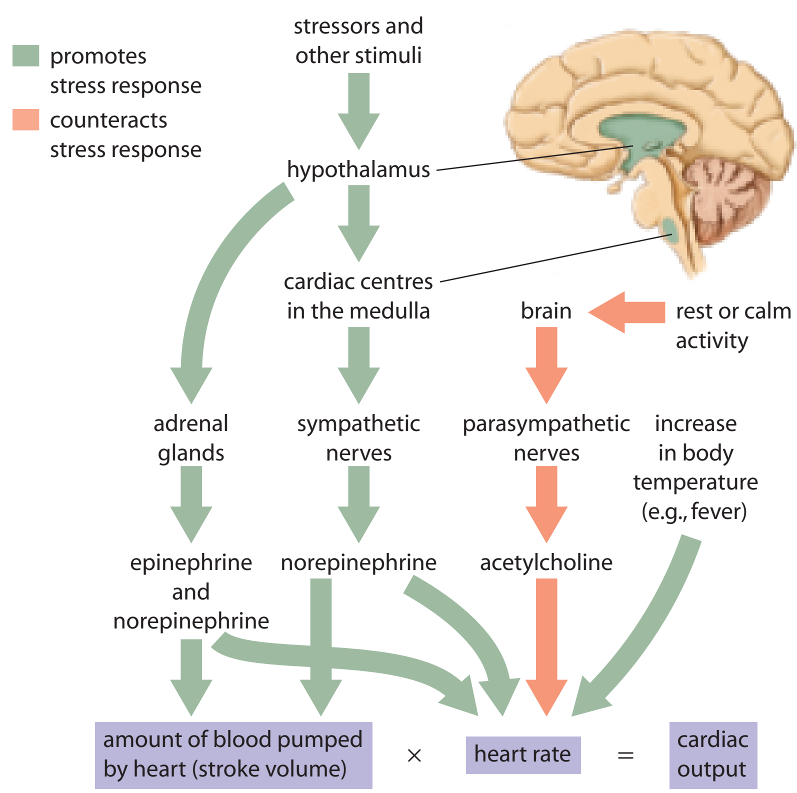


Figure 13.21 Hormonal and nervous system interaction in the stress response.

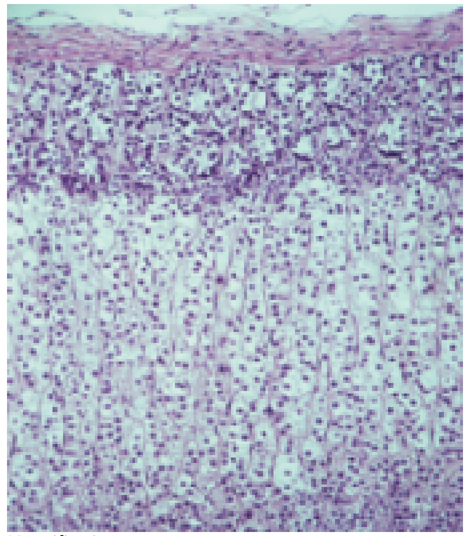
nervous system and endocrine system in the short-term stress response.

Q 18 Describe what is meant by the fight-or-flight response.

Q 19 How is the hypothalamus involved in the release of epinephrine and norepinephrine in the stress response?

The Adrenal Cortex: Regulating the Long-Term Stress Response

The stress hormones produced by the **adrenal cortex** trigger the sustained physiological responses that make up the **long-term stress response**. The glucocorticoids increase blood sugar, and the mineralocorticoids increase blood pressure (Figure 13.22). The adrenal cortex also secretes a small amount of female and male sex hormones, called gonadocorticoids, which supplement the hormones produced by the gonads (testes and ovaries). The different hormone-secreting cells of the adrenal cortex are shown in Figure 13.23.

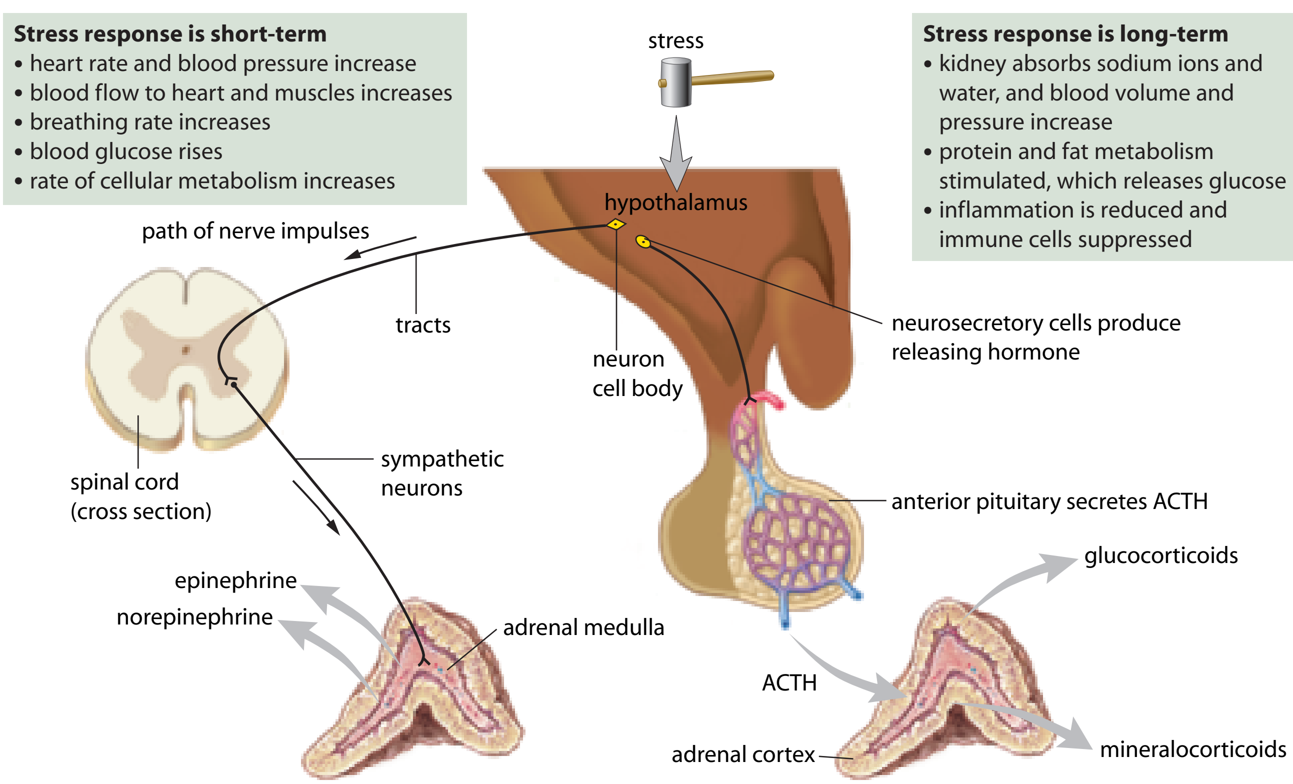


Magnification: 17.5 ×

Figure 13.23 A micrograph of the cells of the adrenal cortex. Notice the bands of cells. The cells in the lower and central bands produce glucocorticoids and gonadocorticoids. The cells in the upper band, underneath the capsule, secrete mineralocorticoids.

Q 20 Compare and contrast the major physiological changes that occur in the short-term and long-term stress responses.

Figure 13.22 The adrenal medulla and adrenal cortex are under the control of the hypothalamus. The adrenal medulla provides a rapid and short-lived stress response, while the adrenal cortex provides a sustained stress response.



BiologyFile

Web Link
Dr. Hans Selye was the first person to describe the stress response in terms of the General Adaptation Syndrome (GAS). Selye, who was a scientist at the University of Montréal in Québec, from 1932 to 1976, theorized that the GAS included three phases: alarm, resistance (during which the body adjusts to stress), and exhaustion. What causes the exhaustion phase? How have recent findings built on Selye's understanding of the stress response?

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Cortisol

Cortisol is the most abundant glucocorticoid. Like the other hormones produced by the adrenal cortex, cortisol is a steroid hormone synthesized from cholesterol. When the brain detects danger, it directs the hypothalamus to secrete a releasing hormone. The releasing hormone stimulates the anterior pituitary gland to secrete **adrenocorticotropic hormone** (**ACTH**). ACTH targets the adrenal cortex, which causes the release of the stress hormone cortisol. Cortisol works often in conjunction with epinephrine, but is longer lasting. The main function of cortisol in the body is to raise the blood glucose levels. Cortisol does this by promoting the breakdown of muscle protein into amino acids. The amino acids are taken out of the blood by the liver, where they are used to make glucose, which is then released back into the blood. Cortisol also prompts the breakdown of fat cells, which also releases glucose. Increased cortisol levels in the blood cause negative feedback on the hypothalamus and anterior pituitary, which suppresses ACTH production, and stops the release of cortisol.

When faced with immediate danger, or playing a vigorous sport, epinephrine and cortisol are just what the body needs. In the long term, however, the sustained high levels of cortisol in chronic stress can impair thinking, damage the heart, cause high blood pressure, lead to diabetes, increase susceptibility to infection, and even cause early death. In Japan, where long work hours and high-stress jobs are common, so many business people have died from heart attacks and strokes that the phenomenon has been named, *karoshi*, which means "death from overwork."

One of the ways the body fights disease is by inflammation, in which cells of the immune system attack foreign material, such as invading bacteria. Cortisol is a natural anti-inflammatory in the body, which is probably why sustained high levels of cortisol make people more susceptible to infections. Synthesized cortisol is commonly used as a medication to reduce the undesirable inflammation associated with asthma, arthritis, or joint injuries. Unfortunately, cortisol inhibits the regeneration of connective tissue, and should therefore be used only when necessary.

Q 21 How does cortisol make more glucose available to cells?

Q 22 How does cortisol affect the immune system?

Aldosterone

The principal mineralocorticoid is a hormone called **aldosterone**. As you learned in Chapter 9, aldosterone stimulates the distal and collecting tubules of the kidneys to increase the absorption of sodium into the bloodstream. This increases the solute concentration of the blood, which then draws in more water from the nephrons, raising blood pressure.

If the adrenal cortex is damaged, Addison's disease can result. In this case, the body secretes inadequate amounts of mineralocorticoids and glucocorticoids. The symptoms of *Addison's disease* include hypoglycemia (low blood sugar), sodium and potassium imbalances, rapid weight loss, and general weakness. Low aldosterone results in a loss of sodium and water from the blood due to increased urine output. As a result, blood pressure drops. A person with this condition needs to be treated within days, or the severe electrolyte imbalance will be fatal (Figure 13.26). Former United States President John F. Kennedy had this condition. Doctors controlled his symptoms with injections of glucocorticoids and mineralocorticoids.

BiologyFile

FYI
Cortisol (medically referred to as hydrocortisone) can be admistered to people with allergies, asthma, arthritis, and skin diseases because of its anti-inflammatory and anti-allergic properties. In people with Addison's disease (the adrenal glands fail to produce cortisol), hydrocortisone injections can reduce many symptoms. For people who produce too much corstisol, as in Cushing's disease, the options include surgery, radiation, and cortisol inhibitor medication.

23 Describe how aldosterone increases blood pressure.

24 Describe how Addison's disease affects the body.

Section 13.3 Summary

- The adrenal glands release several hormones involved in the body's response to stress.
- Each adrenal gland is composed of an outer layer called the adrenal cortex, and an inner part called the adrenal medulla. The adrenal medulla is stimulated by neurons from the hypothalamus.
- In the short-term stress response, also called the fight-or-flight response, the adrenal medulla is stimulated to release epinephrine and norepinephrine. These hormones increase the body's metabolism, breathing rate, and heart rate. This provides more energy for the body to respond to danger.
- When the body is under stress, the hypothalamus secretes a releasing hormone. The releasing hormone stimulates the anterior pituitary to release adrenocorticotropic hormone (ACTH). ACTH in turn stimulates the adrenal cortex to release cortisol, a steroid hormone.
- Cortisol triggers the metabolism of proteins and fats to produce glucose. Cortisol also suppresses the immune system, which is probably one reason that chronic stress is unhealthy.
- Cortisol secretion is suppressed by negative feedback to the hypothalamus and anterior pituitary.
- The adrenal cortex also secretes aldosterone, which stimulates the kidneys to absorb sodium and thus water. This increases the blood pressure. When homeostasis is reached, negative feedback shuts off the secretion of aldosterone.
- Low aldosterone causes low blood pressure, an imbalance of electrolytes (sodium and potassium ions) in the blood, and unhealthy weight loss, which are symptoms of Addison's disease.

BiologyFile

FYI

In a study done on military personnel placed under the duress of interrogation and imprisonment, most could not pick out their interrogator from a line up a few days later. This study suggests that stress has a negative effect on memory.

Section 13.3 Review

1. Create two columns in your notebook. Label one column "short-term stress response" and the second column "long-term stress response." ICT
   a) Indicate which part of the adrenal gland is involved in each response.
   b) Note which system (nervous or endocrine) stimulates the adrenal glands in each response. What hormones are involved in either pathway?
   c) List the substances secreted by the adrenal gland. Briefly compare their effects on the body.
2. If you found yourself in each of the following situations, would the fight-or-flight response be useful or unhelpful?
   a) while playing soccer
   b) during a final exam
   c) when late for your bus
   d) just before heading on stage to act in the school play
3. Name or briefly describe a common but stressful situation that could occur over many weeks or months. Why is it that the body's response in this situation could result in ill health?
4. Suppose a family member has a stressful day. Why might this person crave something sweet to eat at the end of the day?
5. How can synthetic cortisol be used to help athletes suffering from joint injuries? How could its overuse make an injury worse?
6. Is norepinephrine a neurotransmitter or a hormone? Explain your answer.
7. Some skiers and snowboarders report feeling an "adrenaline rush" when they perform their sport. What is an "adrenaline rush" and how does it affect the body?

SECTION 13.4

Hormonal Regulation of Blood Sugar

Section Outcomes

In this section, you will
- **describe** the structure of the pancreas and its role in homeostasis
- **explain** how insulin and glucagon regulate levels of blood glucose
- **describe** the physiological effects of diabetes and how the condition occurs
- **analyze** data and **infer** the role of various hormones based on observations
- **explain** how science and technology are developed to meet societal needs and expand human capability

Key Terms

pancreas
islets of Langerhans
beta cells
alpha cells
insulin
glucagon
diabetes mellitus
hyperglycemia
type 1 diabetes
type 2 diabetes

It had been a difficult afternoon. Josh didn't have time to eat lunch, because he had been studying for his biology exam. In gym class, the run was long and he should have paid attention to his body's warning signs that all was not well. At first he felt tired, then his pulse quickened and he started to perspire. By the time he recognised that his blood glucose was plummeting, his thinking and judgment were impaired. He collapsed, and paramedics had to be called to restore his blood glucose levels.

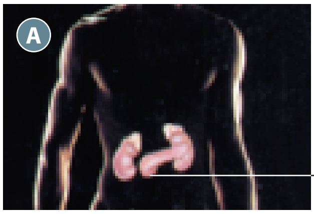
The above scenario describes some of the challenges faced by someone with diabetes. In diabetes, the physiological processes that maintain blood glucose levels in a narrow range do not function properly. In this section, you will learn why it is critical that blood glucose levels are kept in check, and how the pancreatic hormones regulate blood glucose to maintain homeostasis.

The Hormones of the Pancreas

The **pancreas** is located behind the stomach and is connected to the small intestine by the pancreatic duct (Figure 13.24). Much of the pancreatic tissue secretes digestive enzymes into the small intestine. For this reason, the pancreas is considered an *exocrine gland*, which secretes its products through ducts. The pancreas also functions as an endocrine gland. Scattered throughout it are over 2000 groups of endocrine cells, which secrete their hormones directly into the bloodstream. These clusters of cells, called the **islets of Langerhans**, are named after their discoverer, the German anatomist and pathologist, Paul Langerhans.

The islets of Langerhans secrete two hormones, insulin and glucagon, which have opposite effects (they are antagonistic). The **beta cells** of the pancreas secrete insulin, which decreases the level of blood glucose. Glucagon, secreted by the **alpha cells**, increases the level of blood glucose.

Both insulin and glucagon are regulated by negative feedback mechanisms (Figure 13.25). When you eat a meal, your digestive system breaks down the food and releases a substantial amount of glucose into your bloodstream. When the blood glucose levels rise, the pancreatic beta cells secrete appropriate amounts of insulin. **Insulin** circulates throughout the body and acts on specific receptors to make the target cells more permeable to glucose. It especially affects muscle cells, which use large amounts of glucose in cellular respiration, and liver cells, where glucose is converted into



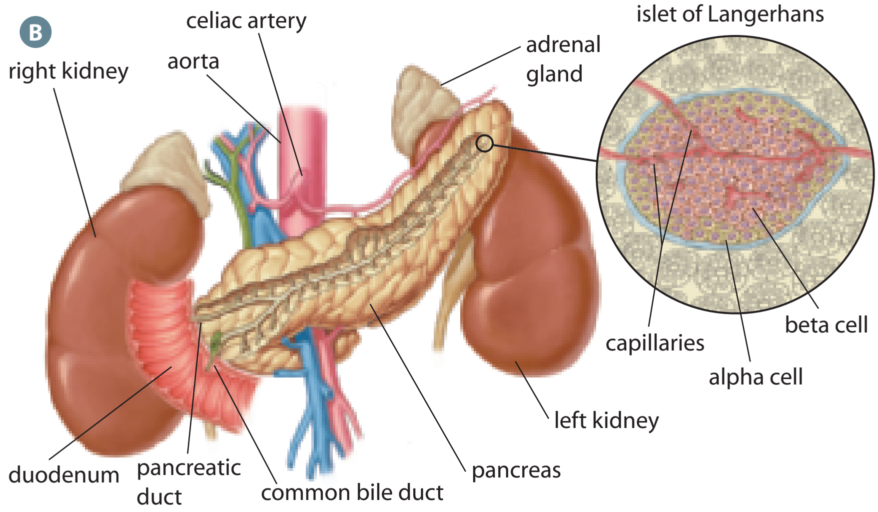


Figure 13.24 **(A)** The location of the pancreas in the human body. **(B)** A close up view of the pancreas and one of the many islets of Langerhans on the pancreas's surface.

glycogen for temporary storage. Other cells of the body also take in and use glucose for energy. As the glucose levels in the blood return to homeostasis, insulin secretion slows.

Rigorous exercise or fasting (skipped meals) can cause blood glucose levels to drop. Low blood sugar stimulates the alpha cells of the islets of Langerhans to release glucagon. **Glucagon** stimulates the liver to convert glycogen back into glucose, which is released into the blood. Other hormones, such as hGH, cortisol, and epinephrine also contribute to increasing the level of blood glucose.

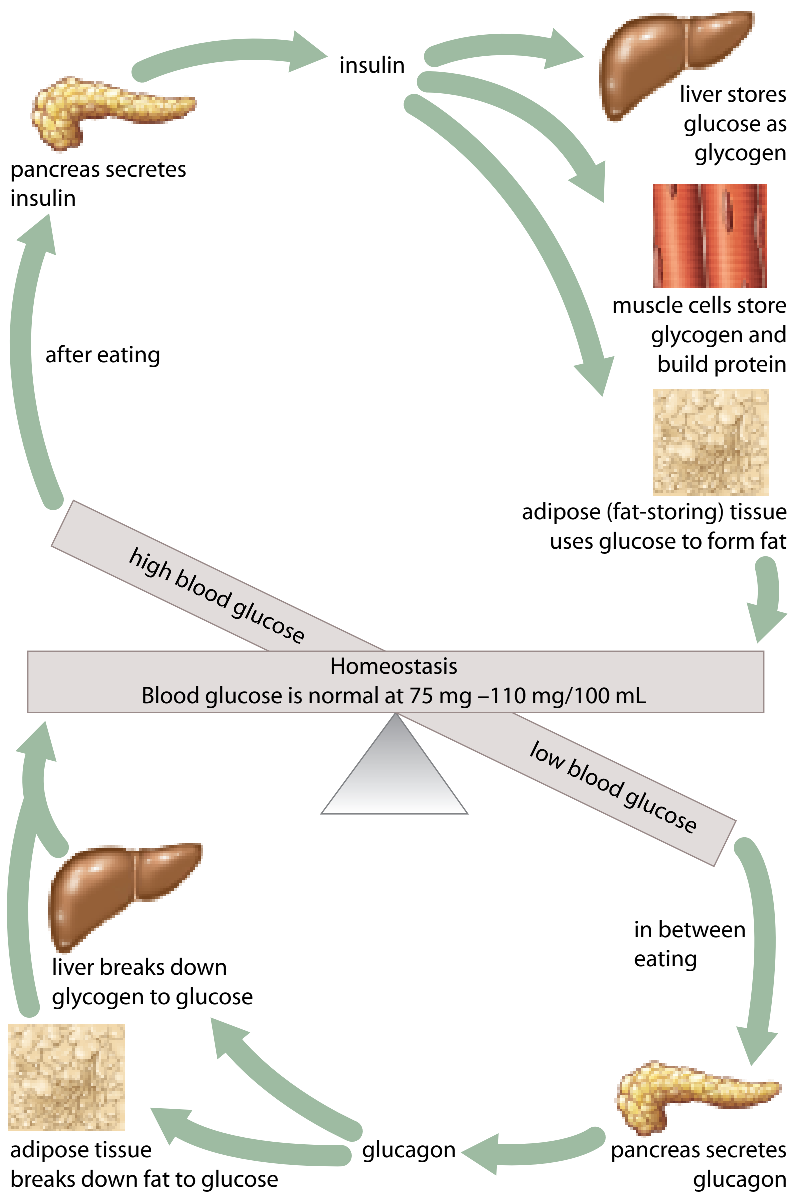


Figure 13.25 Negative feedback regulates blood glucose levels within a very narrow range. How are insulin and glucagon able to help maintain homeostasis in the body?

25 Identify two cell types of the islets of Langerhans and explain their functions.

26 Describe the roles of insulin and glucagon in maintaining homeostasis.

The Effects of Glucose Imbalance

Diabetes mellitus is a serious chronic condition with no known cure. It affects over 150 million people worldwide (as of 2004), including over two million Canadians. Diabetes results when the body does not produce enough insulin, or does not respond properly to insulin. As a result, levels of blood glucose tend to rise sharply after meals, and remain at significantly elevated levels. This condition is called **hyperglycemia**, or high blood sugar, from the Greek word parts *hyper* (too much), *glyco* (sugar), and *emia* (condition of the blood).

Hyperglycemia has various short-term and long-term effects on the body. Without insulin, cells remain relatively impermeable to glucose and cannot obtain enough from the blood. The individual experiences fatigue as the cells become starved for glucose. The body compensates to some degree by switching to protein and fat metabolism for energy. Fats and proteins are less accessible, however, and more difficult than glucose to break down. Fat metabolism also releases ketones, such as acetone, as a toxic by-product, which can be smelled on the breath.

The kidneys are incapable of reabsorbing all of the glucose that is filtered through them from the blood, and so glucose is excreted in the urine. This changes the osmotic gradient across the nephrons of the kidneys. Large volumes of water therefore follow the glucose by osmosis into the kidneys, and get excreted. People with untreated diabetes experience low energy and great thirst, and produce large volumes of glucose-rich urine. In the long-term,

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FYI
Early physicians could diagnose diabetes by tasting the urine for sweetness—*mellitus* is Latin for "honey."

continued high levels of blood glucose can lead to blindness, kidney failure, nerve damage, and gangrene (a severe infection) in the limbs. Also, in many diabetics, the alpha cells that produce glucagon degenerate. Diabetes is one of the leading causes of death in North America.

27 What are the symptoms of diabetes mellitus?

28 What is hyperglycemia?

29 What are the effects of untreated diabetes mellitus on the body?

Causes of Diabetes

There are two major types of diabetes mellitus: **type 1 diabetes** (also called juvenile diabetes and insulin-dependent diabetes) and **type 2 diabetes** (also called adult-onset diabetes and non-insulin-dependent diabetes). In type 1 diabetes, the immune system produces antibodies that attack and destroy the beta cells of the pancreas. As a result, the beta cells degenerate and are unable to produce insulin (Figure 13.26). The condition is usually diagnosed in childhood, and people with it must have daily insulin injections in order to live.

Thought Lab 13.1 Blood Glucose Regulation and Homeostasis

Target Skills

Analyzing and **interpreting** collected data on blood glucose levels

Identifying healthy patterns of changing blood glucose levels

Inferring the effects of diabetes mellitus on blood glucose levels

How do levels of blood glucose fluctuate throughout the day in someone with diabetes compared to someone without diabetes?

Procedure

Compare the following blood glucose concentration data provided for Maria and Tamika. One of these young women has diabetes. Blood glucose concentrations were monitored over 15 h for both. Both women ate identical meals at the same times, and got equal amounts of exercise at the same times. Neither is presently taking insulin.

Maria's and Tamika's Blood Glucose Levels over 15 h

Event/Time	Blood Glucose Concentration (mmol/L)	
	Maria	Tamika
Wake up: 8:00 A.M.	4.0	10.0
1 h after breakfast: 9:00 A.M.	7.0	14.0
Pre-lunch: 12:00 noon	4.5	10.0
2 h after lunch: 2:00 P.M.	6.0	15.0
Mid-afternoon: 3:00 P.M.	4.5	10.0
1 h after vigorous exercise: 4:00 P.M.	4.0	4.0
Pre-supper: 6:00 P.M.	4.5	9.0
1 h after supper: 7:00 P.M.	6.5	18.0
Bedtime: 11:00 P.M.	4.5	12.0

Source: Data provided by Dr. Edmund A. Ryan, Professor of Medicine, University of Alberta, Medical Director of the Clinical Islet Cell Transplant Program.

Analysis

1. Plot both sets of data on the same graph and draw a line of best fit for each. Label your graph appropriately.
2. A healthy range for blood glucose is between 4.5–5.0 mmol/L. In general, a person with moderate diabetes would take an insulin shot if the blood glucose level went above 13–15 mmol/L. On your graph, indicate which woman is diabetic and which is not. Write a paragraph to explain your answer.
3. Indicate the times and activities during which the pancreas of the healthy person would release insulin. How did insulin affect her body at these times?
4. Indicate the times and activities during which the pancreas of the healthy person would release glucagon. How did glucagon affect her body at these times?
5. Suggest a medication that the woman with diabetes could take to help her blood glucose levels return to healthy levels after a meal. Explain how this treatment would work.
6. During exercise, Tamika's blood glucose drops dramatically. What could she do to help raise her blood glucose to a healthy range?

To check blood glucose levels, a test strip with a drop of blood is inserted into the blood glucose monitor.

Figure 13.26 **(A)** A light micrograph of pancreatic beta cells from someone with type 1 diabetes. Many of the beta cells have been destroyed, leaving behind only non-beta cells (stained brown), and so the islet is malformed. **(B)** Oscar winner Halle Berry has had type 1 diabetes since childhood. She also actively promotes diabetes awareness and is shown here at a charity gala to benefit children with diabetes.

Type 2 diabetes tends to develop gradually, often because the insulin receptors on the body's cells stop responding to insulin. In other cases, the beta cells of the pancreas produce less and less insulin over time. People who are overweight have a greater chance of developing type 2 diabetes. It is usually diagnosed in adulthood and often can be controlled with diet, exercise, and oral medications. Most people with diabetes—about 90 percent—have type 2. Without proper care, type 2 diabetes can develop into type 1, which is insulin-dependent.

Type 2 diabetes is increasing worldwide at an alarming rate, especially among certain ethno-cultural groups. Among the Aboriginal peoples of Canada, for example, the incidence of type 2 diabetes is rising at three times the national rate. Health scientists describe the increase as an epidemic. One explanation for it could be that people of Aboriginal ancestry have inherited the ability to store food energy very efficiently, since their ancestors traditionally lived through cycles of "feast or famine." In the past, it would have been advantageous to gain weight when there was lots of food, and when food was scarce, go through a starvation period. Today, not only is food available year round, many people are now eating modern Western diets, which are high in refined carbohydrates. Type 2 diabetes is linked closely to unhealthy diet and weight gain, factors that are influencing the rate of diabetes in many populations.

Q 30 What interferes with the secretion of insulin in type 1 diabetes?

Q 31 What risk factors are associated with developing type 2 diabetes?

Towards a Cure for Diabetes

It was not until 1889, when physician Oscar Minkowski removed the pancreas from a healthy dog, and it developed the symptoms of diabetes, that the relationship between the pancreas and diabetes was established. For the next two decades, researchers attempted to isolate a substance from the pancreas that could be used to treat diabetes, but were unsuccessful.

In 1921, a research team from the University of Toronto, Ontario, led by Frederick Banting and his assistant Charles Best made a breakthrough (Figure 13.27). By tying off a dog's pancreatic duct with some string, they were able to remove some islets of Langerhans from the dog's pancreas, and then isolate insulin from the islets.

Figure 13.27 Best (on the left) and Banting (on the right) and their diabetic dog, around 1922. Banting and J.R.R. Macleod, the head of the university laboratory where Banting and Best worked, were awarded the Nobel Prize in 1923. Best's contribution was not recognized, so Banting shared half his prize money with him.

Banting and his research team soon found a way to isolate insulin from the pancreases of embryonic calves, which were a by-product of the beef industry. Working with a biochemist from the University of Alberta, J.B. Collip, they further purified the extracted insulin and used it to successfully treat a boy with diabetes.

INVESTIGATION 13.B

Target Skills

Analyzing and **comparing** data collected from simulated blood and urine samples

Interpreting data and **identifying** hormonal imbalances suggested by the data

Analyzing Endocrine Disorders

Suppose you are a medical student working in the emergency room of a busy city hospital. The supervising medical resident calls you into the ward. She mentions that today would be a great day to review some endocrine disorders, as a number of patients in the ward have them. She informs you that the nurses have taken blood and urine samples from various patients. She also provides you with a chart of symptoms (shown below). You and your classmates must use your knowledge of the endocrine system to determine which of your five patients (referred to as patients A, B, C, D, and E) has:

- pituitary gland deficiency (limited hGH, epinephrine, and cortisol)
- no hormonal imbalance (is healthy)
- diabetes insipidus
- diabetes mellitus
- Addison's disease

Note: Diabetes insipidus is a rare condition that results from insufficient activity of antidiuretic hormone (ADH); refer to page 316. Diabetes insipidus is unrelated to diabetes mellitus.

Question

Using the information chart provided and some simulated blood and urine samples, how can you diagnose hormonal imbalances?

Safety Precautions

- Do not drink any of the solutions used in the laboratory.
- Wash up any spills and your hands after each trial.
- Benedict's solution is toxic and an irritant. If you get it on your skin or in your eyes, immediately inform your teacher and flush your skin or eyes with clean water.
- Be extremely careful around open flames.

Materials

- simulated samples of blood (5)
- simulated samples of urine (5)
- digital blood glucose monitor (if available)
- blood and urine test strips (if using a monitor)
- cotton swabs
- Benedict's solution (if not using a monitor)
- medicine dropper
- 10 mL test tubes (10)
- test-tube rack
- 10 mL graduated cylinder
- Bunsen burner or small propane torch
- 400 mL beaker
- hot plate
- test-tube clamp
- beaker tongs

Symptoms of Various Endocrine Imbalances

Patient's condition	Substances identified	Blood concentrations (mmol/L)	Present or absent in the urine	Additional information
healthy	glucose	5.0	absent	person experiences no additional symptoms
	sodium	140	absent	
diabetes mellitus	glucose	25	present	person reports being thirsty and must urinate frequently
	sodium	138	absent	
diabetes insipidus	glucose	4.5	absent	person is producing large volumes of dilute, pale urine
	sodium	150	absent	
Addison's disease	glucose	4.0	absent	person is under stress; urine output is high; there is sodium in the urine
	sodium	130	present	
pituitary gland and adrenal gland disorder (reduced cortisol, epinephrine, and hGH)	glucose	3.5	absent	this is an older person whose glucagon-producing cells have deteriorated
	sodium	142	absent	

Source: Data provided by Dr. Edmond A. Ryan, Professor of Medicine, University of Alberta, Medical Director of the Clinical Islet Cell Transplant Program

Procedure

Make a table in your notebook like the one below to record your data.

Patient (A, B, C, D, or E)	Blood glucose concentration	Glucose present or absent in the urine	Sodium present or absent in the urine	Name of the disorder

Part A: Testing for Glucose Concentrations in the Blood and Urine

1. If your school has a glucose monitor, place a drop of the first sample of simulated blood or urine on a clean test strip. Plug the strip into the monitor and take a glucose reading. Record the value that you obtain in your data table. Repeat the procedure for the other samples.

2. If a glucose monitor is not available, you can use the Benedict's test to determine the concentration of glucose in each of the blood samples, and to detect the presence or absence of glucose in the urine. Benedict's solution identifies simple sugars, such as glucose, by causing a colour change. As the concentration of glucose changes, so will the colour of the sample mixed with Benedict's solution, according to the following table.

Benedict's Test Colour Equivalence Table

Colour of Solution	Glucose concentration (percent)	Glucose concentration (mmol/L)
blue	0.0	0
light green	0.1–0.5	5.56–27.8
olive green	0.5–1.0	27.8–55.6
yellow	1.0–1.5	55.6–83.3
orange	1.5–2.0	83.3–111
red-brown	2.0+	111+

a) Test the 5 blood samples first. Label 5 test tubes A through E. Use the 10 mL graduated cylinder to measure 5 mL of Benedict's solution into each test tube.

b) With a medicine dropper, add 5 drops of simulated blood from each of the patient's samples to the appropriately labelled test tube. Rinse out the medicine dropper with clean water between samples.

c) Fill a 400 mL beaker about two-thirds full with water. Place the beaker on a hot plate and turn it on. When the water has had time to warm up, use the test-tube clamps to place the test tubes with the samples and Benedict's solution into the beaker. Leave the test tubes in the beaker until there is a colour change , or a maximum of 5 min.

d) Use the test-tube clamps to remove the test tubes from the water bath. Record the results in your data table.

e) Next, test the 5 urine samples. Use the procedural steps (a) through (d).

Part B: Testing for Sodium in the Urine (Teacher Demonstration)

3. Have your teacher ignite a Bunsen burner or propane torch. Your teacher will dip a cotton swab in one of the urine samples, then immediately place the wet end of the swab in the flame. If sodium is present in the urine, the flame should flare bright orange. If not, the flame should stay blue. Record your observations in your data table. Your teacher will repeat this step for the remaining urine samples, using a new cotton swab for each sample.

Analysis

1. Which patient in this investigation acted as a control?

2. Why were simulated blood and urine samples used in this investigation, instead of real samples?

Conclusions

3. Use the table listing the symptoms of different endocrine imbalances to diagnose the condition of each of the patients (A through E).

Application

4. List the hormones that are imbalanced in each of the patients. For each hormone, describe its effect on blood glucose regulation.

5. For the patient with the pituitary disorder, how would you account for the lack of hGH, epinephrine, and cortisol in the patient's blood? Could another hormone have compensated for these three? If so, how does this other hormone typically affect the body?

6. For each of the hormonal imbalances identified in the investigation, suggest a possible treatment.

Figure 13.28
A continuous blood glucose monitor and insulin pump. The pump releases small amounts of insulin throughout the day, which minimizes the need for insulin injections.

Today, synthetic insulin is produced by genetically engineered bacteria and other organisms. Furthermore, the Edmonton Protocol, led by James Shapiro at the University of Alberta, has pioneered the first successful islet cell transplants to restore functioning beta cells to the pancreas.

The technology of blood glucose monitoring devices is also improving. Many people with diabetes use digital blood glucose monitors. Advances in insulin injection technology have led to the development of the insulin pump, which mimics the pattern of release of insulin from a healthy pancreas (Figure 13.28).

Although we all have in common the same types of body systems and the requirement for homeostasis, our particular perceptions, and conscious and autonomic responses, are unique. It is likely that, in the future, pain medication, drugs to correct hormonal imbalances, and other pharmaceuticals will be tailor-made for individuals, taking into account our genes. As imaging techniques continue to improve, scientists will have more tools to solve medical problems, and to piece together the many facets of homeostasis.

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Web Link
To learn more about the Edmonton Protocol, clinical trials, and transplantation, read the Career Focus at the end of this unit and check out the web site.

www.albertabiology.ca
WWW

32 What was Banting and Best's contribution to the treatment of diabetes?

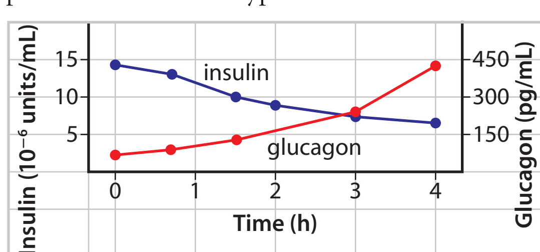
33 How can people with diabetes monitor their blood glucose levels?

Section 13.4 Summary

- Blood glucose levels must stay within a narrow range for the body to maintain homeostasis.
- The islets of Langerhans in the pancreas contain beta cells, which secrete insulin in response to high levels of blood glucose.
- Insulin stimulates the cells of the liver to take up and store glucose.
- Other cells respond to insulin by taking up more glucose for cellular respiration.
- The islets of Langerhans also contain alpha cells, which secrete glucagon in response to low levels of blood glucose.
- Glucagon stimulates the liver cells to break down glycogen, which releases glucose.
- If the beta cells are destroyed, type 1 diabetes results. Type 2 diabetes develops when the insulin receptors on the cells do not respond properly to insulin.

Section 13.4 Review

1. Draw a negative feedback mechanism to show how a healthy pancreas regulates blood glucose levels after a meal high in carbohydrates.
2. Suppose you wake up late and skip breakfast in order to get to school on time. How would your pancreas enable you to have enough energy to get through the morning until you have a chance to eat lunch?
3. Why might insulin injections not be an effective treatment for type 2 diabetes? What other treatment options are available?
4. Insulin can be produced synthetically using genetically engineered bacteria. List an advantage and a drawback or risk of using synthetic insulin.
5. The graph shows a person's insulin and glucagon levels during a four hour hike with no break for food. Answer the following questions based on the graph.
   a) When does the level of insulin drop? What is the effect on the body?
   b) When does the level of glucagon rise? What is the effect on the body?
   c) How would having a large meal at the 4 h time point affect the person's levels of insulin and glucagon?
   d) Hypothesize what this graph would look like if this person had untreated type 1 diabetes mellitus.



Chapter 13 SUMMARY

The nervous and endocrine systems work together to maintain homeostasis. The hormones and endocrine glands comprise the endocrine system. The endocrine glands release hormones directly into the blood stream. Hormones travel throughout the body and affect specific target cells. Tropic hormones, such as TSH, affect endocrine glands.

Hormones bind to receptor proteins on the surface of, or within, target cells. This triggers changes within the target cells, such as the secretion of another hormone. Insulin and hGH are examples of protein hormones. Progesterone and testosterone are examples of steroid hormones. Some actions or events (stimuli), such as stress, can initiate a chain of events in the nervous system and possibly have long-term effects on nervous system function or health.

Many hormones are regulated by negative feedback loops. For example, in response to low blood pressure, ADH secretion increases and water reabsorption by the kidneys increases. This leads to an increase in blood pressure, which shuts off ADH secretion and water reabsorption. This cycle of maintaining body fluids at a constant level is called osmoregulation.

The hypothalamus links the nervous system to the endocrine system by regulating hormone secretion by the pituitary gland. The anterior pituitary secretes human growth hormone (hGH), which stimulates fat metabolism, protein synthesis, and bone and muscle growth. Pituitary dwarfism, gigantism, and acromegaly are caused by imbalances in hGH.

The thyroid gland secretes thyroxine and other hormones, which regulate cell metabolism, growth, and development. An underactive thyroid can lead to hypothyroidism. An overactive thyroid can lead to hyperthyroidism. Insufficient iodine in the diet causes goiter.

The hypothalamus controls the secretion of thyroxine via releasing hormones, which stimulate the release of thyroid-stimulating hormone (TSH). A negative feedback loop regulates this system.

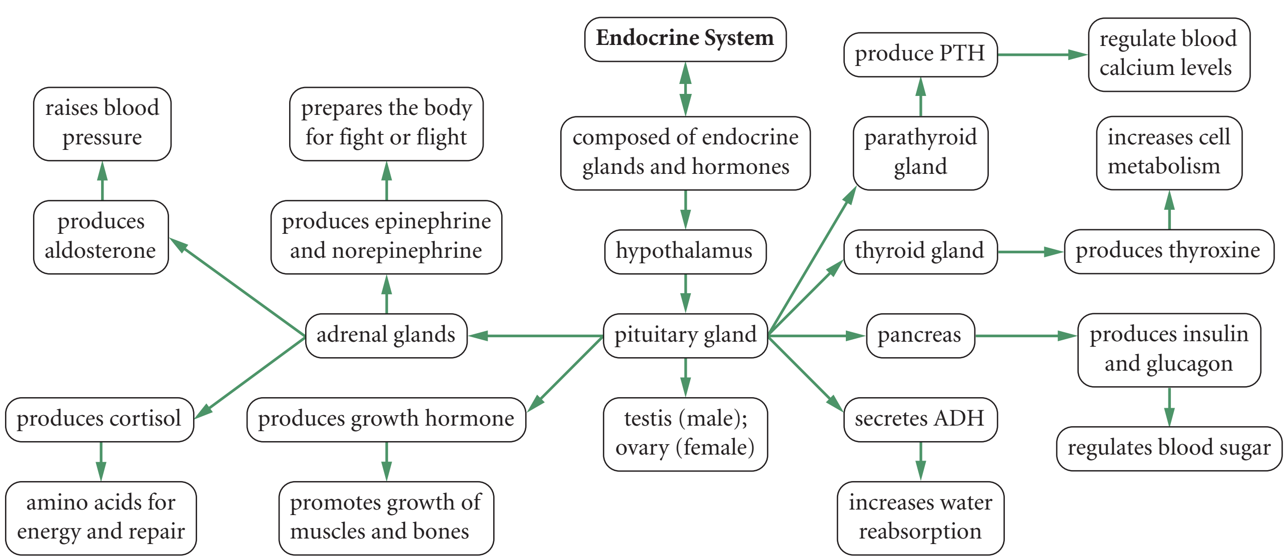
The four parathyroid glands regulate calcium levels by secreting parathyroid hormone (PTH).

In response to stressors, the sympathetic nervous system initiates stress responses. The short-term stress response (fight-or-flight response) includes increases in heart rate, blood pressure, and blood glucose. In response to a perceived threat, the hypothalamus sends nerve signals to the adrenal medulla, which releases the short-term stress hormones, epinephrine and norepinephrine.

In the long-term stress response, the hypothalamus secretes adrenocorticotropic hormone (ACTH), which triggers the adrenal cortex to secrete cortisol. The adrenal cortex also secretes aldosterone, which increases blood pressure and balances electrolytes in the blood.

The hormones of the pancreas act antagonistically to regulate blood glucose levels. The beta cells of the islets of Langerhans secrete insulin, which lowers blood glucose. The alpha cells secrete glucagons, which raise blood glucose. Type 1 diabetes causes hyperglycemia. Type 2 diabetes results from insulin-resistance of the insulin target cells.

Chapter 13 Graphic Organizer



Chapter 13 REVIEW

Understanding Concepts

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

2. a) Explain why the pituitary gland is sometimes called the "master gland."
b) Describe how the anterior pituitary and posterior pituitary are regulated.

3. Using ACTH as an example, explain what a tropic hormone is.

4. Describe three modern methods that researchers use to learn about human endocrine glands and their hormones.

5. Suppose you are tutoring a younger student in biology. The student tells you that the beta cells of the pancreas secrete glucagon, and the alpha cells secrete a hormone that lowers blood glucose levels. Is this statement correct? If not, rewrite it to make it correct.

6. Compare how cortisol, epinephrine, insulin, and glucagon affect blood glucose levels.

7. Assuming there is adequate iodine in the diet, how would secretion of thyroid-stimulating hormone (TSH) affect the production of thyroxine by the thyroid gland? How would increased levels of thyroxine affect the production of TSH?

8. Distinguish between the structure and function of the adrenal medulla and adrenal cortex.

9. How do levels of hGH change as people age? How do the changing levels of hGH affect the body?

10. Explain why glucagon and insulin are considered antagonistic hormones.

11. a) Explain how the lack of dietary iodine interferes with basic cellular metabolism.
b) What is this condition called? Why is it relatively uncommon in Canada?

12. Suppose you are lost in concentration while studying biology. Suddenly, the phone rings. Outline the physiological changes that occur in your body due to release of the stress hormones, cortisol and epinephrine. What triggers the release of each of these hormones? ICT

13. Compare and contrast the role of norepinephrine in the nervous system with its role in the endocrine system.

14. How does aldosterone help the body cope with an ongoing stressful situation? How is this response different from the fight-or-flight response?

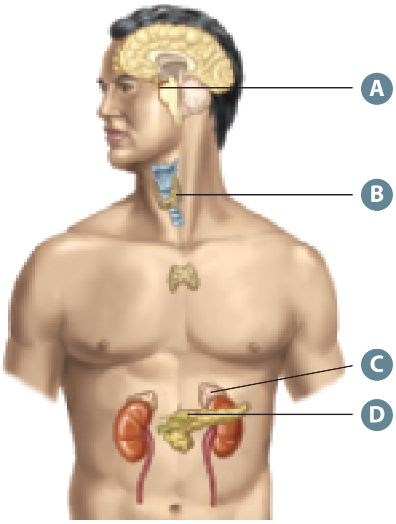
15. Why are the effects of hypothyroidism different when this condition occurs in a developing child compared to when the condition occurs in adulthood?

Applying Concepts

16. Suppose an early researcher was trying to determine the function of the pituitary. The researcher removed the pituitary from a laboratory animal and observed the effects on the animal. Suggest two or more reasons why this approach probably would have given the researcher confusing results.

17. Using the headings in the example table below, make a similar table in your notebook. In your table, write the name of each endocrine gland indicated on the following diagram by a letter. Complete the table, and include the hormonal imbalances associated with each gland, including diabetes mellitus, diabetes insipidus, acromegaly, hyperthyroidism, hypothyroidism, Addison's disease, and goitre.

Letter on diagram	Name of hormonal imbalance	Endocrine gland or glands involved	Hormones involved	Symptoms of the condition



18. An individual is playing hockey without a helmet. He receives a severe blow to the head that causes severe damage to his anterior pituitary gland. In your notebook list all the hormones that might be affected, and how this might affect the body in each case.

19. A doctor has a patient with very low levels of thyroxine in the blood but high levels of TSH. Is the person's problem in the thyroid gland or the pituitary gland? Explain your answer. What condition might this hormonal imbalance cause?

20. A tumour (overgrowth of cells) in an endocrine gland can sometimes cause the gland to become overactive. What hormonal effects might occur in someone with a tumour in the adrenal gland?

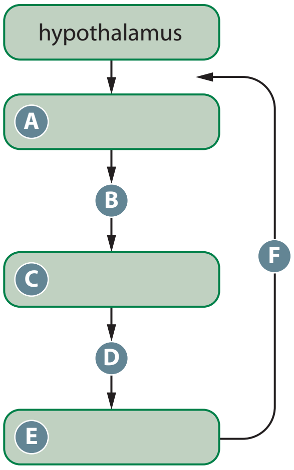
21. Suppose you are a doctor. You see a patient who has symptoms of sluggishness, depression, and intolerance to the cold. After eliminating several other possible causes, you diagnose a hormonal imbalance. What condition would produce these symptoms? Infer the endocrine gland that is probably involved.

22. A man reports having extreme thirst and fatigue. He drinks water almost constantly and urinates a great deal. Name two hormonal imbalances that could produce these symptoms. How could a doctor determine what the disorder is?

23. Studies with rats suggest that overcrowding causes behaviour changes due to increased stress levels.
   a) Hypothesize how overcrowding might affect people.
   b) How could you investigate whether people living in cities experience more or less stress than people living in less crowded environments?
   c) Supposing city dwellers were found to be more prone to stress, could you conclusively link this observation to overcrowding? Explain why or why not.

24. Based on what you know about the actions of insulin and glucagon, would a person with diabetes mellitus be more likely to require more insulin or more sugar following strenuous exercise? Explain your answer.

25. Copy the following flowchart into your notebook. Label the flowchart "Regulation of ACTH." On the flowchart, identify the following. ICT
   a) lobe of the pituitary affected
   b) hormone released from the pituitary gland
   c) endocrine gland affected
   d) hormone released from this endocrine gland
   e) effects on the body systems and tissues
   f) what regulates the hormone



Making Connections

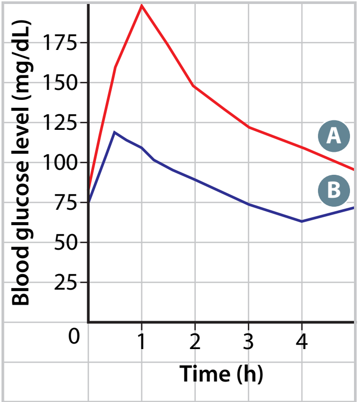
26. Explain why adequate lipid (fat) intake is essential for the healthy functioning of some endocrine glands and their hormones.

27. Some parents are asking their doctors to prescribe synthetic human growth hormone (hGH) treatments to their children, to improve their children's chance of winning sports scholarships for university. Based on what you know about the effects of synthetic hGH, do you think it should be prescribed in this situation? Justify your response.

28. Many types of animals (such as mice, rats, dogs, and monkeys) are sometimes used in medical research to investigate disorders of the endocrine system. How do such studies benefit human life? In your opinion, under what (if any) circumstances should animals be used for medical research? Suggest one or more effective alternative research methods that could replace some procedures involving laboratory animals.

29. There is a strong correlation between people with type 2 diabetes and obesity. What are some societal factors that might be contributing to the rise of type 2 diabetes in countries such as Canada? Suggest how one of these factors could be addressed.

30. The graph below shows the blood glucose levels of two individuals.
   a) Identify what event most likely occurred at time 0.
   b) Identify which of these individuals has diabetes and which does not. Explain your reasoning.
   c) Explain which hormone the person with diabetes took to cause the drop in glucose from 1 to 5 h.
   d) What caused the drop in glucose from 1 to 5 h in the person without diabetes?
   e) If both people exercised heavily at 5 h, what would you predict would happen to their blood glucose levels?
   f) Identify the hormone that would be released to regulate the blood glucose levels at 5 h.
   g) Identify the substance the person with diabetes could take following exercise to restore the blood glucose to a healthy level.



Career Focus: Ask an Endocrinologist

Dr. Edmond Ryan is the Medical Director of the University of Alberta Clinical Islet Transplant Program and a Professor of Medicine at the University of Alberta, in the Division of Endocrinology and Metabolism. He works alongside Program Director, Dr. James Shapiro, Islet Laboratory Director, Dr. Jonathan Lakey, and others to take people who have hard-to-manage type 1 diabetes through the islet transplant procedure known as the Edmonton Protocol.

Q What is the significance of the Clinical Islet Transplant Program?

First and foremost it gives hope to people with diabetes that there will be a treatment that doesn't involve insulin injections. The second thing is, this is the first time that cellular therapy for diabetes has been proven to be effective. Prior to this the only way of getting someone completely off insulin injections was to do a whole pancreas transplant, which is a very technical and major surgery. (The Edmonton Protocol) is relatively straightforward and people can be in and out of hospital within a day or two. Third, the fact that we can get people off insulin using the islet cells is stimulus for the whole area of stem cell research. And finally, it is an effective way of managing very difficult diabetes.

Q Who make good candidates for islet cell transplants?

The major indications for an islet transplantation at this time are people who have very labile diabetes—in other words, the glucose is swinging from high to low and there's no pattern to it. It's unpredictable and it is not responding to the standard treatment … The other major group are people who have profound problems with low blood sugar, or hypoglycemia. Most people with hypoglycemia get warning of it. They get shaky and they feel their blood glucose dropping, and they can deal with it effectively by taking some carbohydrate. But some people lose these warning signs. It becomes very precarious for them and they can pass out.

Q What is your role as Medical Director of the program?

With my colleagues, Drs. Breay Paty and Peter Senior, I evaluate patients' diabetes and put forward the pros and cons (of islet transplantation) in a fashion that they can understand to make an informed decision, and work with patients and their physicians following treatment … The pros are that you may come off insulin, and you may have cells working for you and that will stabilize your blood glucose. The cons are that you have to undergo the procedure. You also have to take immunosuppressive drugs on a life-long basis, and these drugs carry a significant risk. My role is to be an understanding person who appreciates the difficulties of having the diabetes, but also can give perspective on treatment advances.

Q Your work sounds very demanding. What keeps you motivated?

It's busy! But diabetes in and of itself is a phenomenally interesting disease. It affects the circulation, it affects the kidneys, it affects the eyes, it affects the nerves. So the person dealing with diabetes has to treat the whole person rather than just the blood sugars … What motivates me is the strength of people who have diabetes. It's a disease that has an impact all day, every day, and my job is to help them cope with it until we have better ways of handling it—and this will ultimately lead to a cure.

Q What does the future hold for islet transplant treatment?

Huge question. There aren't easy answers. The two major hurdles are a source of cells, and to be able to give the cells either with safer immunosuppression or with no immunosuppression. The sources of the cells could either be animal sources (xenotransplantation), or a stem cell source. There is also the issue of immunity, not only the immune reaction against the foreign, transplanted cells, but also the fact that type 1 diabetes, itself, is an autoimmune condition, so that even with a perfect transplant match, the body would still attack and destroy the islet cells. This is where gene therapy could come in. Canada has been a leader in diabetes from the time that insulin was discovered. We have a strong tradition and we want to continue that.

Other Careers Related to Diabetes Management

Biomedical Engineer Engineers apply mathematical principles to design and test medical tools, such as blood glucose monitors and insulin delivery devices. Software engineers in this field write computer programs to record, analyze, and organize medical data, such as real-time measurements of blood glucose levels. An undergraduate degree in engineering or biomedical engineering is needed to work in a research laboratory or with an industrial design team.

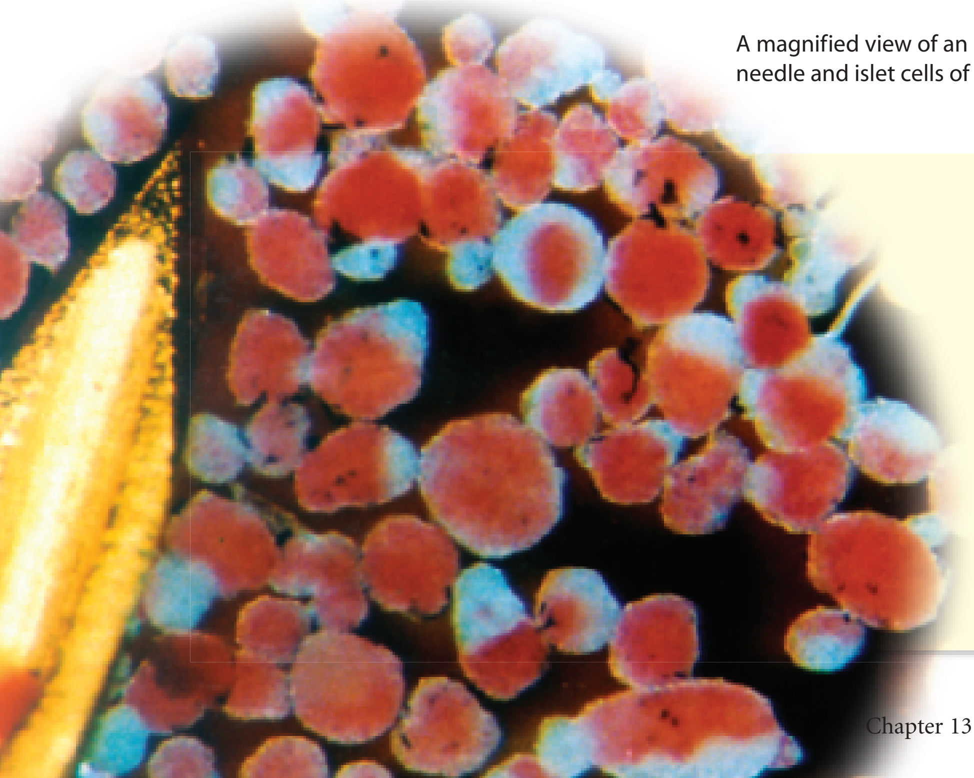
Fitness Consultant Kinesiologists (specialists in human movement), physiologists, and fitness instructors help motivate and educate people to meet various fitness goals, including weight loss, improved cardiovascular health, or improved strength or flexibility. Certified fitness consultants are trained in cardiopulmonary resuscitation (CPR), and have relevant certificates, college diplomas, or undergraduate degrees. Exercise specialists require post-degree certification in order to assist people with chronic conditions, such as diabetes.

Foot Care Nurse Registered nurses with special training in foot care examine, clean, groom, and otherwise care for the feet of elderly patients or patients with chronic conditions. For example, people with diabetes can develop poor circulation and lose sensation in the feet, and unknowingly develop life-threatening injuries and infections. Some foot care nurses are self-employed and provide home care for patients, while other nurses work in hospitals or clinics. In Alberta, registered nurses must have a diploma or undergraduate degree in nursing.

Ophthalmologist Eye doctors are physicians with specialized training in eye health and diseases. For instance, people with type 1 or type 2 diabetes are at risk for diabetic retinopathy, which damages blood vessels in the eye, and can lead to blindness if untreated. Ophthalmologists perform eye examinations to check for signs of disease or injury, prescribe medications, and perform laser surgery to correct diabetic retinopathy and other conditions.

Pharmacist/Pharmacy Assistant Many pharmacy degree graduates work as pharmacists in community drug stores, where they dispense and sell prescription and non-prescription medications and medical supplies. In the hospital setting, pharmacists dispense medications and provide advice on disease or pain management, and may help conduct drug trials and related research. Pharmacy assistants and technicians, who require up to two years' training, answer patient and physician inquiries, input patient records, and restock medical kits, among other activities.

Registered Dietician Graduates of a four-year degree in foods and nutrition can work as registered dieticians or nutritionists to help people better manage their diets. Registered dieticians can work as consultants or with a team of health professionals, and may counsel individuals or educate groups. A Certified Diabetes Dietician Educator teaches people how to prevent or better deal with diabetes through healthy eating habits.



A magnified view of an insulin needle and islet cells of the pancreas

Go Further...

1. Explain why hypoglycemia (low blood sugar) could cause someone to lose consciousness.
2. Islet transplant candidates must wait for the treatment until donated organs become available. Suggest three other potential sources of islet cells, and issues related to their use.
3. Adaptations of the Edmonton Protocol are used around the world. Investigate and discuss the benefits of the latest advance in this procedure.

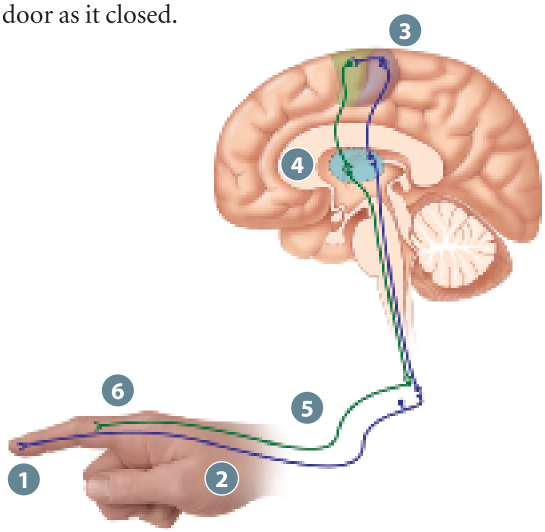
UNIT 5 REVIEW

Understanding Concepts

1. In your notebook, draw a diagram of a neuron. Label the dendrites, cell body, axon, and synaptic terminals. Identify the location of the sodium-potassium pump.

2. Which type of glial cell is responsible for increasing the speed of nerve impulses? Identify the structure that this type of glial cell forms, and explain how the structure speeds impulse transmission.

3. The diagram below shows the nerve pathway that would be involved if you accidentally caught your finger in a door as it closed.

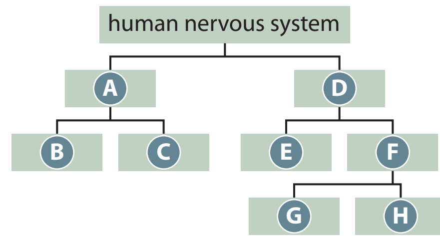


a) Name the types of neurons indicated by numbers 2, 3, and 5 on the diagram, and describe their functions.
b) Describe what is occurring at each number, from 1 through 6. Identify the stimulus and effector.
c) Identify the two brain structures at number 3, and describe their functions.
d) Name the brain structure at number 4, and describe its function.
e) Explain how this nerve pathway differs from a reflex arc.
f) Explain how using a painkiller, such as Aspirin™, would affect this nerve pathway and alleviate pain.

4. An obvious symptom of bovine spongiform encephalitis (BSE) is extreme lack of co-ordination. Infer the areas of the brain that BSE affects to cause this symptom.

5. Draw a graph that represents the change in voltage across a neuron's membrane during impulse transmission. Label the *x*-axis "Voltage" and the *y*-axis "Time." Label polarization, depolarization, repolarization, and the return to polarization on your graph. Indicate the voltage during each of these events. ICT

6. Identify the major divisions of the nervous system indicated by the letters in the diagram below. List the major roles of each division.



7. Name three areas of the body with specialized clusters of sensory neurons that relay information to the brain. Which structure of the brain does each cluster of sensory neurons affect?

8. As you have learned, there are four types of sensory receptors: mechanoreceptors, photoreceptors, chemoreceptors, and thermoreceptors. For each type, name **a)** the form of energy that is converted into electrochemical impulses, and **b)** the human sense(s) that rely on this type of receptor.

9. The light-detecting cells of the eye are found at the back of the retina, under several layers of cells. Identify and describe the structures of the eye that light passes through, from the outside of the eyeball to the light-detecting cells. What are the names and functions of the light-detecting cells?

10. Which structures of the ear enable a person to maintain balance while dancing? Which structures of the ear enable a person to maintain balance while standing still, watching birds fly overhead? Compare and contrast the functions of these different structures.

11. Outline the structures of the outer, middle, and inner ear. How does each structure contribute to hearing? ICT

12. Draw a flowchart to show how light is transformed into nerve impulses in the retina. ICT

13. What are the functions of the aqueous humour and vitreous humour of the eye?

14. Think about walking from a dark room to a bright room. Explain how your eyes adjust to the bright light.

15. What do neurotransmitters and hormones have in common? In general, how are they different?

16. In a table, list the ways in which the sympathetic and parasympathetic nervous systems act antagonistically to maintain homeostasis in the body. ICT

17. Name the human system (nervous and/or endocrine) that would be most important in each activity, and justify your choice.
   a) driving a car
   b) raising your blood glucose levels when you are hungry
   c) regulating your blood glucose levels when you are playing soccer

18. After playing a game of softball on a hot, sunny day, you are perspiring and very thirsty. List the glands and hormones that help your body maintain homeostasis in this situation. Describe the effects of these glands and hormones.

19. Describe the hormonal response that is involved in the short-term response to a stressful situation, such as being surprised by a fire alarm. What is this response called?

20. Draw and annotate a feedback loop to explain how a lack of dietary iodine can result in a goitre. ICT

21. Describe three challenges that were faced by the researchers who first determined the structures and functions of the major endocrine glands and hormones.

22. In general, how is a hormone able to "recognize" and stimulate its target cells?

23. Using a specific example, explain how the hormones of the adrenal medulla complement the actions of the sympathetic branch of the autonomic nervous system.

24. People with diabetes tend to avoid foods that are high in sugar. Explain why someone with type 1 diabetes would keep juice or a chocolate bar handy.

25. a) Why has the pituitary gland often been called "the master gland"?
   b) Explain how the hypothalamus controls the pituitary gland. Is "the master gland" a suitable name for the pituitary gland?

26. What causes diabetes insipidus? Describe the symptoms of this condition.

27. Various endocrine glands and their hormones regulate the concentration of glucose in the blood.
   a) List these hormones, and explain their effects on blood glucose levels.
   b) Form a hypothesis to explain why several hormones in the body, rather than just one, control blood glucose levels.

28. Use a flowchart to show why thyroid-stimulating hormone (TSH) is considered to be a tropic hormone. What regulates the release of TSH?

29. List the three hormones that are produced by the adrenal cortex. Compare and contrast the functions of these hormones and their effects on the body. ICT

30. Draw a concept map to organize the following endocrine structures and their functions: hypothalamus, anterior pituitary, posterior pituitary, thyroid, adrenal medulla, adrenal cortex, kidneys, pancreas, hGH, ADH, TSH, thyroxine, ACTH, cortisol, insulin, glucagon. ICT

Applying Concepts

31. Many people consider the Ironman Triathlon to be the most gruelling endurance event in the world. World champion contender, Chris Legh, almost died during the 1997 championship in Hawaii, when he pushed his body systems well past their homeostatic limits. He collapsed just metres before the finish line and had to be rushed to hospital. Doctors found that many of his body's systems had been damaged from severe dehydration and heat. Name five physiological conditions that were probably not operating at homeostasis in Chris Legh's body by the end of the race. Which responses of the nervous and endocrine systems would ordinarily have regulated these physiological conditions in order to restore homeostasis in his body?

32. Suppose that Alan, a six-year boy, is growing so quickly that he is 80 percent taller than his Grade 1 peers. An MRI scan reveals that he has a tumour in the anterior pituitary gland. What is most likely causing his rapid growth? What condition could Alan develop if corrective measures are not taken to deal with his hormonal imbalance?

33. Draw an outline diagram of yourself, and identify and label the major structures in your nervous system. Indicate the structures you are using to complete these questions. ICT

34. Suppose that you stub your foot on a chair leg. Your foot recoils before you feel any pain. Draw a flowchart of the nerve pathway that is involved in this reaction. What is this reaction called? How does this reaction protect you? When you later feel pain, what structures in your nervous system are involved? ICT

35. A neurosurgeon is probing a person's brain in order to map the brain's functions. The person is awake and feels no pain during the procedure. As each area of the brain is probed, the person perceives a different sensation, as described in the following table. Make a table in your notebook to list the structures of the brain that are stimulated by the probes, and the function of each structure.

Responses During Brain Probe

Area probed	Person's response
A	"I can hear a radio playing."
B	"I see a flash of bright light."
C	"I can smell the flowers in my garden."
D	"I remember a happy moment from my childhood."
E	"I can feel pain in my foot."
F	"My finger just twitched."

36. Researchers used a squid giant axon to study changes in the neuron's membrane during nerve impulse transmission. They manipulated the ion concentrations around the neuron, but kept ion concentrations within the neuron constant. Predict the results they obtained when they

a) added sodium ions to the fluid surrounding the axon

b) added potassium ions to the fluid surrounding the axon

Justify each of your predictions. Suggest a third change that the researchers could make to ion concentrations around the neuron and the effect this change would have.

37. Use the table below to answer the questions that follow.

Sodium Ion and Potassium Ion Concentrations Inside and Outside a Neuron

Ion	Concentration inside neuron (mmol/L)	Concentration in body fluid outside neuron (mmol/L)
sodium ion	12	145
potassium ion	140	4

a) What do the ion concentrations in the table suggest about the state of polarization of the neuron? Indicate the voltage across the membrane with respect to the inside of the neuron. How does a neuron establish this charge difference across the membrane?

b) How might a strong stimulus affect the state of polarization of the neuron? What would the ion concentrations and voltage across the membrane become? What would the generated response be called?

c) Qualitatively describe how the ion concentrations would change during repolarization. How would this affect the voltage across the membrane?

38. a) In your notebook, draw a simple diagram that shows a presynaptic neuron, a neuromuscular junction, and the associated facial muscle.

b) Illustrate the transmission of a nerve impulse at this neuromuscular junction. Label the synaptic vesicles, acetylcholine, cholinesterase, and receptor proteins.

c) Explain why Botox® injections around the forehead smooth facial wrinkles. On your diagram, indicate how Botox® affects the neuromuscular junction.

39. An eagle has a large number of densely packed cones in the retina. What advantages might this adaptation give the eagle?

40. Most elephants can detect sound frequencies between 1 Hz and 20 000 Hz. The following table lists the data collected when different sound frequencies were used to stimulate a single auditory neuron from an elephant and a single auditory neuron from a human. Write a paragraph that explains the results in terms of threshold potential and the all-or-none response. Note whether or not nerve activity increases as sound frequency increases.

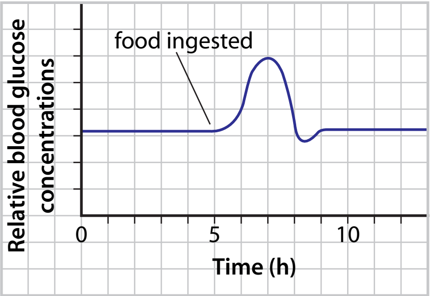
Sound Stimulation of an Elephant Ear Neuron and a Human Ear Neuron

Frequency of sound (Hz)	Elephant ear neuron stimulated?	Human ear neuron stimulated?
0.5	no	no
1	yes	no
20	yes	yes
40	yes	yes

41. On a dare, a high-school student foolishly drinks 4 L of water in 20 min. How would this affect the concentrations of sodium in the student's blood? Describe how the endocrine system would help to return the body systems to homeostasis. Name the hormones and gland(s) that would be involved.

42. The following graph illustrates the changes in a person's blood glucose concentrations before and after a meal. Study the graph, and answer the following questions.

Relative Blood Glucose Concentrations over 12 h



a) Describe what happened to the person's blood glucose concentration at 5 h.

b) Identify the hormone that was released at 7 h, the gland that released it, and the stimulus.

c) Identify the hormone that was released at 8 h, the gland that released it, and the stimulus.

d) Predict how the graph would look if the person engaged in strenuous exercise at 12 h. What hormone would be released during exercise?

e) Suppose that the person has type 1 diabetes. When would he have taken insulin?

43. The following data were collected from one person over 40 years as part of an experimental study. Results were always collected 3 h after a main meal.

Daily Blood Glucose Concentrations over 40 Years

Age	Average daily blood glucose concentration (mmol/L)
10	4.5
20	5.0
30	6.5
40	8.0
50	16.5

a) Why were the readings always taken 3 h after the main meal of the day?

b) The concentrations given are averages of 10 readings taken over one month. Why are averages given instead of raw data?

c) What has happened to the person's blood glucose concentrations over the 40 years?

d) What condition is associated with her symptoms? What causes this condition?

e) Suggest two things that she can do to improve her condition.

44. Your friend is frustrated in math class because his desk is at the back of the room and he cannot see the chalkboard. Other students at the back of the room say, however, that they have no trouble seeing the chalkboard. Tell your friend what kind of corrective lenses may help him. Draw a simple diagram to show him why his eyes likely have trouble focussing on distant objects. ICT

Making Connections

45. People who work with heavy equipment without ear protection often suffer hearing loss, but only for certain sound frequencies. Explain why.

46. When children are between six months and 10 years of age, the frontal lobe of their brain consumes twice as much energy as the frontal lobe of an adult brain. Name the major functions of the frontal lobe. Suggest why the frontal lobe of a child's brain needs more energy than the frontal lobe of an adult's brain.

47. Give two practical uses for a PET scan of the brain. If a PET scan of the brain is going to be used to gather research results, do the researchers have an ethical obligation to explain to study participants what data is being collected and how the results will be used? Justify your response in a brief paragraph.

48. The Students' Union at your school has raised $5000 for medical research. Students are being polled to determine what research they would like to support: research on multiple sclerosis, Alzheimer's disease, or Creutzfeldt-Jakob disease. Explain how each of these diseases affects the nervous system. Argue why each disease is worthy of the money for research.

49. Suggest how a medication that binds and interferes with dopamine could be used to help someone recover from a cocaine addiction. Use a diagram to show how the medication might work. Do you think that someone with a cocaine addiction should be forced to take the medication? Justify your response.

50. Suppose that you belong to a health promotion committee. The committee is preparing a campaign to teach people about treatments for cancer, high blood pressure, and heart disease. Explain to the committee how the endocrine system reacts to long-term stress and how this reaction affects the body. Explain why the campaign should also teach people ways to reduce stress.

51. Six months ago, your friend started a sodium-free diet. She has eliminated table salt, seafood, and dairy products from her diet. She tells you that recently her throat has been swollen, she has been feeling more tired and cold than usual, and she has gained weight. Based on her symptoms, what do you think has occurred in her endocrine system? Why should she see a doctor?