Patient B has symptoms including weight loss, profuse sweating, increased heart rate, and difficulty sleeping.

Humoral Stimuli

The term "humoral" is derived from the term "humor," which refers to bodily fluids such as blood. A **humoral stimulus** refers to the control of hormone release in response to changes in extracellular fluids such as blood or the ion concentration in the blood. For example, a rise in blood glucose levels triggers the pancreatic release of insulin. Insulin causes blood glucose levels to drop, which signals the pancreas to stop producing insulin in a negative feedback loop.

Hormonal Stimuli

Hormonal stimuli refers to the release of a hormone in response to another hormone. A number of endocrine glands release hormones when stimulated by hormones released by other endocrine glands. For example, the hypothalamus produces hormones that stimulate the anterior portion of the pituitary gland. The anterior pituitary in turn releases hormones that regulate hormone production by other endocrine glands. The anterior pituitary releases the thyroid-stimulating hormone, which then stimulates the thyroid gland to produce the hormones T_3 and T_4. As blood concentrations of T_3 and T_4 rise, they inhibit both the pituitary and the hypothalamus in a negative feedback loop.

Neural Stimuli

In some cases, the nervous system directly stimulates endocrine glands to release hormones, which is referred to as **neural stimuli**. Recall that in a short-term stress response, the hormones epinephrine and norepinephrine are important for providing the bursts of energy required for the body to respond. Here, neuronal signaling from the sympathetic nervous system directly stimulates the adrenal medulla to release the hormones epinephrine and norepinephrine in response to stress.

37.5 Endocrine Glands

By the end of this section, you will be able to do the following:

- Describe the role of different glands in the endocrine system
- Explain how the different glands work together to maintain homeostasis

Both the endocrine and nervous systems use chemical signals to communicate and regulate the body's physiology. The endocrine system releases hormones that act on target cells to regulate development, growth, energy metabolism, reproduction, and many behaviors. The nervous system releases neurotransmitters or neurohormones that regulate neurons, muscle cells, and endocrine cells. Because the neurons can regulate the release of hormones, the nervous and endocrine systems work in a coordinated manner to regulate the body's physiology.

Hypothalamic-Pituitary Axis

The **hypothalamus** in vertebrates integrates the endocrine and nervous systems. The hypothalamus is an endocrine organ located in the diencephalon of the brain. It receives input from the body and other brain areas and initiates endocrine responses to environmental changes. The hypothalamus acts as an endocrine organ, synthesizing hormones and transporting them along axons to the posterior pituitary gland. It synthesizes and secretes regulatory hormones that control the endocrine cells in the anterior pituitary gland. The hypothalamus contains autonomic centers that control endocrine cells in the adrenal medulla via neuronal control.

The **pituitary gland**, sometimes called the hypophysis or "master gland" is located at the base of the brain in the sella turcica, a groove of the sphenoid bone of the skull, illustrated in Figure 37.15. It is attached to the hypothalamus via a stalk called the **pituitary stalk** (or infundibulum). The anterior portion of the pituitary gland is regulated by releasing or release-inhibiting hormones produced by the hypothalamus, and the posterior pituitary receives signals via neurosecretory cells to release hormones produced by the hypothalamus. The pituitary has two distinct regions—the anterior pituitary and the posterior pituitary—which between them secrete nine different peptide or protein hormones. The posterior lobe of the pituitary gland contains axons of the hypothalamic neurons.

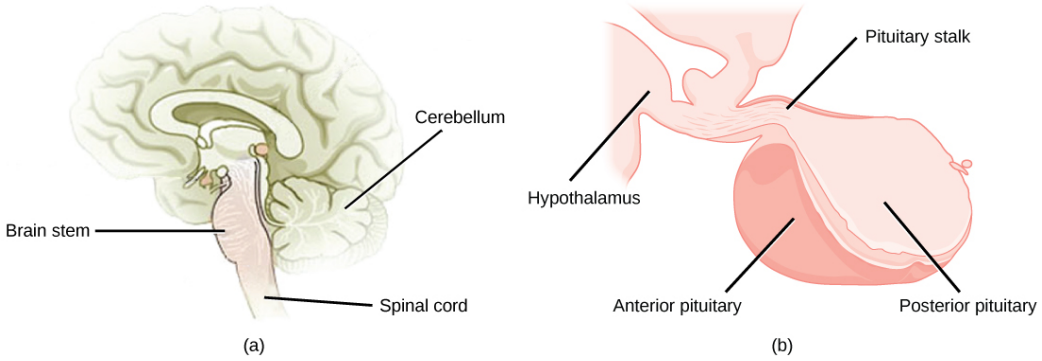

Figure 37.15 The pituitary gland is located at (a) the base of the brain and (b) connected to the hypothalamus by the pituitary stalk. (credit a: modification of work by NCI; credit b: modification of work by Gray's Anatomy)

Anterior Pituitary

The **anterior pituitary** gland, or adenohypophysis, is surrounded by a capillary network that extends from the hypothalamus, down along the infundibulum, and to the anterior pituitary. This capillary network is a part of the **hypophyseal portal system** that carries substances from the hypothalamus to the anterior pituitary and hormones from the anterior pituitary into the circulatory system. A portal system carries blood from one capillary network to another; therefore, the hypophyseal portal system allows hormones produced by the hypothalamus to be carried directly to the anterior pituitary without first entering the circulatory system.

The anterior pituitary produces seven hormones: growth hormone (GH), prolactin (PRL), thyroid-stimulating hormone (TSH), melanin-stimulating hormone (MSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), and luteinizing hormone (LH). Anterior pituitary hormones are sometimes referred to as tropic hormones, because they control the functioning of other organs. While these hormones are produced by the anterior pituitary, their production is controlled by regulatory hormones produced by the hypothalamus. These regulatory hormones can be releasing hormones or inhibiting hormones, causing more or less of the anterior pituitary hormones to be secreted. These travel from the hypothalamus through the hypophyseal portal system to the anterior pituitary where they exert their effect. Negative feedback then regulates how much of these regulatory hormones are released and how much anterior pituitary hormone is secreted.

Posterior Pituitary

The **posterior pituitary** is significantly different in structure from the anterior pituitary. It is a part of the brain, extending down from the hypothalamus, and contains mostly nerve fibers and neuroglial cells, which support axons that extend from the hypothalamus to the posterior pituitary. The posterior pituitary and the infundibulum together are referred to as the neurohypophysis.

The hormones antidiuretic hormone (ADH), also known as vasopressin, and oxytocin are produced by neurons in the hypothalamus and transported within these axons along the infundibulum to the posterior pituitary. They are released into the circulatory system via neural signaling from the hypothalamus. These hormones are considered to be posterior pituitary hormones, even though they are produced by the hypothalamus, because that is where they are released into the circulatory system. The posterior pituitary itself does not produce hormones, but instead stores hormones produced by the hypothalamus and releases them into the bloodstream.

Thyroid Gland

The **thyroid gland** is located in the neck, just below the larynx and in front of the trachea, as shown in Figure 37.16. It is a butterfly-shaped gland with two lobes that are connected by the **isthmus**. It has a dark red color due to its extensive vascular system. When the thyroid swells due to dysfunction, it can be felt under the skin of the neck.

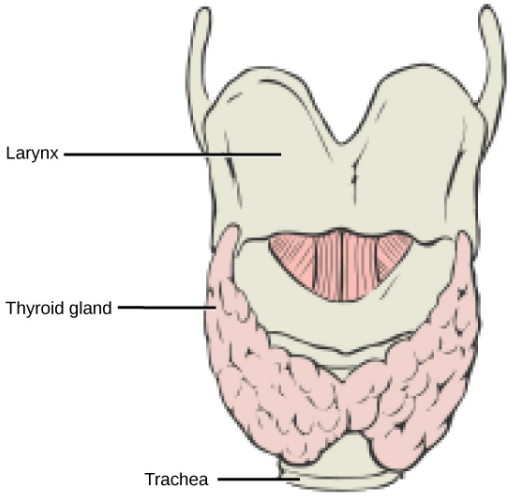

Figure 37.16 This illustration shows the location of the thyroid gland.

The thyroid gland is made up of many spherical thyroid follicles, which are lined with a simple cuboidal epithelium. These follicles contain a viscous fluid, called **colloid**, which stores the glycoprotein thyroglobulin, the precursor to the thyroid hormones. The follicles produce hormones that can be stored in the colloid or released into the surrounding capillary network for transport to the rest of the body via the circulatory system.

Thyroid follicle cells synthesize the hormone thyroxine, which is also known as T_4 because it contains four atoms of iodine, and triiodothyronine, also known as T_3 because it contains three atoms of iodine. Follicle cells are stimulated to release stored T_3 and T_4 by thyroid stimulating hormone (TSH), which is produced by the anterior pituitary. These thyroid hormones increase the rates of mitochondrial ATP production.

A third hormone, calcitonin, is produced by **parafollicular cells** of the thyroid either releasing hormones or inhibiting hormones. Calcitonin release is not controlled by TSH, but instead is released when calcium ion concentrations in the blood rise. Calcitonin functions to help regulate calcium concentrations in body fluids. It acts in the bones to inhibit osteoclast activity and in the kidneys to stimulate excretion of calcium. The combination of these two events lowers body fluid levels of calcium.

Parathyroid Glands

Most people have four **parathyroid glands**; however, the number can vary from two to six. These glands are located on the posterior surface of the thyroid gland, as shown in Figure 37.17. Normally, there is a superior gland and an inferior gland associated with each of the thyroid's two lobes. Each parathyroid gland is covered by connective tissue and contains many secretory cells that are associated with a capillary network.

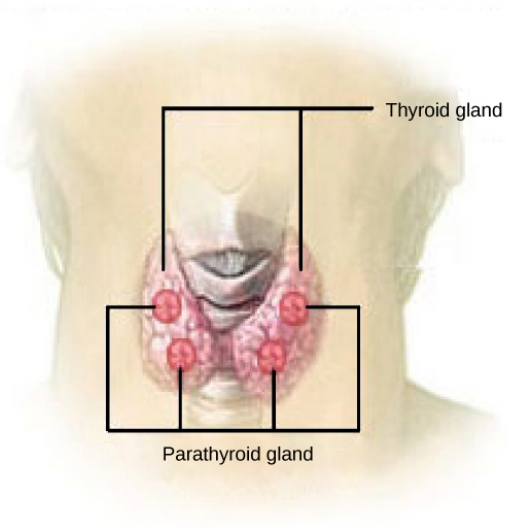

Figure 37.17 The parathyroid glands are located on the posterior of the thyroid gland. (credit: modification of work by NCI)

The parathyroid glands produce parathyroid hormone (PTH). PTH increases blood calcium concentrations when calcium ion levels fall below normal. PTH (1) enhances reabsorption of Ca^{2+} by the kidneys, (2) stimulates osteoclast activity and inhibits osteoblast activity, and (3) it stimulates synthesis and secretion of calcitriol by the kidneys, which enhances Ca^{2+} absorption by the digestive system. PTH is produced by chief cells of the parathyroid. PTH and calcitonin work in opposition to one another to maintain homeostatic Ca^{2+} levels in body fluids. Another type of cells, oxyphil cells, exist in the parathyroid but their function is not known. These hormones encourage bone growth, muscle mass, and blood cell formation in children and women.

Adrenal Glands

The **adrenal glands** are associated with the kidneys; one gland is located on top of each kidney as illustrated in Figure 37.18. The adrenal glands consist of an outer adrenal cortex and an inner adrenal medulla. These regions secrete different hormones.

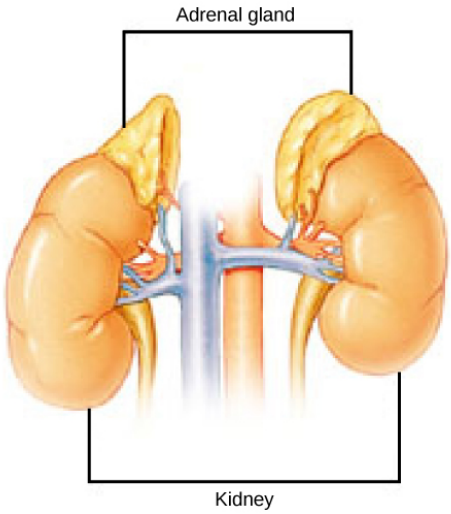

Figure 37.18 The location of the adrenal glands on top of the kidneys is shown. (credit: modification of work by NCI)

Adrenal Cortex

The **adrenal cortex** is made up of layers of epithelial cells and associated capillary networks. These layers form three distinct regions: an outer zona glomerulosa that produces mineralocorticoids, a middle zona fasciculata that produces glucocorticoids, and an inner zona reticularis that produces androgens.

The main mineralocorticoid is aldosterone, which regulates the concentration of Na^+ ions in urine, sweat, pancreas, and saliva. Aldosterone release from the adrenal cortex is stimulated by a decrease in blood concentrations of sodium ions, blood volume, or blood pressure, or by an increase in blood potassium levels.

The three main glucocorticoids are cortisol, corticosterone, and cortisone. The glucocorticoids stimulate the synthesis of glucose and gluconeogenesis (converting a non-carbohydrate to glucose) by liver cells and they promote the release of fatty acids from adipose tissue. These hormones increase blood glucose levels to maintain levels within a normal range between meals. These hormones are secreted in response to ACTH and levels are regulated by negative feedback.

Androgens are sex hormones that promote masculinity. They are produced in small amounts by the adrenal cortex in both males and females. They do not affect sexual characteristics and may supplement sex hormones released from the gonads.

Adrenal Medulla

The **adrenal medulla** contains large, irregularly shaped cells that are closely associated with blood vessels. These cells are innervated by preganglionic autonomic nerve fibers from the central nervous system.

The adrenal medulla contains two types of secretory cells: one that produces epinephrine (adrenaline) and another that produces norepinephrine (noradrenaline). Epinephrine is the primary adrenal medulla hormone accounting for 75 to 80 percent of its secretions. Epinephrine and norepinephrine increase heart rate, breathing rate, cardiac muscle contractions, blood pressure, and blood glucose levels. They also accelerate the breakdown of glucose in skeletal muscles and stored fats in adipose tissue.

The release of epinephrine and norepinephrine is stimulated by neural impulses from the sympathetic nervous system. Secretion of these hormones is stimulated by acetylcholine release from preganglionic sympathetic fibers innervating the adrenal medulla. These neural impulses originate from the hypothalamus in response to stress to prepare the body for the fight-or-flight response.

Pancreas

The **pancreas**, illustrated in Figure 37.19, is an elongated organ that is located between the stomach and the proximal portion of the small intestine. It contains both exocrine cells that excrete digestive enzymes and endocrine cells that release hormones. It is sometimes referred to as a heterocrine gland because it has both endocrine and exocrine functions.

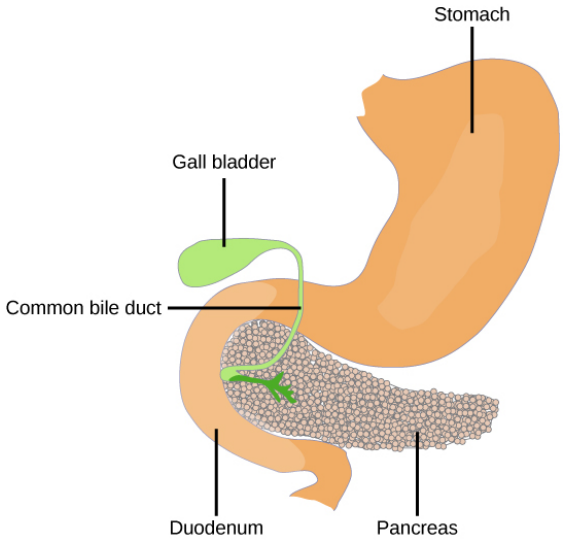

Figure 37.19 The pancreas is found underneath the stomach and points toward the spleen. (credit: modification of work by NCI)

The endocrine cells of the pancreas form clusters called pancreatic islets or the **islets of Langerhans**, as visible in the micrograph shown in Figure 37.20. The pancreatic islets contain two primary cell types: **alpha cells**, which produce the hormone glucagon, and **beta cells**, which produce the hormone insulin. These hormones regulate blood glucose levels. As blood glucose levels decline, alpha cells release glucagon to raise the blood glucose levels by increasing rates of glycogen breakdown and glucose release by the liver. When blood glucose levels rise, such as after a meal, beta cells release insulin to lower blood glucose levels by increasing the rate of glucose uptake in most body cells, and by increasing glycogen synthesis in skeletal muscles and the liver. Together, glucagon and insulin regulate blood glucose levels.

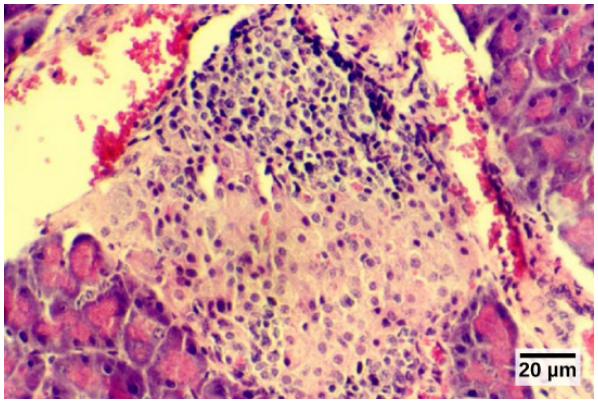

Figure 37.20 The islets of Langerhans are clusters of endocrine cells found in the pancreas; they stain lighter than surrounding cells. (credit: modification of work by Muhammad T. Tabiin, Christopher P. White, Grant Morahan, and Bernard E. Tuch; scale-bar data from Matt Russell)

Pineal Gland

The pineal gland produces melatonin. The rate of melatonin production is affected by the photoperiod. Collaterals from the visual pathways innervate the pineal gland. During the day photoperiod, little melatonin is produced; however, melatonin production increases during the dark photoperiod (night). In some mammals, melatonin has an inhibitory affect on reproductive functions by decreasing production and maturation of sperm, oocytes, and reproductive organs. Melatonin is an effective antioxidant, protecting the CNS from free radicals such as nitric oxide and hydrogen peroxide. Lastly, melatonin is involved in biological rhythms, particularly circadian rhythms such as the sleep-wake cycle and eating habits.

Gonads

The gonads—the male testes and female ovaries—produce steroid hormones. The testes produce androgens, testosterone being the most prominent, which allow for the development of secondary sex characteristics and the production of sperm cells. The ovaries produce estradiol and progesterone, which cause secondary sex characteristics and prepare the body for childbirth.

Endocrine Glands and their Associated Hormones

Endocrine Gland	Associated Hormones	Effect
Hypothalamus	releasing and inhibiting hormones	regulate hormone release from pituitary gland; produce oxytocin; produce uterine contractions and milk secretion in females
	antidiuretic hormone (ADH)	water reabsorption from kidneys; vasoconstriction to increase blood pressure
Pituitary (Anterior)	growth hormone (GH)	promotes growth of body tissues, protein synthesis; metabolic functions
	prolactin (PRL)	promotes milk production
	thyroid stimulating hormone (TSH)	stimulates thyroid hormone release
	adrenocorticotropic hormone (ACTH)	stimulates hormone release by adrenal cortex, glucocorticoids

Table 37.1

Endocrine Gland	Associated Hormones	Effect
	follicle-stimulating hormone (FSH)	stimulates gamete production (both ova and sperm); secretion of estradiol
	luteinizing hormone (LH)	stimulates androgen production by gonads; ovulation, secretion of progesterone
	melanocyte-stimulating hormone (MSH)	stimulates melanocytes of the skin increasing melanin pigment production.
Pituitary (Posterior)	antidiuretic hormone (ADH)	stimulates water reabsorption by kidneys
	oxytocin	stimulates uterine contractions during childbirth; milk ejection; stimulates ductus deferens and prostate gland contraction during emission
Thyroid	thyroxine, triiodothyronine	stimulate and maintain metabolism; growth and development
	calcitonin	reduces blood Ca^{2+} levels
Parathyroid	parathyroid hormone (PTH)	increases blood Ca^{2+} levels
Adrenal (Cortex)	aldosterone	increases blood Na^{+} levels; increases K^{+} secretion
	cortisol, corticosterone, cortisone	increase blood glucose levels; anti-inflammatory effects
Adrenal (Medulla)	epinephrine, norepinephrine	stimulate fight-or-flight response; increase blood gluclose levels; increase metabolic activities
Pancreas	insulin	reduces blood glucose levels
	glucagon	increases blood glucose levels
Pineal gland	melatonin	regulates some biological rhythms and protects CNS from free radicals
Testes	androgens	regulate, promote, increase or maintain sperm production; male secondary sexual characteristics
Ovaries	estrogen	promotes uterine lining growth; female secondary sexual characteristics
	progestins	promote and maintain uterine lining growth

Table 37.1

Organs with Secondary Endocrine Functions

There are several organs whose primary functions are non-endocrine but that also possess endocrine functions. These include the heart, kidneys, intestines, thymus, gonads, and adipose tissue.

The heart possesses endocrine cells in the walls of the atria that are specialized cardiac muscle cells. These cells release the hormone **atrial natriuretic peptide (ANP)** in response to increased blood volume. High blood volume causes the cells to be stretched, resulting in hormone release. ANP acts on the kidneys to reduce the reabsorption of Na^+, causing Na^+ and water to be excreted in the urine. ANP also reduces the amounts of renin released by the kidneys and aldosterone released by the adrenal cortex, further preventing the retention of water. In this way, ANP causes a reduction in blood volume and blood pressure, and reduces the concentration of Na^+ in the blood.

The gastrointestinal tract produces several hormones that aid in digestion. The endocrine cells are located in the mucosa of the GI tract throughout the stomach and small intestine. Some of the hormones produced include gastrin, secretin, and cholecystokinin, which are secreted in the presence of food, and some of which act on other organs such as the pancreas, gallbladder, and liver. They trigger the release of gastric juices, which help to break down and digest food in the GI tract.

While the adrenal glands associated with the kidneys are major **endocrine glands**, the kidneys themselves also possess endocrine function. Renin is released in response to decreased blood volume or pressure and is part of the renin-angiotensin-aldosterone system that leads to the release of aldosterone. Aldosterone then causes the retention of Na^+ and water, raising blood volume. The kidneys also release calcitriol, which aids in the absorption of Ca^{2+} and phosphate ions. **Erythropoietin (EPO)** is a protein hormone that triggers the formation of red blood cells in the bone marrow. EPO is released in response to low oxygen levels. Because red blood cells are oxygen carriers, increased production results in greater oxygen delivery throughout the body. EPO has been used by athletes to improve performance, as greater oxygen delivery to muscle cells allows for greater endurance. Because red blood cells increase the viscosity of blood, artificially high levels of EPO can cause severe health risks.

The **thymus** is found behind the sternum; it is most prominent in infants, becoming smaller in size through adulthood. The thymus produces hormones referred to as thymosins, which contribute to the development of the immune response.

Adipose tissue is a connective tissue found throughout the body. It produces the hormone **leptin** in response to food intake. Leptin increases the activity of anorexigenic neurons and decreases that of orexigenic neurons, producing a feeling of satiety after eating, thus affecting appetite and reducing the urge for further eating. Leptin is also associated with reproduction. It must be present for GnRH and gonadotropin synthesis to occur. Extremely thin females may enter puberty late; however, if adipose levels increase, more leptin will be produced, improving fertility.

KEY TERMS

acromegaly condition caused by overproduction of GH in adults

Addison's disease disorder caused by the hyposecretion of corticosteroids

adenylate cyclase an enzyme that catalyzes the conversion of ATP to cyclic AMP

adrenal cortex outer portion of adrenal glands that produces corticosteroids

adrenal gland endocrine glands associated with the kidneys

adrenal medulla inner portion of adrenal glands that produces epinephrine and norepinephrine

adrenocorticotropic hormone (ACTH) hormone released by the anterior pituitary, which stimulates the adrenal cortex to release corticosteroids during the long-term stress response

aldosterone steroid hormone produced by the adrenal cortex that stimulates the reabsorption of Na^+ from extracellular fluids and secretion of K^+

alpha cell endocrine cell of the pancreatic islets that produces the hormone glucagon

amino acid-derived hormone hormone derived from amino acids

androgen male sex hormone such as testosterone

anterior pituitary portion of the pituitary gland that produces six hormones; also called adenohypophysis

antidiuretic hormone (ADH) hormone produced by the hypothalamus and released by the posterior pituitary that increases water reabsorption by the kidneys

atrial natriuretic peptide (ANP) hormone produced by the heart to reduce blood volume, pressure, and Na^+ concentration

beta cell endocrine cell of the pancreatic islets that produces the hormone insulin

calcitonin hormone produced by the parafollicular cells of the thyroid gland that functions to lower blood Ca^{2+} levels and promote bone growth

colloid fluid inside the thyroid gland that contains the glycoprotein thyroglobulin

corticosteroid hormone released by the adrenal cortex in response to long-term stress

cortisol glucocorticoid produced in response to stress

Cushing's disease disorder caused by the hypersecretion of glucocorticoids

diabetes insipidus disorder caused by underproduction of ADH

diabetes mellitus disorder caused by low levels of insulin activity

diabetogenic effect effect of GH that causes blood glucose levels to rise similar to diabetes mellitus

down-regulation a decrease in the number of hormone receptors in response to increased hormone levels

endocrine gland gland that secretes hormones into the surrounding interstitial fluid, which then diffuse into blood and are carried to various organs and tissues within the body

epinephrine hormone released by the adrenal medulla in response to a short term stress

erythropoietin (EPO) hormone produced by the kidneys to stimulate red blood cell production in the bone marrow

estrogens a group of steroid hormones, including estradiol and several others, that are produced by the ovaries and elicit secondary sex characteristics in females as well as control the maturation of the ova

first messenger the hormone that binds to a plasma membrane hormone receptor to trigger a signal transduction pathway

follicle-stimulating hormone (FSH) hormone produced by the anterior pituitary that stimulates gamete production

G-protein a membrane protein activated by the hormone first messenger to activate formation of cyclic AMP

gigantism condition caused by overproduction of GH in children

glucagon hormone produced by the alpha cells of the pancreas in response to low blood sugar; functions to raise blood sugar levels

glucocorticoid corticosteroid that affects glucose metabolism

gluconeogenesis synthesis of glucose from amino acids

glucose-sparing effect effect of GH that causes tissues to use fatty acids instead of glucose as an energy source

glycogenolysis breakdown of glycogen into glucose

goiter enlargement of the thyroid gland caused by insufficient dietary iodine levels

gonadotropin hormone that regulates the gonads, including FSH and LH

growth hormone (GH) hormone produced by the anterior pituitary that promotes protein synthesis and body growth

growth hormone-inhibiting hormone (GHIH) hormone produced by the hypothalamus that inhibits growth hormone production, also called somatostatin

growth hormone-releasing hormone (GHRH) hormone released by the hypothalamus that triggers the release of GH

hormonal stimuli release of a hormone in response to another hormone

hormone receptor the cellular protein that binds to a hormone

humoral stimuli control of hormone release in response to changes in extracellular fluids such as blood or the ion concentration in the blood

hyperglycemia high blood sugar level

hyperthyroidism overactivity of the thyroid gland

hypoglycemia low blood sugar level
hypophyseal portal system system of blood vessels that carries hormones from the hypothalamus to the anterior pituitary
hypothyroidism underactivity of the thyroid gland
insulin hormone produced by the beta cells of the pancreas in response to high blood glucose levels; functions to lower blood glucose levels
insulin-like growth factor (IGF) growth-promoting protein produced by the liver
intracellular hormone receptor a hormone receptor in the cytoplasm or nucleus of a cell
islets of Langerhans (pancreatic islets) endocrine cells of the pancreas
isthmus tissue mass that connects the two lobes of the thyroid gland
leptin hormone produced by adipose tissue that promotes feelings of satiety and reduces hunger
lipid-derived hormone hormone derived mostly from cholesterol
mineralocorticoid corticosteroid that affects ion and water balance
neural stimuli stimulation of endocrine glands by the nervous system
norepinephrine hormone released by the adrenal medulla in response to a short-term stress hormone production by the gonads
osmoreceptor receptor in the hypothalamus that monitors the concentration of electrolytes in the blood
oxytocin hormone released by the posterior pituitary to stimulate uterine contractions during childbirth and milk let-down in the mammary glands
pancreas organ located between the stomach and the small intestine that contains exocrine and endocrine cells
parafollicular cell thyroid cell that produces the hormone calcitonin
parathyroid gland gland located on the surface of the thyroid that produces parathyroid hormone
parathyroid hormone (PTH) hormone produced by the parathyroid glands in response to low blood Ca^{2+} levels; functions to raise blood Ca^{2+} levels
peptide hormone hormone composed of a polypeptide chain
phosphodiesterase (PDE) enzyme that deactivates cAMP, stopping hormone activity
pituitary dwarfism condition caused by underproduction of GH in children
pituitary gland endocrine gland located at the base of the brain composed of an anterior and posterior region; also called hypophysis
pituitary stalk (also, infundibulum) stalk that connects the pituitary gland to the hypothalamus
plasma membrane hormone receptor a hormone receptor on the surface of the plasma membrane of a cell
posterior pituitary extension of the brain that releases hormones produced by the hypothalamus; along with the infundibulum, it is also referred to as the neurohypophysis
prolactin (PRL) hormone produced by the anterior pituitary that stimulates milk production
prolactin-inhibiting hormone hormone produced by the hypothalamus that inhibits the release of prolactin
prolactin-releasing hormone hormone produced by the hypothalamus that stimulates the release of prolactin
renin enzyme produced by the juxtaglomerular apparatus of the kidneys that reacts with angiotensinogen to cause the release of aldosterone
thymus gland located behind the sternum that produces thymosin hormones that contribute to the development of the immune system
thyroglobulin glycoprotein found in the thyroid that is converted into thyroid hormone
thyroid gland endocrine gland located in the neck that produces thyroid hormones thyroxine and triiodothyronine
thyroid-stimulating hormone (TSH) hormone produced by the anterior pituitary that controls the release of T_3 and T_4 from the thyroid gland
thyroxine (tetraiodothyronine, T_4) thyroid hormone containing 4 iodines that controls the basal metabolic rate
triiodothyronine (T_3) thyroid hormone containing 3 iodines that controls the basal metabolic rate
up-regulation an increase in the number of hormone receptors in response to increased hormone levels

CHAPTER SUMMARY

37.1 Types of Hormones

There are three basic types of hormones: lipid-derived, amino acid-derived, and peptide. Lipid-derived hormones are structurally similar to cholesterol and include steroid hormones such as estradiol and testosterone. Amino acid-derived hormones are relatively small molecules and include the adrenal hormones epinephrine and norepinephrine. Peptide hormones are polypeptide chains or proteins and include the pituitary hormones, antidiuretic hormone (vasopressin), and oxytocin.

37.2 How Hormones Work

Hormones cause cellular changes by binding to receptors on target cells. The number of receptors on a target cell can increase or decrease in response to hormone activity. Hormones can affect cells directly through intracellular hormone receptors or indirectly through plasma membrane

hormone receptors.

Lipid-derived (soluble) hormones can enter the cell by diffusing across the plasma membrane and binding to DNA to regulate gene transcription and to change the cell's activities by inducing production of proteins that affect, in general, the long-term structure and function of the cell. Lipid insoluble hormones bind to receptors on the plasma membrane surface and trigger a signaling pathway to change the cell's activities by inducing production of various cell products that affect the cell in the short-term. The hormone is called a first messenger and the cellular component is called a second messenger. G-proteins activate the second messenger (cyclic AMP), triggering the cellular response. Response to hormone binding is amplified as the signaling pathway progresses. Cellular responses to hormones include the production of proteins and enzymes and altered membrane permeability.

37.3 Regulation of Body Processes

Water levels in the body are controlled by antidiuretic hormone (ADH), which is produced in the hypothalamus and triggers the reabsorption of water by the kidneys. Underproduction of ADH can cause diabetes insipidus. Aldosterone, a hormone produced by the adrenal cortex of the kidneys, enhances Na^+ reabsorption from the extracellular fluids and subsequent water reabsorption by diffusion. The renin-angiotensin-aldosterone system is one way that aldosterone release is controlled.

The reproductive system is controlled by the gonadotropins follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which are produced by the pituitary gland. Gonadotropin release is controlled by the hypothalamic hormone gonadotropin-releasing hormone (GnRH). FSH stimulates the maturation of sperm cells in males and is inhibited by the hormone inhibin, while LH stimulates the production of the androgen testosterone. FSH stimulates egg maturation in females, while LH stimulates the production of estrogens and progesterone. Estrogens are a group of steroid hormones produced by the ovaries that trigger the development of secondary sex characteristics in females as well as control the maturation of the ova. In females, the pituitary also produces prolactin, which stimulates milk production after childbirth, and oxytocin, which stimulates uterine contraction during childbirth and milk let-down during suckling.

Insulin is produced by the pancreas in response to rising blood glucose levels and allows cells to utilize blood glucose and store excess glucose for later use. Diabetes mellitus is caused by reduced insulin activity and causes high blood glucose levels, or hyperglycemia. Glucagon is released by the pancreas in response to low blood glucose levels and stimulates the breakdown of glycogen into glucose, which can be used by the body. The body's basal metabolic rate is controlled by the thyroid hormones thyroxine (T_4) and triiodothyronine (T_3). The anterior pituitary produces thyroid stimulating hormone (TSH), which controls the release of T_3 and T_4 from the thyroid gland. Iodine is necessary in the production of thyroid hormone, and the lack of iodine can lead to a condition called goiter.

Parathyroid hormone (PTH) is produced by the parathyroid glands in response to low blood Ca^{2+} levels. The parafollicular cells of the thyroid produce calcitonin, which reduces blood Ca^{2+} levels. Growth hormone (GH) is produced by the anterior pituitary and controls the growth rate of muscle and bone. GH action is indirectly mediated by insulin-like growth factors (IGFs). Short-term stress causes the hypothalamus to trigger the adrenal medulla to release epinephrine and norepinephrine, which trigger the fight or flight response. Long-term stress causes the hypothalamus to trigger the anterior pituitary to release adrenocorticotropic hormone (ACTH), which causes the release of corticosteroids, glucocorticoids, and mineralocorticoids, from the adrenal cortex.

37.4 Regulation of Hormone Production

Hormone levels are primarily controlled through negative feedback, in which rising levels of a hormone inhibit its further release. The three mechanisms of hormonal release are humoral stimuli, hormonal stimuli, and neural stimuli. Humoral stimuli refers to the control of hormonal release in response to changes in extracellular fluid levels or ion levels. Hormonal stimuli refers to the release of hormones in response to hormones released by other endocrine glands. Neural stimuli refers to the release of hormones in response to neural stimulation.

37.5 Endocrine Glands

The pituitary gland is located at the base of the brain and is attached to the hypothalamus by the infundibulum. The anterior pituitary receives products from the hypothalamus by the hypophyseal portal system and produces six hormones. The posterior pituitary is an extension of the brain and releases hormones (antidiuretic hormone and oxytocin) produced by the hypothalamus.

The thyroid gland is located in the neck and is composed of two lobes connected by the isthmus. The thyroid is made up of follicle cells that produce the hormones thyroxine and triiodothyronine. Parafollicular cells of the thyroid produce calcitonin. The parathyroid glands lie on the posterior surface of the thyroid gland and produce parathyroid hormone.

The adrenal glands are located on top of the kidneys and consist of the renal cortex and renal medulla. The adrenal

cortex is the outer part of the adrenal gland and produces the corticosteroids, glucocorticoids, and mineralocorticoids. The adrenal medulla is the inner part of the adrenal gland and produces the catecholamines epinephrine and norepinephrine.

The pancreas lies in the abdomen between the stomach and the small intestine. Clusters of endocrine cells in the pancreas form the islets of Langerhans, which are composed of alpha cells that release glucagon and beta cells that release insulin.

Some organs possess endocrine activity as a secondary function but have another primary function. The heart produces the hormone atrial natriuretic peptide, which functions to reduce blood volume, pressure, and Na^+ concentration. The gastrointestinal tract produces various hormones that aid in digestion. The kidneys produce renin, calcitriol, and erythropoietin. Adipose tissue produces leptin, which promotes satiety signals in the brain.

VISUAL CONNECTION QUESTIONS

1. Figure 37.5 Heat shock proteins (HSP) are so named because they help refold misfolded proteins. In response to increased temperature (a "heat shock"), heat shock proteins are activated by release from the NR/HSP complex. At the same time, transcription of HSP genes is activated. Why do you think the cell responds to a heat shock by increasing the activity of proteins that help refold misfolded proteins?

2. Figure 37.11 Pancreatic tumors may cause excess secretion of glucagon. Type I diabetes results from the failure of the pancreas to produce insulin. Which of the following statement about these two conditions is true?
   a. A pancreatic tumor and type I diabetes will have the opposite effects on blood sugar levels.
   b. A pancreatic tumor and type I diabetes will both cause hyperglycemia.
   c. A pancreatic tumor and type I diabetes will both cause hypoglycemia.
   d. Both pancreatic tumors and type I diabetes result in the inability of cells to take up glucose.

3. Figure 37.14 Hyperthyroidism is a condition in which the thyroid gland is overactive. Hypothyroidism is a condition in which the thyroid gland is underactive. Which of the conditions are the following two patients most likely to have?
   Patient A has symptoms including weight gain, cold sensitivity, low heart rate, and fatigue.
   Patient B has symptoms including weight loss, profuse sweating, increased heart rate, and difficulty sleeping.

REVIEW QUESTIONS

4. A newly discovered hormone contains four amino acids linked together. Under which chemical class would this hormone be classified?
   a. lipid-derived hormone
   b. amino acid-derived hormone
   c. peptide hormone
   d. glycoprotein

5. Which class of hormones can diffuse through plasma membranes?
   a. lipid-derived hormones
   b. amino acid-derived hormones
   c. peptide hormones
   d. glycoprotein hormones

6. Why are steroids able to diffuse across the plasma membrane?
   a. Their transport protein moves them through the membrane.
   b. They are amphipathic, allowing them to interact with the entire phospholipid.
   c. Cells express channels that let hormones flow down their concentration gradient into the cells.
   d. They are non-polar molecules.

7. A new antagonist molecule has been discovered that binds to and blocks plasma membrane receptors. What effect will this antagonist have on testosterone, a steroid hormone?
   a. It will block testosterone from binding to its receptor.
   b. It will block testosterone from activating cAMP signaling.
   c. It will increase testosterone-mediated signaling.
   d. It will not affect testosterone-mediated signaling.

8. What effect will a cAMP inhibitor have on a peptide hormone-mediated signaling pathway?
   a. It will prevent the hormone from binding its receptor.
   b. It will prevent activation of a G-protein.
   c. It will prevent activation of adenylate cyclase.
   d. It will prevent activation of protein kinases.

9. When insulin binds to its receptor, the complex is endocytosed into the cell. This is an example of _____ in response to hormone signaling.
   a. cAMP activation
   b. generating an intracellular receptor
   c. activation of a hormone response element
   d. receptor down-regulation

10. Drinking alcoholic beverages causes an increase in urine output. This most likely occurs because alcohol:
   a. inhibits ADH release.
   b. stimulates ADH release.
   c. inhibits TSH release.
   d. stimulates TSH release.

11. FSH and LH release from the anterior pituitary is stimulated by _____.
   a. TSH
   b. GnRH
   c. T_3
   d. PTH

12. What hormone is produced by beta cells of the pancreas?
   a. T_3
   b. glucagon
   c. insulin
   d. T_4

13. When blood calcium levels are low, PTH stimulates:
   a. excretion of calcium from the kidneys.
   b. excretion of calcium from the intestines.
   c. osteoblasts.
   d. osteoclasts.

14. How would mutations that completely ablate the function of the androgen receptor impact the phenotypic development of humans with XY chromosomes?
   a. Patients would appear phenotypically female.
   b. Patients would appear phenotypically male with underdeveloped secondary sex characteristics.
   c. Patients would appear phenotypically male, but cannot produce sperm.
   d. Patients would express both male and female secondary sex characteristics.

15. A rise in blood glucose levels triggers release of insulin from the pancreas. This mechanism of hormone production is stimulated by:
   a. humoral stimuli
   b. hormonal stimuli
   c. neural stimuli
   d. negative stimuli

16. Which mechanism of hormonal stimulation would be affected if signaling and hormone release from the hypothalamus was blocked?
   a. humoral and hormonal stimuli
   b. hormonal and neural stimuli
   c. neural and humoral stimuli
   d. hormonal and negative stimuli

17. A scientist hypothesizes that the pancreas's hormone production is controlled by neural stimuli. Which observation would support this hypothesis?
   a. Insulin is produced in response to sudden stress without a rise in blood glucose.
   b. Insulin is produced in response to a rise in glucagon levels.
   c. Beta cells express epinephrine receptors.
   d. Insulin is produced in response to a rise in blood glucose in the brain.

18. Which endocrine glands are associated with the kidneys?
   a. thyroid glands
   b. pituitary glands
   c. adrenal glands
   d. gonads

19. Which of the following hormones is not produced by the anterior pituitary?
   a. oxytocin
   b. growth hormone
   c. prolactin
   d. thyroid-stimulating hormone

20. Recent studies suggest that blue light exposure can impact human circadian rhythms. This suggests that blue light disrupts the function of the _____ gland(s).
   a. adrenal
   b. pituitary
   c. pineal
   d. thyroid

CRITICAL THINKING QUESTIONS

21. Although there are many different hormones in the human body, they can be divided into three classes based on their chemical structure. What are these classes and what is one factor that distinguishes them?

22. Where is insulin stored, and why would it be released?

23. Glucagon is the peptide hormone that signals for the body to release glucose into the bloodstream. How does glucagon contribute to maintaining homeostasis throughout the body? What other hormones are involved in regulating the blood glucose cycle?

24. Name two important functions of hormone receptors.

25. How can hormones mediate changes?

26. Why is cAMP-mediated signal amplification not required in steroid hormone signaling? Describe how steroid signaling is amplified instead.

27. Name and describe a function of one hormone produced by the anterior pituitary and one hormone produced by the posterior pituitary.

28. Describe one direct action of growth hormone (GH).

29. Researchers have recently demonstrated that stressed people are more susceptible to contracting the common cold than people who are not stressed. What kind of stress must the infected patients be experiencing, and why does it make them more susceptible to the virus?

30. How is hormone production and release primarily controlled?

31. Compare and contrast hormonal and humoral stimuli.

32. Oral contraceptive pills work by delivering synthetic progestins to a woman every day. Describe why this is an effective method of birth control.

33. What does aldosterone regulate, and how is it stimulated?

34. The adrenal medulla contains two types of secretory cells, what are they and what are their functions?

35. How would damage to the posterior pituitary gland affect the production and release of ADH and inhibiting hormones?