PHYSIOLOGY

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LECTURE 13- ENDOCRINE SYSTEM

Objectives

1. Discuss **comparison of control by the nervous and endocrine systems.**

2. Describe **pituitary gland - anterior and posterior.**

3. Explore **thyroid gland, adrenal cortex and, medulla, parathyroid and, calcium homeostasis, and endocrine pancreas and insulin disorders.**

(Pages 615- 646, 654-656 of the reference)

THE ENDOCRINE SYSTEM

- Multitudes of hormones help maintain homeostasis on a daily basis. They regulate the activity of smooth muscle, cardiac muscle, and some glands; alter metabolism; influence reproductive processes; and participate in circadian (daily) rhythms established by the suprachiasmatic nucleus of the hypothalamus.

THE ENDOCRINE SYSTEM

- **A hormone** is a mediator molecule that is released in one part of the body but regulates the activity of cells in other parts of the body.

- Most hormones enter interstitial fluid and then the bloodstream.

- The circulating blood delivers hormones to cells throughout the body.

- Both neurotransmitters and hormones exert their effects by binding to receptors on or in their "target" cells.

- **Responses of the endocrine system often are slower than responses of the nervous system**; although some hormones act within seconds, most take several minutes or more to cause a response.

THE ENDOCRINE SYSTEM

- **The effects of nervous system activation** are generally briefer than those of the endocrine system. The nervous system acts on specific muscles and glands.
- The influence of the endocrine system is much broader; it helps regulate virtually all types of body cells.

TABLE 18.1

Comparison of Control by the Nervous and Endocrine Systems

CHARACTERISTIC	NERVOUS SYSTEM	ENDOCRINE SYSTEM
Mediator molecules	Neurotransmitters released locally in response to nerve impulses.	Hormones delivered to tissues throughout body by blood.
Site of mediator action	Close to site of release, at synapse; binds to receptors in postsynaptic membrane.	Far from site of release (usually); binds to receptors on or in target cells.
Types of target cells	Muscle (smooth, cardiac, and skeletal) cells, gland cells, other neurons.	Cells throughout body.
Time to onset of action	Typically within milliseconds (thousandths of a second).	Seconds to hours or days.
Duration of action	Generally briefer (milliseconds).	Generally longer (seconds to days).

FUNCTIONS OF HORMONES

FUNCTIONS OF HORMONES

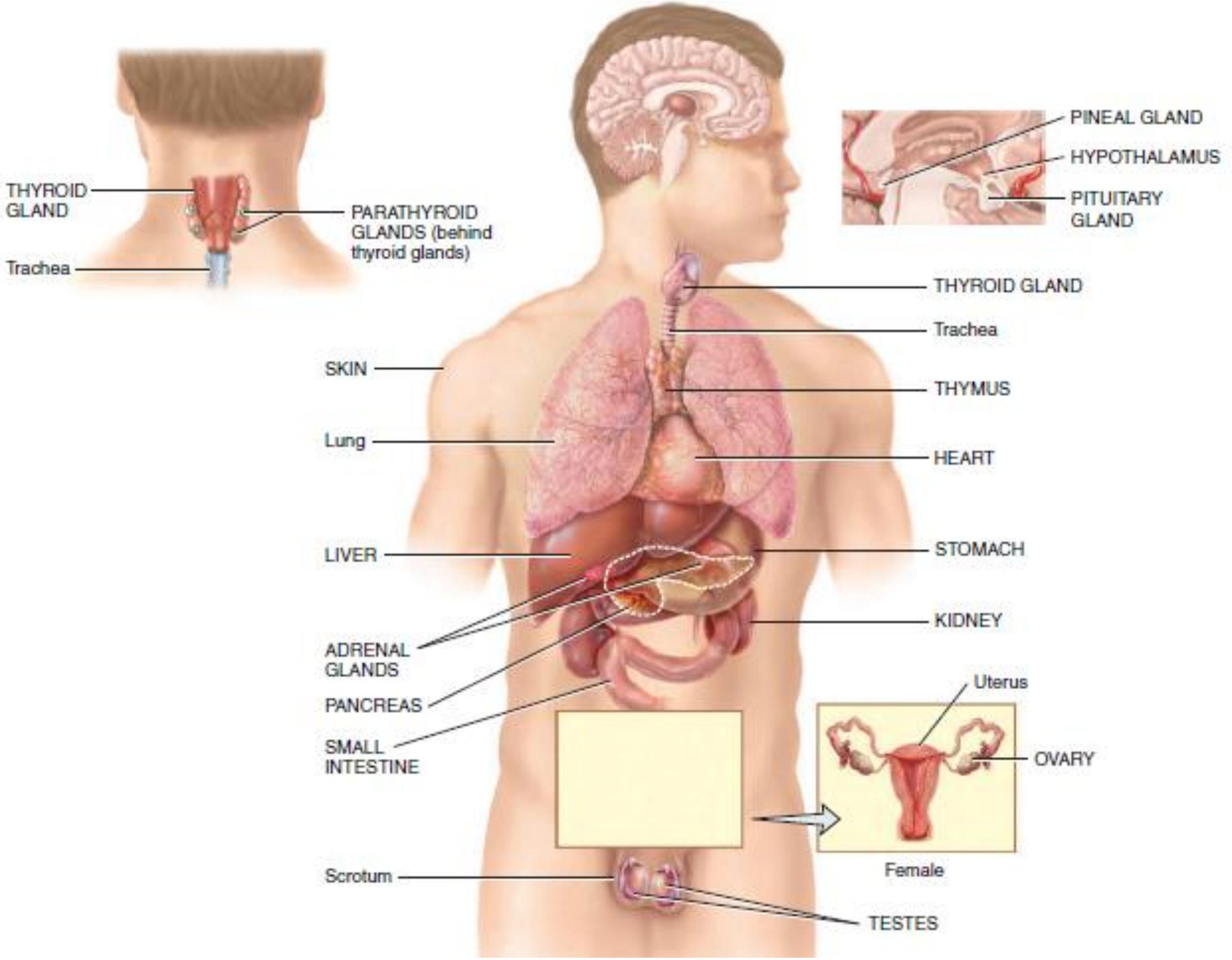
1. Help regulate:
   - Chemical composition and volume of internal environment (interstitial fluid).
   - Metabolism and energy balance.
   - Contraction of smooth and cardiac muscle fibers.
   - Glandular secretions.
   - Some immune system activities.
2. Control growth and development.
3. Regulate operation of reproductive systems.
4. Help establish circadian rhythms.

ENDOCRINE GLANDS

- **Exocrine glands** secrete their products into ducts that carry the secretions into body cavities, into the lumen of an organ, or to the outer surface of the body. Exocrine glands include sudoriferous (sweat), sebaceous (oil), mucous, and digestive glands.

- **Endocrine glands** secrete their products (hormones) into the interstitial fluid surrounding the secretory cells rather than into ducts.

The <u>endocrine glands include the pituitary, thyroid, parathyroid, adrenal, and pineal glands</u>. In addition, several organs and tissues are not exclusively classified as endocrine glands but contain cells that secrete hormones. These include the hypothalamus, thymus, pancreas, ovaries, testes, kidneys, stomach, liver, small intestine, skin, heart, adipose tissue, and placenta. **<u>Taken together, all endocrine glands and hormone-secreting cells constitute the endocrine system.</u>**



HORMONE ACTIVITY

The role of hormone receptors:

Although a given hormone travels throughout the body in the blood, it affects only specific target cells.

Only the target cells for a given hormone have receptors that bind and recognize that hormone. For example, thyroid-stimulating hormone (TSH) binds to receptors on cells of the thyroid gland, but it does not bind to cells of the ovaries because ovarian cells do not have TSH receptors.

HORMONE ACTIVITY

If a hormone is present in excess, the number of target-cell receptors may decrease— an effect called down-regulation. For example, when certain cells of the testes are exposed to a high concentration of luteinizing hormone (LH), the number of LH receptors decreases. Downregulation makes a target cell less sensitive to a hormone. In contrast, when a hormone is deficient, the number of receptors may increase. This phenomenon, known as up-regulation, makes a target cell more sensitive to a hormone.

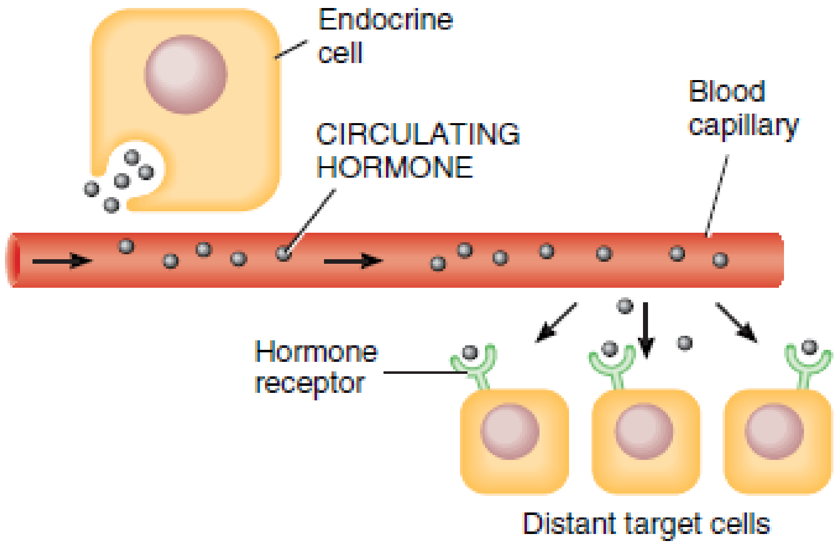
CIRCULATING AND LOCAL HORMONES

- Most endocrine hormones are **circulating hormones**—they pass from the secretory cells that make them into interstitial fluid and then into the blood.
- Other hormones, termed **local hormones**, act locally on neighboring cells or on the same cell that secreted them without first entering the bloodstream.
- **Local hormones that act on neighboring cells** are called **paracrines**, and **those that act on the same cell that secreted them** are called **autocrines**.
- **Local hormones usually are inactivated quickly**; **circulating hormones may linger in the blood and exert their effects for a few minutes or occasionally for a few hours**. In time, **circulating hormones are inactivated by the liver and excreted by the kidneys.** **In cases of kidney or liver failure, excessive levels of hormones may build up in the blood.**

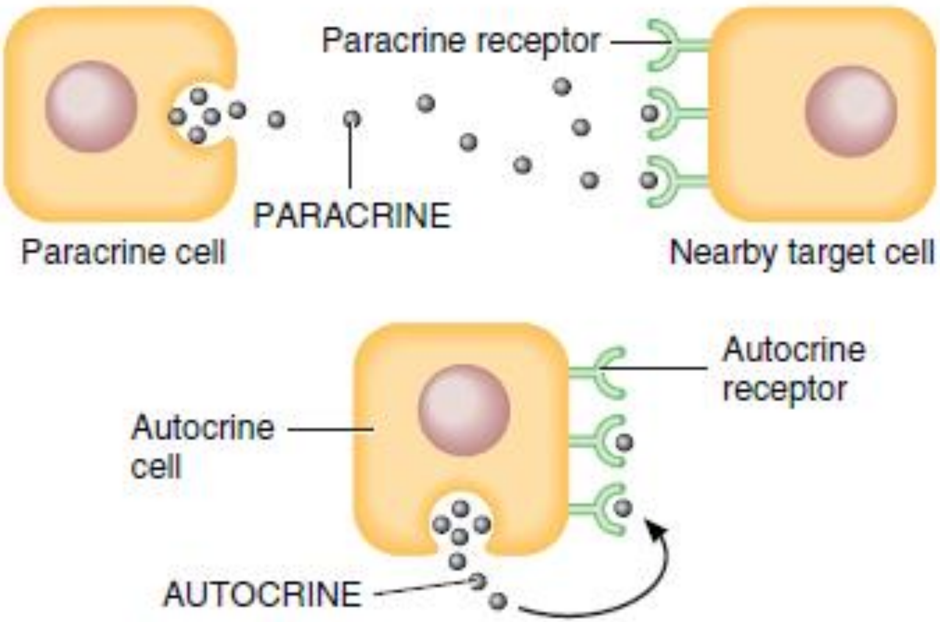
CIRCULATING AND LOCAL HORMONES

Figure 18.2 **Comparison between circulating hormones and local hormones (autocrines and paracrines).**

Circulating hormones are carried through the bloodstream to act on distant target cells. Paracrines act on neighboring cells, and autocrines act on the same cells that produced them.



(a) Circulating hormones



(b) Local hormones (paracrines and autocrines)

CHEMICAL CLASSES OF HORMONES

Chemically, **hormones can be divided into two broad classes:** those that are soluble in lipids, and those that are soluble in water. This chemical classification is also useful functionally because the two classes exert their effects differently.

LIPID-SOLUBLE HORMONES

The lipid-soluble hormones include steroid hormones, thyroid hormones, and nitric oxide.

1. **Steroid hormones** are derived from cholesterol. Each steroid hormone is unique due to the presence of different chemical groups attached at various sites on the four rings at the core of its structure. These small differences allow for a large diversity of functions.
2. **Two thyroid hormones (T3 and T4)** are synthesized by attaching iodine to the amino acid tyrosine. The presence of two benzene rings within a T3 or T4 molecule makes these molecules very lipid-soluble.
3. **The gas nitric oxide (NO)** is both a hormone and a neurotransmitter. Its synthesis is catalyzed by the enzyme nitric oxide synthase.

WATER-SOLUBLE HORMONES

The **water-soluble hormones** include amine hormones, peptide and protein hormones, and eicosanoid hormones.

1. **Amine hormones** are synthesized by decarboxylating (removing a molecule of CO2) and otherwise modifying certain amino acids. They are called amines because they retain an amino group. The catecholamines—epinephrine, norepinephrine, and dopamine—are synthesized by modifying the amino acid tyrosine. Histamine is synthesized from the amino acid histidine by mast cells and platelets. Serotonin and melatonin are derived from tryptophan.

WATER-SOLUBLE HORMONES

2. **Peptide hormones and protein hormones** are amino acid polymers. The smaller peptide hormones consist of chains of 3 to 49 amino acids; the larger protein hormones include 50 to 200 amino acids. **Examples of peptide hormones** are antidiuretic hormone and oxytocin; **protein hormones** include human growth hormone and insulin. Several of the protein hormones, such as thyroid-stimulating hormone, have attached carbohydrate groups and thus are glycoprotein hormones.

WATER-SOLUBLE HORMONES

3. **The eicosanoid hormones** are derived from arachidonic acid, a 20-carbon fatty acid. The two major types of eicosanoids are prostaglandins (PGs) and leukotrienes (LTs). The eicosanoids are important local hormones, and they may act as circulating hormones as well.

HORMONE TRANSPORT IN THE BLOOD

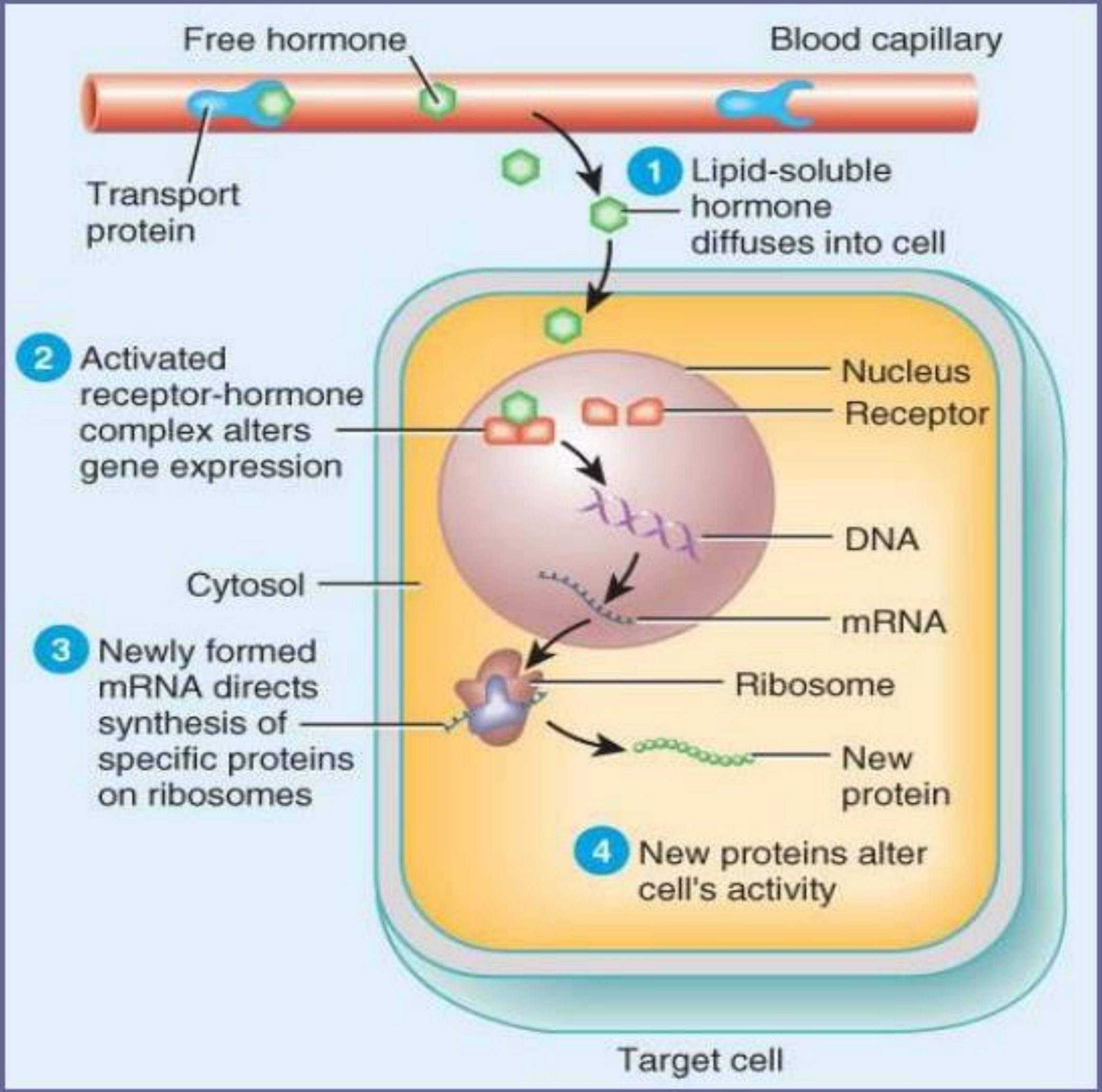
Most water-soluble hormone molecules circulate in the water blood plasma in a "free" form (not attached to other molecules) but **most lipid-soluble hormone molecules are bound to transport proteins**. **The transport proteins, which are synthesized by cells in the liver, have three functions:**

- **1. They make lipid-soluble hormones temporarily water-soluble**, thus increasing their solubility in blood.
- **2. They retard passage of small hormone molecules through the filtering mechanism in the kidneys**, thus slowing the rate of hormone loss in the urine.
- **3. They provide a ready reserve of hormone, already present in the bloodstream.**

MECHANISMS OF HORMONE ACTION

- **The response to a hormone depends on both the hormone itself and the target cell**. Various target cells respond differently to the same hormone. Insulin, for example, stimulates synthesis of glycogen in liver cells and synthesis of triglycerides in adipose cells.
- **The receptors for lipid soluble hormones** are located inside target cells.
- **The receptors for water-soluble hormones** are part of the plasma membrane of target cells.

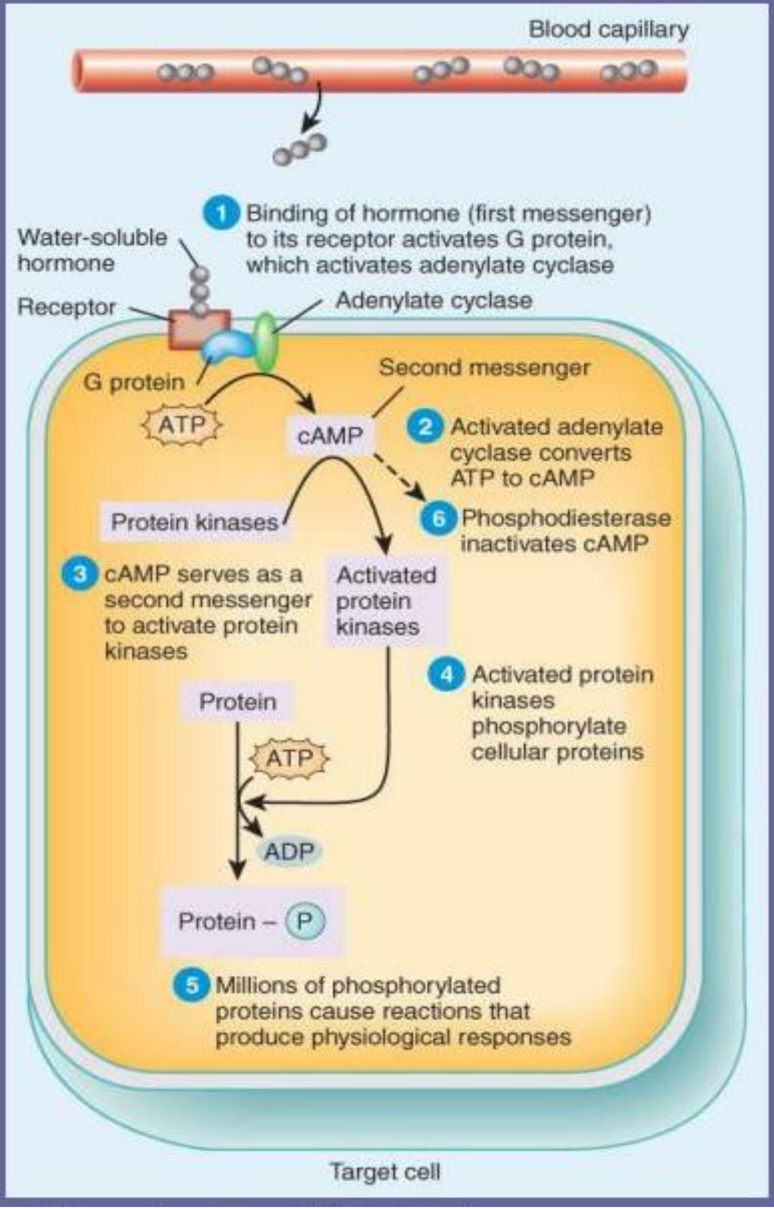
Action of Lipid-Soluble Hormones



- Hormone diffuses through phospholipid bilayer & into cell
- Binds to receptor turning on/off specific genes
- New mRNA is formed & directs synthesis of new proteins
- New protein alters cell's activity

Lipid-soluble hormones, including steroid hormones and thyroid hormones, bind to receptors within target cells.

Water-soluble Hormones



- Cyclic AMP is the 2nd messenger
  - kinases in the cytosol speed up/slow down physiological responses
- Phosphodiesterase inactivates cAMP quickly
- Cell response is turned off unless new hormone molecules arrive

Because amine, peptide, protein, and eicosanoid hormones are not lipid-soluble, they cannot diffuse through the lipid bilayer of the plasma membrane and bind to receptors inside target cells.

HORMONE INTERACTIONS

- **The responsiveness of a target cell to a hormone depends on (1) the hormone's concentration in the blood, (2) the abundance of the target cell's hormone receptors, and (3) influences exerted by other hormones.**
- Target cell responds more vigorously when the level of a hormone rises or when it has more receptors (upregulation).
- In addition, the actions of some hormones on target cells require a simultaneous or recent exposure to a second hormone. In such cases, the second hormone is said to have a **permissive effect**.
- When the effect of two hormones acting together is greater or more extensive than the effect of each hormone acting alone, the two hormones are said to have a **synergistic effect**.
- When one hormone opposes the actions of another hormone, the two hormones are said to have **antagonistic effects**.

HYPOTHALAMUS AND PITUITARY GLAND

- **For many years, the pituitary gland or hypophysis was called the "master" endocrine gland because it secretes several hormones that control other endocrine glands.**

- **The pituitary gland itself has a master—the hypothalamus.**

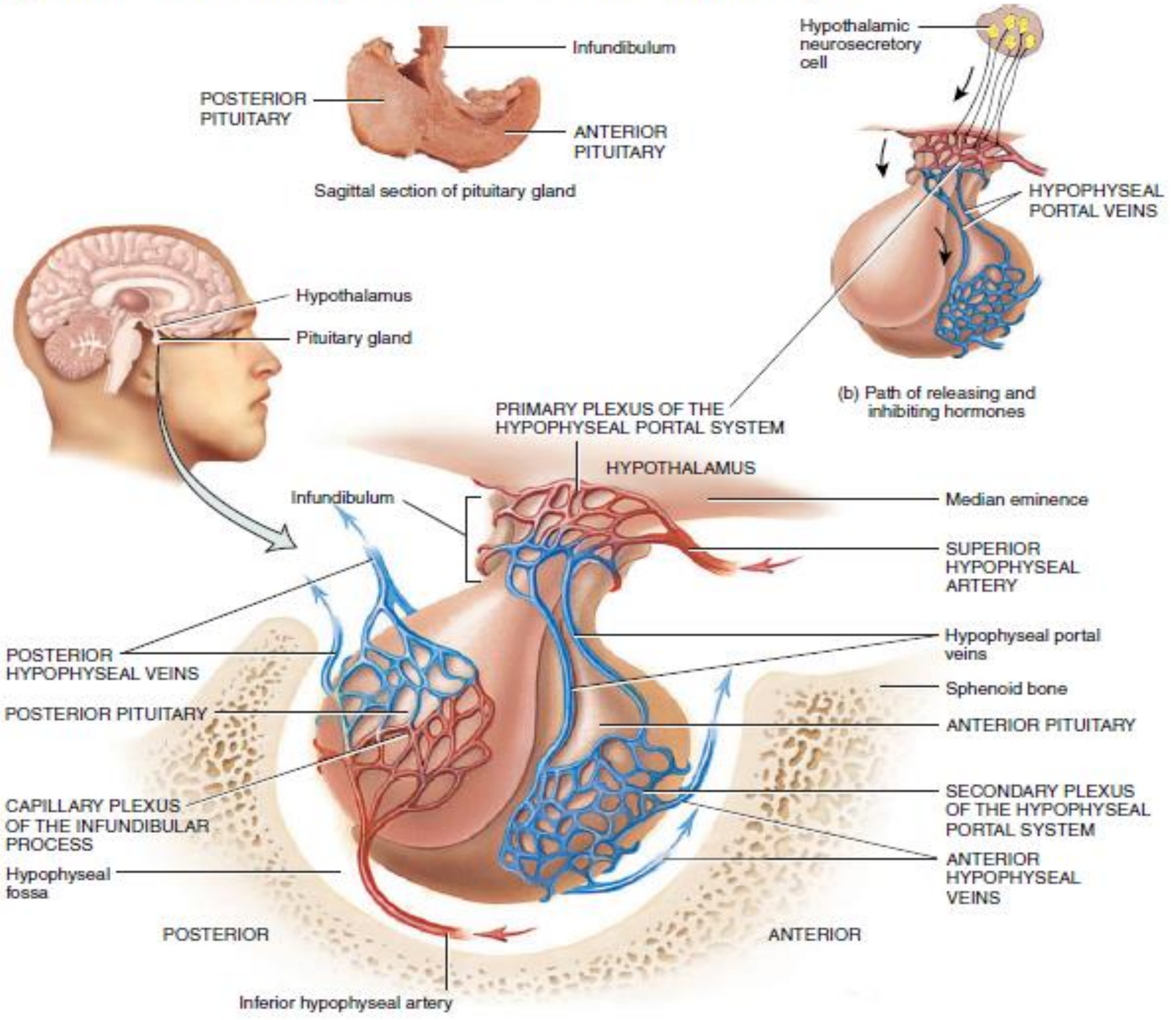
- **Cells in the hypothalamus synthesize at least nine different hormones, and the pituitary gland secretes seven. Together, these hormones play important roles in the regulation of virtually all aspects of growth, development, metabolism, and homeostasis.**

HYPOTHALAMUS AND PITUITARY GLAND

- **Releasing and inhibiting hormones synthesized by hypothalamic neurosecretory cells are transported within axons and released at the axon terminals.**

- **The hormones diffuse into capillaries of the primary plexus of the hypophyseal portal system and are carried by the hypophyseal portal veins to the secondary plexus of the hypophyseal portal system for distribution to target cells in the anterior pituitary.**

Hypothalamic hormones are an important link between the nervous and endocrine systems.



(a) Relationship of the hypothalamus to the pituitary gland

TYPES OF ANTERIOR PITUITARY CELLS AND THEIR HORMONES

1. **Somatotrophs**, **secrete human growth hormone (hGH), also known as somatotropin. Human growth hormone in turn stimulates several tissues to secrete insulin-like growth factors (IGFs), hormones that stimulate general body growth and regulate aspects of metabolism.**

2. **Thyrotrophs**, **secrete thyroid-stimulating hormone (TSH), also known as thyrotropin. TSH controls the secretions and other activities of the thyroid gland.**

3. **Gonadotrophs**, **secrete two gonadotropins: follicle-stimulating hormone (FSH) and luteinizing hormone. FSH and LH both act on the gonads. They stimulate secretion of estrogens and progesterone and the maturation of oocytes in the ovaries, and they stimulate sperm production and secretion of testosterone in the testes.**

TYPES OF ANTERIOR PITUITARY CELLS AND THEIR HORMONES

4. **Lactotrophs, secrete prolactin (PRL), which initiates milk production in the mammary glands.**

5. **Corticotrophs, secrete adrenocorticotropic hormone (ACTH), also known as corticotropin, which stimulates the adrenal cortex to secrete glucocorticoids such as cortisol.**

CONTROL OF SECRETION BY THE ANTERIOR PITUITARY

TABLE 18.3

Hormones of the Anterior Pituitary

HORMONE	SECRETED BY	HYPOTHALAMIC RELEASING HORMONE (STIMULATES SECRETION)	HYPOTHALAMIC INHIBITING HORMONE (SUPPRESSES SECRETION)
Human growth hormone (hGH), also known as somatotropin	Somatotrophs.	Growth hormone–releasing hormone (GHRH), also known as somatocrinin.	Growth hormone–inhibiting hormone (GHIH), also known as somatostatin.
Thyroid-stimulating hormone (TSH), also known as thyrotropin	Thyrotrophs.	Thyrotropin-releasing hormone (TRH).	Growth hormone–inhibiting hormone (GHIH).
Follicle-stimulating hormone (FSH)	Gonadotrophs.	Gonadotropin-releasing hormone (GnRH).	—
Luteinizing hormone (LH)	Gonadotrophs.	Gonadotropin-releasing hormone (GnRH).	—
Prolactin (PRL)	Lactotrophs.	Prolactin-releasing hormone (PRH).*	Prolactin-inhibiting hormone (PIH), which is dopamine.
Adrenocorticotropic hormone (ACTH), also known as corticotropin	Corticotrophs.	Corticotropin-releasing hormone (CRH).	—
Melanocyte-stimulating hormone (MSH)	Corticotrophs.	Corticotropin-releasing hormone (CRH).	Dopamine.

*Thought to exist, but exact nature is uncertain.

HUMAN GROWTH HORMONE AND INSULIN-LIKE GROWTH FACTORS

- **Somatotrophs are the most numerous cells in the anterior pituitary, and human growth hormone (hGH) is the most plentiful anterior pituitary hormone.**

- **The main function of hGH** is to promote synthesis and secretion of small protein hormones called insulin-like growth factors or somatomedins.

- **In response to human growth hormone**, cells in the liver, skeletal muscles, cartilage, bones, and other tissues **secrete IGFs**, which may either enter the bloodstream from the liver or act locally in other tissues as autocrines or paracrines.

THE FUNCTIONS OF IGFS INCLUDE THE FOLLOWING:

1. IGFs **cause cells to grow and multiply** by increasing uptake of amino acids into cells and accelerating protein synthesis. Due to these effects of the IGFs, human growth hormone **increases the growth rate of the skeleton and skeletal muscles during childhood and the teenage years.** In adults, human growth hormone and IGFs help **maintain the mass of muscles and bones and promote healing of injuries and tissue repair.**

2. IGFs also **enhance lipolysis in adipose tissue**, which **results in increased use of the released fatty acids for ATP production by body cells.**

3. Human growth hormone and IGFs influence carbohydrate metabolism by **decreasing glucose uptake, which decreases the use of glucose for ATP production by most body cells**.

THE FUNCTIONS OF IGFS INCLUDE THE FOLLOWING:

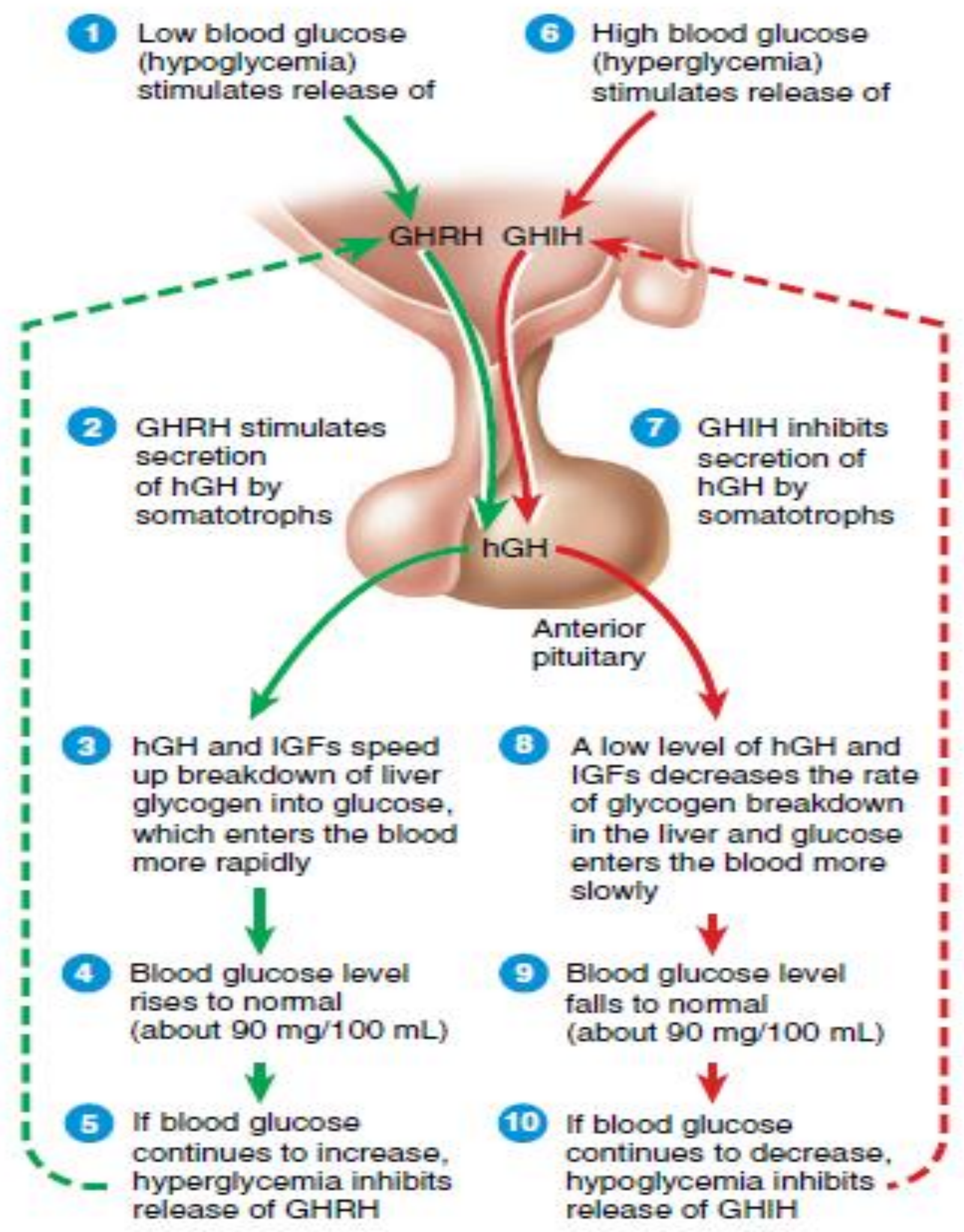
- **Somatotrophs in the anterior pituitary release bursts of human growth hormone every few hours, especially during sleep.**

- **Their secretory activity is controlled mainly by two hypothalamic hormones:** (1) growth hormone–releasing hormone (GHRH) promotes secretion of human growth hormone, and (2) growth hormone–inhibiting hormone (GHIH) suppresses it.

- A major regulator of GHRH and GHIH secretion is the blood glucose level.

NEGATIVE FEEDBACK REGULATION OF HYPOTHALAMIC NEUROSECRETORY CELLS AND ANTERIOR PITUITARY CORTICOTROPHS

Secretion of hGH is stimulated by growth hormone–releasing hormone (GHRH) and inhibited by growth hormone–inhibiting hormone (GHIH).



OTHER STIMULI THAT PROMOTE SECRETION OF HUMAN GROWTH HORMONE

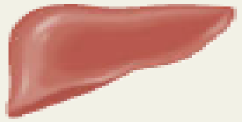
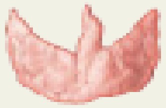
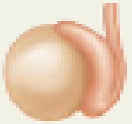
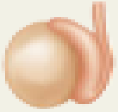
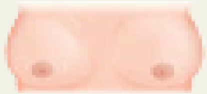
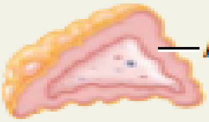
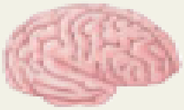
1. Decreased fatty acids and increased amino acids in the blood.
2. Deep sleep (stages 3 and 4 of non-rapid eye movement sleep).
3. Increased activity of the sympathetic division of the autonomic nervous system, such as might occur with stress or vigorous physical exercise.
4. Other hormones, including glucagon, estrogens, cortisol, and insulin.

FACTORS THAT INHIBIT HUMAN GROWTH HORMONE SECRETION

1. Increased levels of fatty acids and decreased levels of amino acids in the blood.
2. Rapid eye movement sleep.
3. Emotional deprivation.
4. Obesity.
5. Low levels of thyroid hormones and human growth hormone itself (through negative feedback).
6. Growth hormone–inhibiting hormone (GHIH), alternatively known as somatostatin, also inhibits the secretion of human growth hormone.

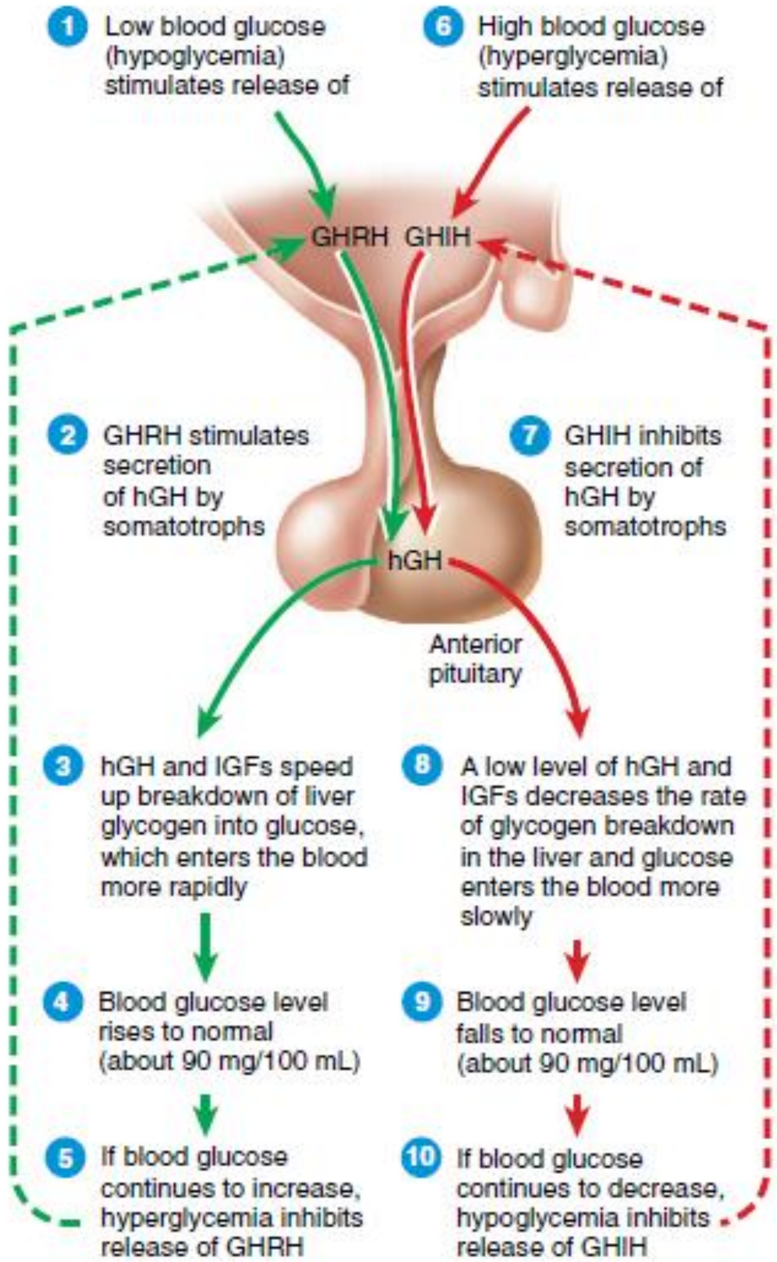
TABLE 18.4

Summary of the Principal Actions of Anterior Pituitary Hormones

HORMONE	TARGET TISSUES	PRINCIPAL ACTIONS
Human growth hormone (hGH), also known as somatotropin	 Liver (and other tissues)	Stimulates liver, muscle, cartilage, bone, and other tissues to synthesize and secrete insulinlike growth factors (IGFs); IGFs promote growth of body cells, protein synthesis, tissue repair, lipolysis, and elevation of blood glucose concentration.
Thyroid-stimulating hormone (TSH), also known as thyrotropin	 Thyroid gland	Stimulates synthesis and secretion of thyroid hormones by thyroid gland.
Follicle-stimulating hormone (FSH)	 Ovary  Testis	In females, initiates development of oocytes and induces ovarian secretion of estrogens. In males, stimulates testes to produce sperm.
Luteinizing hormone (LH)	 Ovary  Testis	In females, stimulates secretion of estrogens and progesterone, ovulation, and formation of corpus luteum. In males, stimulates testes to produce testosterone.
Prolactin (PRL)	 Mammary glands	Together with other hormones, promotes milk production by mammary glands.
Adrenocorticotropic hormone (ACTH), also known as corticotropin		Stimulates secretion of glucocorticoids (mainly cortisol) by adrenal cortex.
Melanocyte-stimulating hormone (MSH)	 Brain	Exact role in humans is unknown but may influence brain activity; when present in excess, can cause darkening of skin.

EFFECTS OF HUMAN GROWTH HORMONE (HGH) AND INSULIN-LIKE GROWTH FACTORS (IGFS)

Secretion of hGH is stimulated by growth hormone–releasing hormone (GHRH) and inhibited by growth hormone–inhibiting hormone (GHIH).



POSTERIOR PITUITARY

- **Although the posterior pituitary or neurohypophysis does not synthesize hormones**, it does store and release two hormones (oxytocin (OT) and antidiuretic hormone (ADH), also called vasopressin).

- After their production in the cell bodies of neurosecretory cells, **oxytocin and antidiuretic hormone are packaged into secretory vesicles**, which move by fast axonal transport to the axon terminals in the posterior pituitary, where they are stored until nerve impulses trigger exocytosis and release of the hormone.

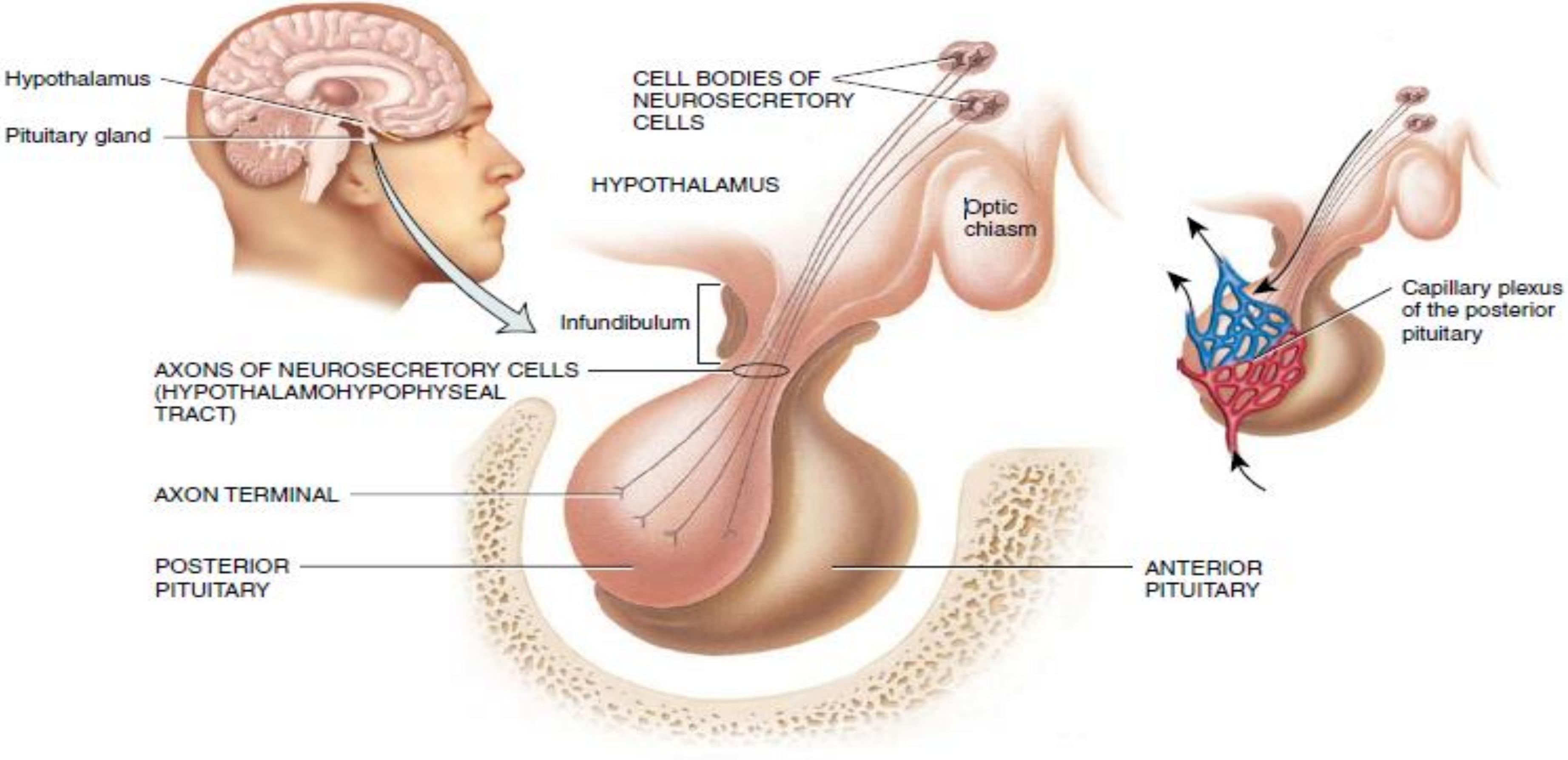
POSTERIOR PITUITARY

- Blood is supplied to the posterior pituitary by the inferior hypophyseal arteries, which branch from the internal carotid arteries.
- **In the posterior pituitary**, the inferior hypophyseal arteries drain into the capillary plexus of the infundibular process, a capillary network that receives secreted oxytocin and antidiuretic hormone.
- From this plexus, hormones pass into the posterior hypophyseal veins for distribution to target cells in other tissues.

THE HYPOTHALAMOHYPOPHYSEAL TRACT

Figure 18.8 **The hypothalamohypophyseal tract.** Axons of hypothalamic neurosecretory cells form the hypothalamohypophyseal tract, which extends from the paraventricular and supraoptic nuclei to the posterior pituitary. Hormone molecules synthesized in the cell body of a neurosecretory cell are packaged into secretory vesicles that move down to the axon terminals. Nerve impulses trigger exocytosis of the vesicles, thereby releasing the hormone.

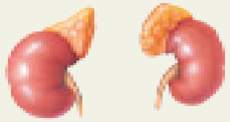
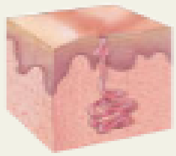
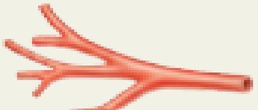
Oxytocin and antidiuretic hormone are synthesized in the hypothalamus and released into the capillary plexus of the infundibular process in the posterior pituitary.



CONTROL OF SECRETION BY THE POSTERIOR PITUITARY

TABLE 18.5

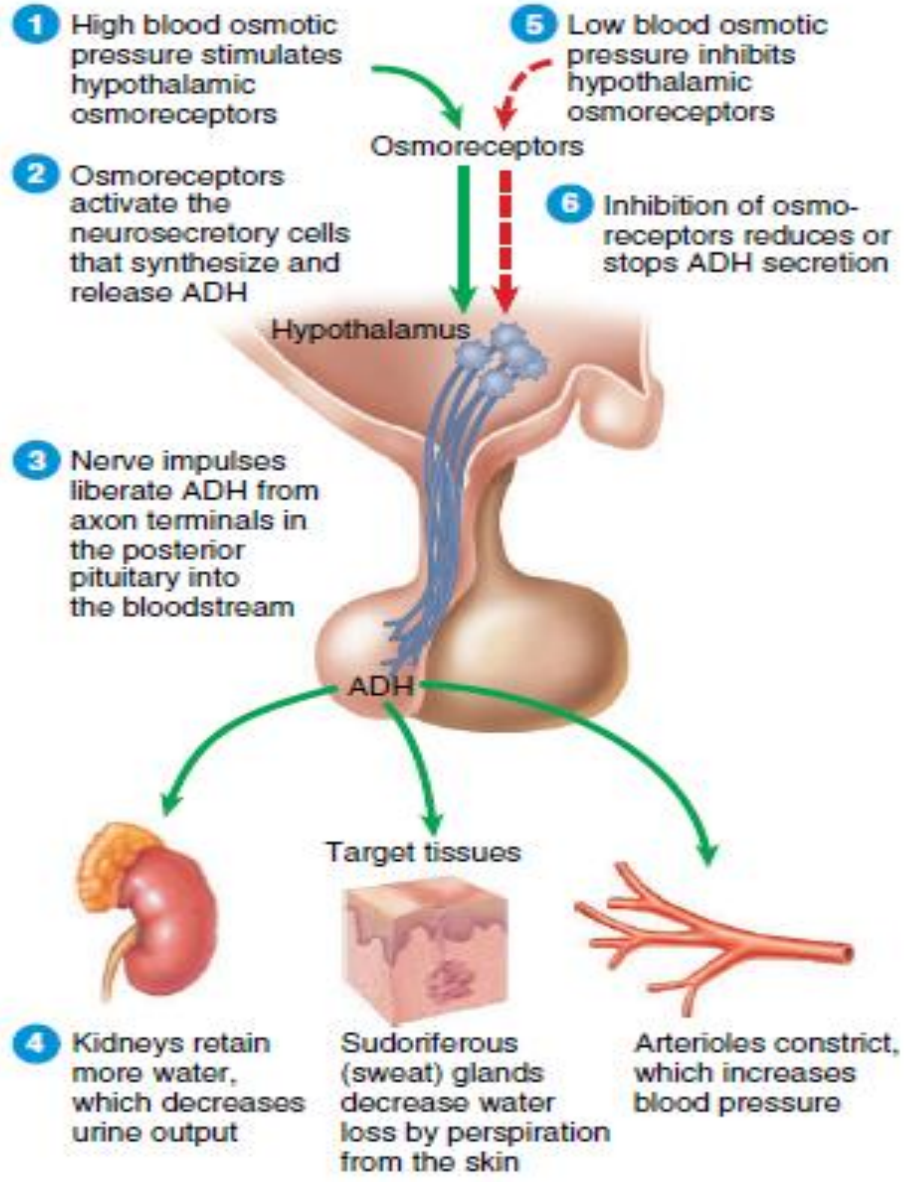
Summary of Posterior Pituitary Hormones

HORMONE AND TARGET TISSUES	CONTROL OF SECRETION	PRINCIPAL ACTIONS
Oxytocin (OT)  Uterus  Mammary glands	Neurosecretory cells of hypothalamus secrete OT in response to uterine distension and stimulation of nipples.	Stimulates contraction of smooth muscle cells of uterus during childbirth; stimulates contraction of myoepithelial cells in mammary glands to cause milk ejection.
Antidiuretic hormone (ADH) or vasopressin  Kidneys  Sudoriferous (sweat) glands  Arterioles	Neurosecretory cells of hypothalamus secrete ADH in response to elevated blood osmotic pressure, dehydration, loss of blood volume, pain, or stress; inhibitors of ADH secretion include low blood osmotic pressure, high blood volume, and alcohol.	Conserves body water by decreasing urine volume; decreases water loss through perspiration; raises blood pressure by constricting arterioles.

REGULATION OF SECRETION AND ACTIONS OF ANTIDIURETIC HORMONE (ADH).

Figure 18.9 Regulation of secretion and actions of antidiuretic hormone (ADH).

ADH acts to retain body water and increase blood pressure.



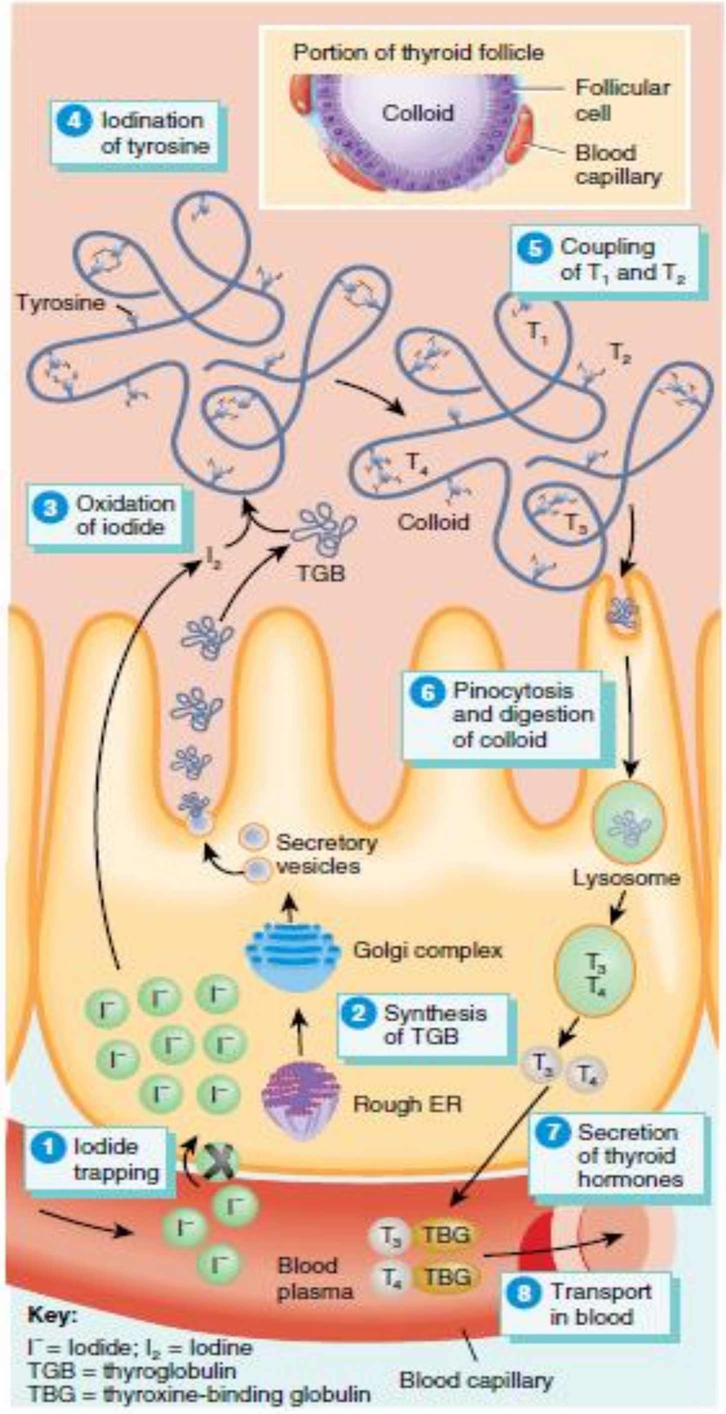
THYROID GLAND

- **The butterfly-shaped thyroid gland** is located just inferior to the larynx (voice box).

- The thyroid gland is the only endocrine gland that stores its secretory product in large quantities—normally about a 100-day supply.

STEPS IN THE SYNTHESIS AND SECRETION OF THYROID HORMONES.

- **Iodide trapping**: Thyroid follicular cells trap iodide ions by actively transporting them from the blood into the cytosol. As a result, the thyroid gland normally contains most of the iodide in the body.
- **Synthesis of thyroglobulin**: While the follicular cells are trapping iodide ions, they are also synthesizing thyroglobulin (TGB), a large glycoprotein that is released into the lumen of the follicle.
- **Oxidation of iodide**: Some of the amino acids in TGB are tyrosines that will become iodinated. However, negatively charged iodide ions cannot bind to tyrosine until they undergo oxidation (removal of electrons) to iodine large glycoprotein that is released into the lumen of the follicle. As the iodide ions are being oxidized, they pass through the membrane into the lumen of the follicle.

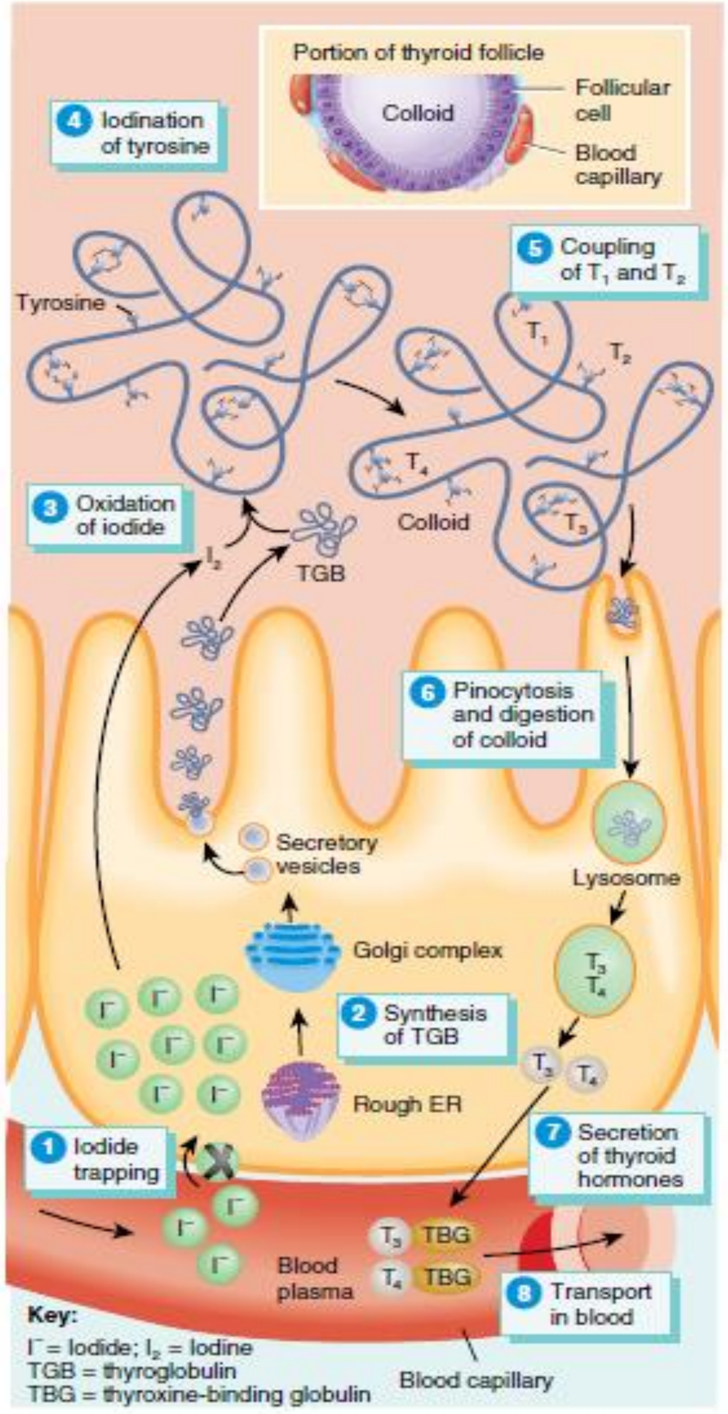


STEPS IN THE SYNTHESIS AND SECRETION OF THYROID HORMONES.

- **Iodination of tyrosine**: As iodine molecules (I_2) form, they react with tyrosines that are part of thyroglobulin molecules. Binding of one iodine atom yields monoiodotyrosine (T_1), and a second iodination produces diiodotyrosine (T_2). The TGB with attached iodine atoms, a sticky material that accumulates and is stored in the lumen of the thyroid follicle, is termed colloid.

- **Coupling of T_1 and T_2**: During the last step in the synthesis of thyroid hormone, two T_2 molecules join to form T_4, or one T1 and one T_2 join to form T_3.

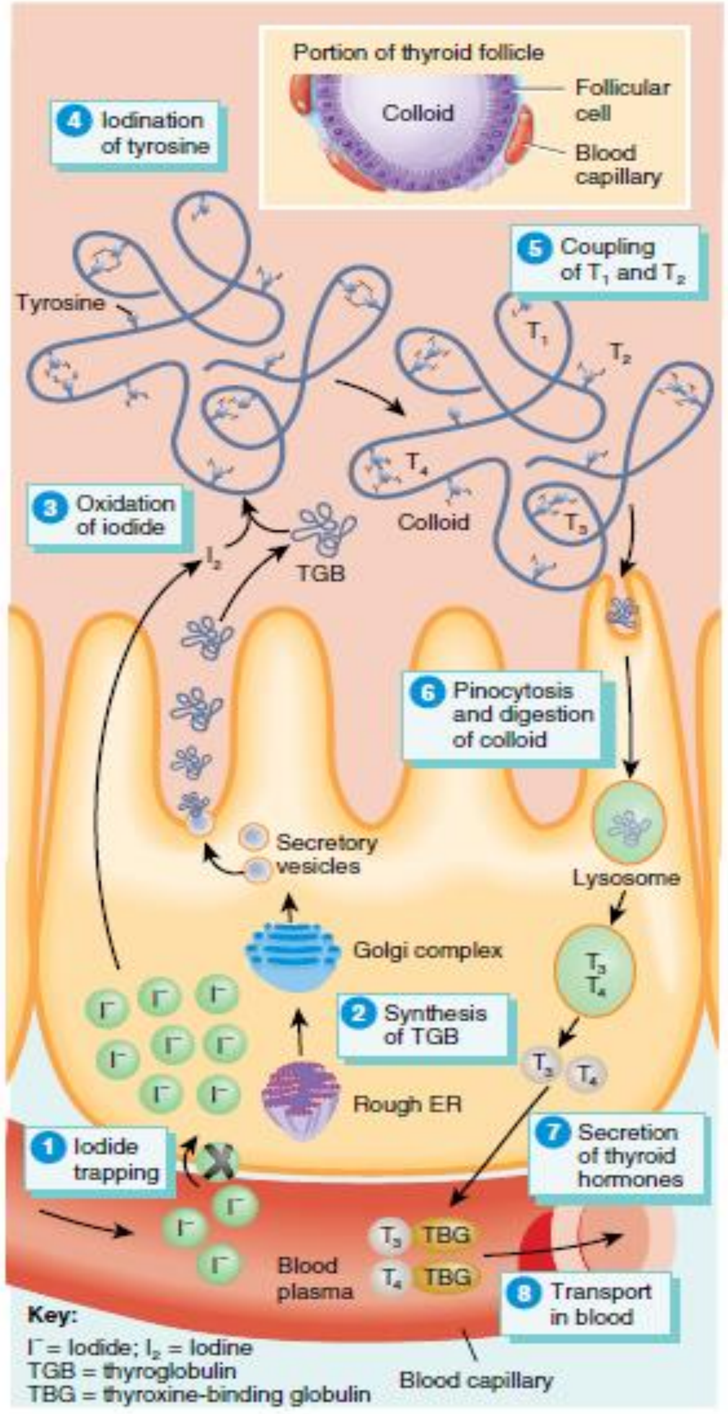
- **Pinocytosis and digestion of colloid**: Droplets of colloid reenter follicular cells by pinocytosis and merge with lysosomes. Digestive enzymes in the lysosomes break down TGB, cleaving off molecules of T_3 and T_4.



STEPS IN THE SYNTHESIS AND SECRETION OF THYROID HORMONES.

- **Secretion of thyroid hormones**: Because T3 and T4 are lipid soluble, they diffuse through the plasma membrane into interstitial fluid and then into the blood. T4 normally is secreted in greater quantity than T3, but T3 is several times more potent. Moreover, after T4 enters a body cell, most of it is converted to T3 by removal of one iodine.

- **Transport in the blood**: More than 99% of both the T3 and the T4 combine with transport proteins in the blood, mainly thyroxine-binding globulin (TBG).



ACTIONS OF THYROID HORMONES

1. Thyroid hormones **increase basal metabolic rate (BMR), the rate of oxygen consumption under standard or basal conditions (awake, at rest, and fasting)**, by stimulating the use of cellular oxygen to produce ATP. **When the basal metabolic rate increases, cellular metabolism of carbohydrates, lipids, and proteins increases**.

2. Second major effect of thyroid hormones is **to stimulate synthesis of additional sodium–potassium pumps**, which use large amounts of ATP to continually eject sodium ions from the cytosol into the extracellular fluid and potassium ions from the extracellular fluid into the cytosol.

3. Thyroid hormones play an important role in **the maintenance of normal body temperature**. Normal mammals can survive in freezing temperatures, but those whose thyroid glands have been removed cannot.

ACTIONS OF THYROID HORMONES

4. In the regulation of metabolism, **the thyroid hormones stimulate protein synthesis and increase the use of glucose and fatty acids for ATP production.** They also **increase lipolysis and enhance cholesterol excretion, thus reducing blood cholesterol level**.

5. The thyroid hormones **enhance some actions of the catecholamines (norepinephrine and epinephrine) because they upregulate beta receptors**. For this reason, **symptoms of hyperthyroidism include increased heart rate, more forceful heartbeats, and increased blood pressure**.

6. Together with human growth hormone and insulin, thyroid hormones **accelerate body growth, particularly the growth of the nervous and skeletal systems. Deficiency of thyroid hormones during fetal development, infancy, or childhood causes severe mental retardation and stunted bone growth**.

CONTROL OF THYROID HORMONE SECRETION

Figure 18.12 Regulation of secretion and actions of thyroid hormones. TRH = thyrotropin-releasing hormone, TSH = thyroid-stimulating hormone, T_3 = triiodothyronine, and T_4 = thyroxine (tetraiodothyronine).

TSH promotes release of thyroid hormones (T_3 and T_4) by the thyroid gland.

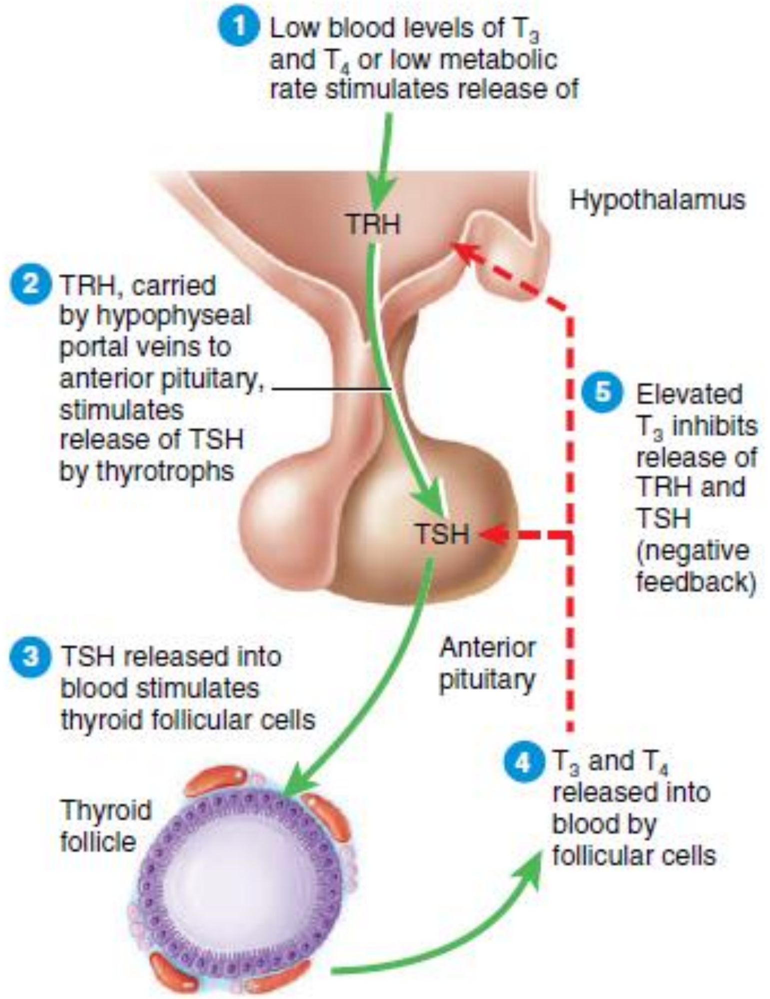
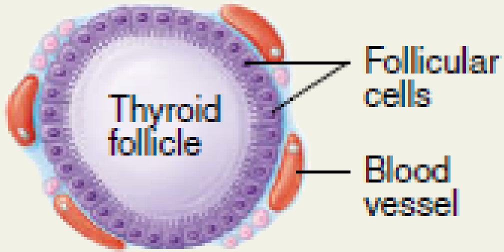
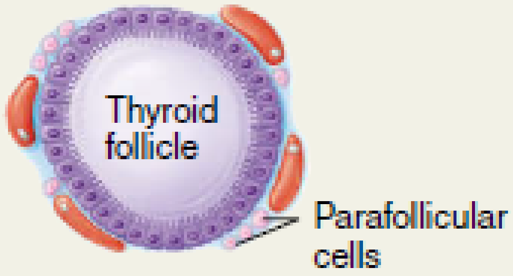


TABLE 18.6

Summary of Thyroid Gland Hormones

HORMONE AND SOURCE	CONTROL OF SECRETION	PRINCIPAL ACTIONS
T_3 (triiodothyronine) and **T_4 (thyroxine)** or thyroid hormones from follicular cells 	Secretion is increased by thyrotropin-releasing hormone (TRH), which stimulates release of thyroid-stimulating hormone (TSH) in response to low thyroid hormone levels, low metabolic rate, cold, pregnancy, and high altitudes; TRH and TSH secretions are inhibited in response to high thyroid hormone levels; high iodine level suppresses T_3/T_4 secretion.	Increase basal metabolic rate; stimulate synthesis of proteins; increase use of glucose and fatty acids for ATP production; increase lipolysis; enhance cholesterol excretion; accelerate body growth; contribute to development of nervous system.
Calcitonin (CT) from parafollicular cells 	High blood Ca^{2+} levels stimulate secretion; low blood Ca^{2+} levels inhibit secretion.	Lowers blood levels of Ca^{2+} and HPO_4^{2-} by inhibiting bone resorption by osteoclasts and by accelerating uptake of calcium and phosphates into bone extracellular matrix.

PARATHYROID GLANDS

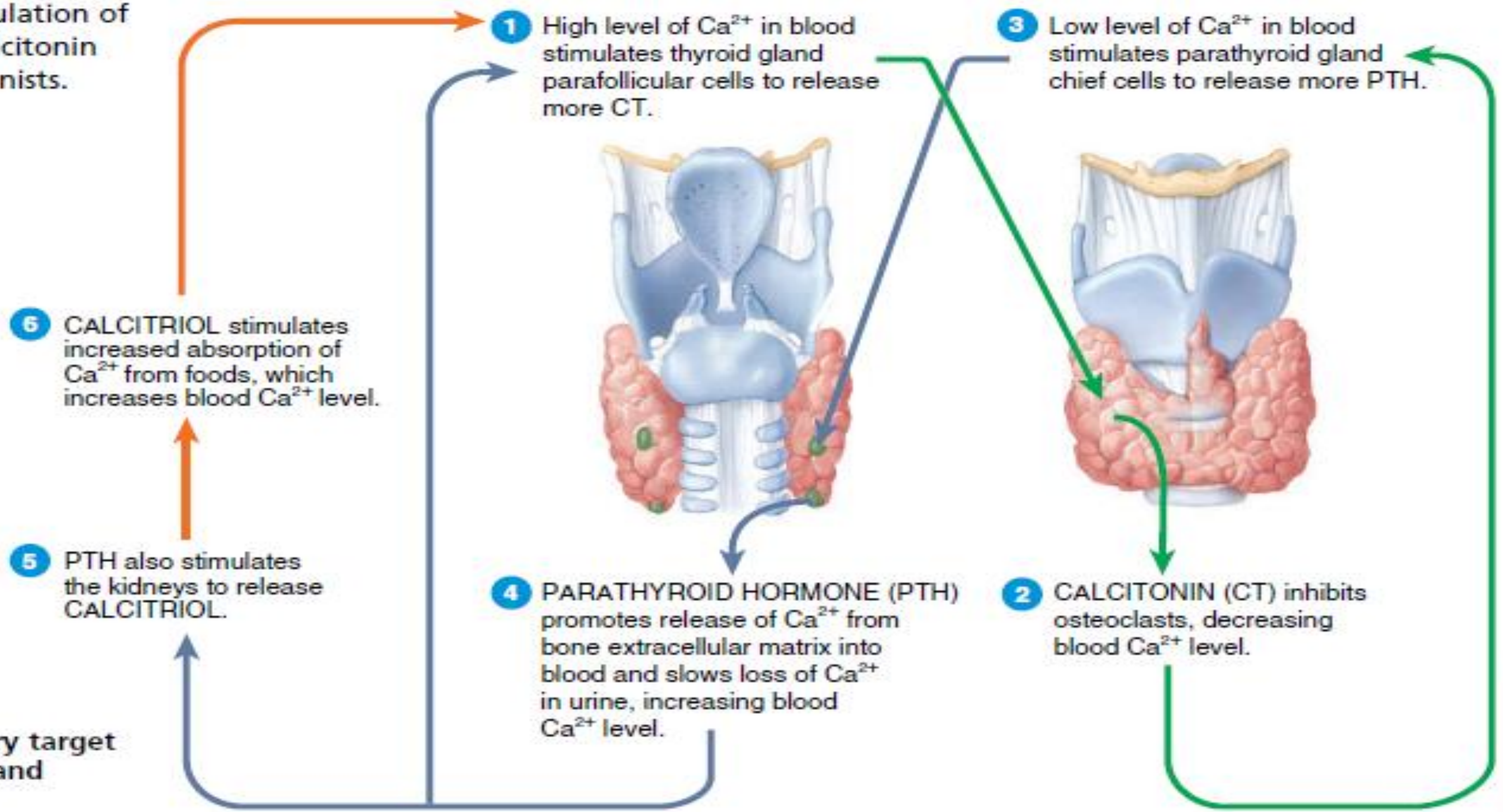
Microscopically, **the parathyroid glands contain two kinds of epithelial cells**. The more numerous cells, called **chief cells or principal cells**, **produce parathyroid hormone (PTH)**, also called parathormone. The function of the other kind of cell, called an **oxyphil cell**, **is not known in a normal parathyroid gland. However, its presence clearly helps to identify the parathyroid gland histologically due to its unique staining characteristics. Furthermore, in a cancer of the parathyroid glands, oxyphil cells secrete excess PTH.**

PARATHYROID HORMONE

- Parathyroid hormone is the **major regulator of the levels of calcium, magnesium, and phosphate ions in the blood.**
- The specific action of PTH is **to increase the number and activity of osteoclasts**. The result is **elevated bone resorption, which releases ionic calcium and phosphates into the blood**.
- PTH also **acts on the kidneys**:
- ✓ First, it **slows the rate at which calcium and magnesium are lost from blood into the urine**.
- ✓ Second, **it increases loss of phosphates from blood into the urine**. Because more phosphates is lost in the urine than is gained from the bones, **PTH decreases blood phosphates level and increases blood calcium and magnesium levels.**
- ✓ A third effect of PTH on the kidneys is to **promote formation of the hormone calcitriol**, **the active form of vitamin D. Calcitriol, also known as 1,25-dihydroxyvitamin D3, increases the rate of calcium, phosphates and magnesium absorption from the gastrointestinal tract into the blood.**

gure 18.14 **The roles of calcitonin (green arrows), parathyroid hormone (blue arrows), and calcitriol (orange arrows) in calcium homeostasis.**

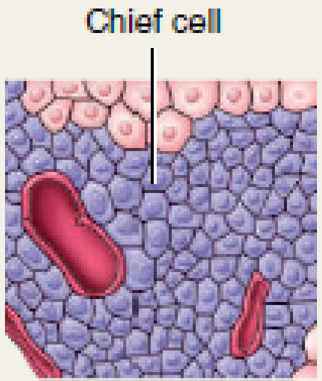
With respect to regulation of blood Ca^{2+} level, calcitonin and PTH are antagonists.



What are the primary target tissues for PTH, CT, and calcitriol?

TABLE 18.7

Summary of Parathyroid Gland Hormone

HORMONE AND SOURCE		CONTROL OF SECRETION	PRINCIPAL ACTIONS
	**Parathyroid hormone (PTH) from chief cells**	Low blood Ca^{2+} levels stimulate secretion; high blood Ca^{2+} levels inhibit secretion.	Increases blood Ca^{2+} and Mg^{2+} levels and decreases blood HPO_4^{2-} level; increases bone resorption by osteoclasts; increases Ca^{2+} reabsorption and HPO_4^{2-} excretion by kidneys; promotes formation of calcitriol (active form of vitamin D), which increases rate of dietary Ca^{2+} and Mg^{2+} absorption.

ADRENAL GLANDS

- During embryonic development, the **adrenal glands differentiate into two structurally and functionally distinct regions:** a large, peripherally located **adrenal cortex**, comprising 80–90% of the gland, and a small, centrally located **adrenal medulla**.

- The **adrenal cortex produces steroid hormones that are essential for life (i.e. mineralocorticoids which they affect mineral homeostasis, glucocorticoids primarily cortisol, so named because they affect glucose homeostasis)**. **Complete loss of adrenocortical hormones leads to death due to dehydration and electrolyte imbalances in a few days to a week, unless hormone replacement therapy begins promptly**.

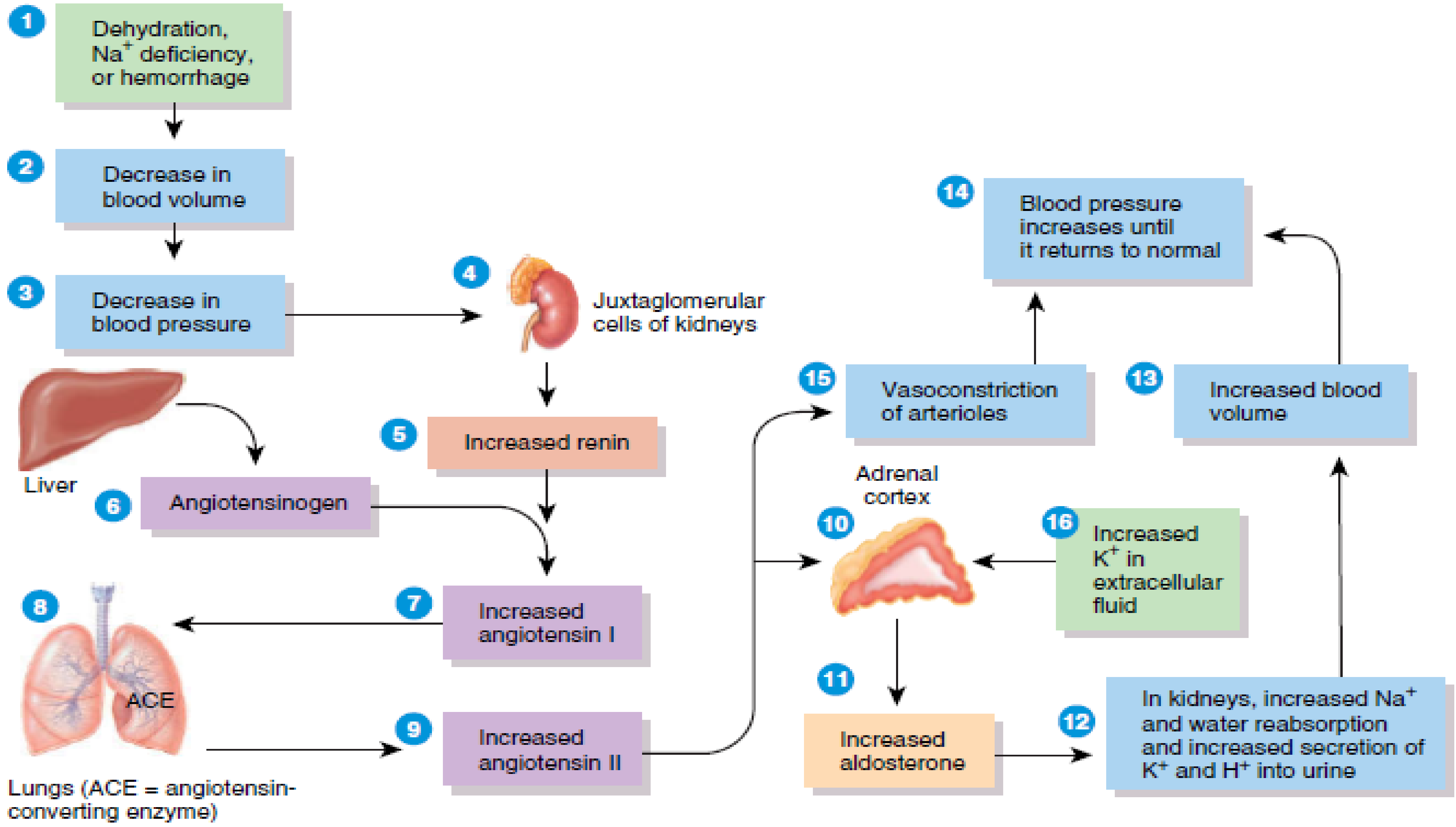
- **The adrenal medulla produces three catecholamine hormones—norepinephrine, epinephrine, and a small amount of dopamine**.

MINERALOCORTICOIDS

Aldosterone is the major mineralocorticoid. It **regulates homeostasis of two mineral ions—namely, sodium ions and potassium ions**—and **helps adjust blood pressure and blood volume**. Aldosterone also **promotes excretion of hydrogen ions in the urine; this removal of acids from the body can help prevent acidosis (blood pH below 7.35).**

Figure 18.16 **Regulation of aldosterone secretion by the renin–angiotensin–aldosterone (RAA) pathway.**

Aldosterone helps regulate blood volume, blood pressure, and levels of Na^+, K^+, and H^+ in the blood.



GLUCOCORTICOIDS

- The glucocorticoids, which **regulate metabolism and resistance to stress,** include **cortisol; (also called hydrocortisone), corticosterone, and cortisone**.

- **Glucocorticoids have the following effects:**

1. **Protein breakdown: Glucocorticoids increase the rate of protein breakdown, mainly in muscle fibers, and thus increase the liberation of amino acids into the bloodstream. The amino acids may be used by body cells for synthesis of new proteins or for ATP production.**
2. **Glucose formation: On stimulation by glucocorticoids, liver cells may convert certain amino acids or lactic acid to glucose, which neurons and other cells can use for ATP production. Such conversion of a substance other than glycogen or another monosaccharide into glucose is called gluconeogenesis.**

GLUCOCORTICOIDS

- Glucocorticoids have the following effects:

3. **Lipolysis**: Glucocorticoids stimulate lipolysis, the breakdown of triglycerides and release of fatty acids from adipose tissue into the blood.
4. **Resistance to stress**: The additional glucose supplied by the liver cells provides tissues with a ready source of ATP to combat a range of stresses, including exercise, fasting, fright, temperature extremes, high altitude, bleeding, infection, surgery, trauma, and disease.
5. **Anti-inflammatory effects**: Glucocorticoids inhibit white blood cells that participate in inflammatory responses. Unfortunately, glucocorticoids also retard tissue repair; as a result, they slow wound healing. Although high doses can cause severe mental disturbances, glucocorticoids are very useful in the treatment of chronic inflammatory disorders such as rheumatoid arthritis.

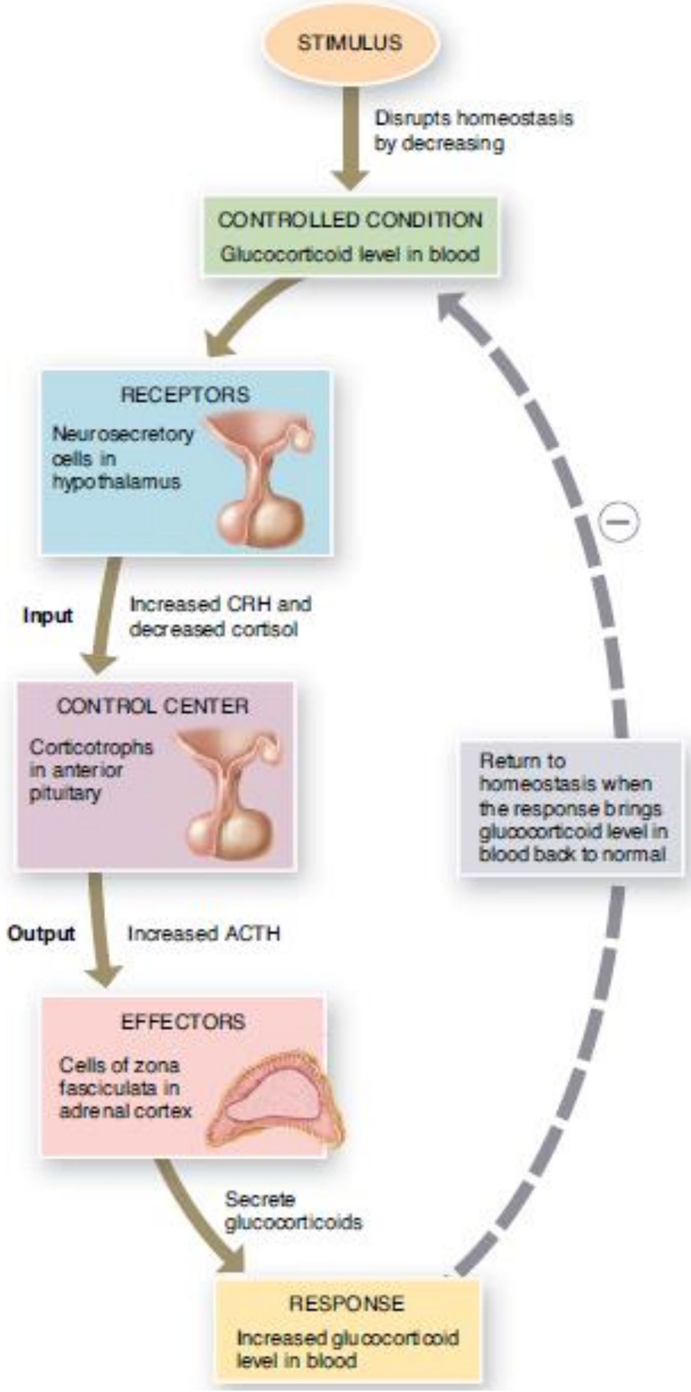
GLUCOCORTICOIDS

- **Glucocorticoids have the following effects:**

6. **Depression of immune responses: High doses of glucocorticoids depress immune responses. For this reason, glucocorticoids are prescribed for organ transplant recipients to retard tissue rejection by the immune system.**

NEGATIVE FEEDBACK REGULATION OF GLUCOCORTICOID SECRETION

- A high level of corticotropin-releasing hormone (CRH) and a low level of glucocorticoids promote the release of adrenocorticotropic (ACTH), which stimulates glucocorticoid secretion by the adrenal cortex.



CONTROL OF GLUCOCORTICOID SECRETION

- **Androgens:**

- In both males and females, **the adrenal cortex secretes small amounts of weak androgens**. **The major androgen secreted by the adrenal gland is dehydroepiandrosterone (DHEA).**

- After puberty in males, the androgen testosterone is also released in much greater quantity by the testes. Thus, **the amount of androgens secreted by the adrenal gland in males is usually so low that their effects are insignificant**. **In females, however, adrenal androgens play important roles.** They promote libido (sex drive) and are converted into estrogens (feminizing sex steroids) by other body tissues. After menopause, when ovarian secretion of estrogens ceases, all female estrogens come from conversion of adrenal androgens.

ADRENAL MEDULLA

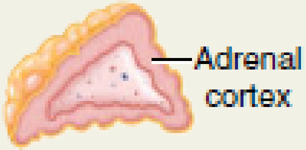
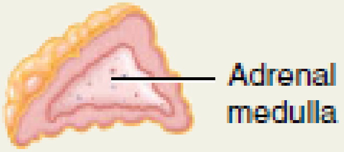
- **The inner region of the adrenal gland, the adrenal medulla, is a modified sympathetic ganglion of the autonomic nervous system (ANS).**

- **The cells of the adrenal medulla secrete hormones. The hormone-producing cells, called chromaffin cells, are innervated by sympathetic preganglionic neurons of the ANS. Because the ANS exerts direct control over the chromaffin cells, hormone release can occur very quickly.**

- **The two major hormones synthesized by the adrenal medulla are epinephrine and norepinephrine (NE), also called adrenaline and noradrenaline, respectively**. The chromaffin cells of the adrenal medulla **secrete an unequal amount of these hormones—about 80% epinephrine and 20% norepinephrine.** The hormones of the adrenal medulla **intensify sympathetic responses that occur in other parts of the body.**

TABLE 18.8

Summary of Adrenal Gland Hormones

HORMONE AND SOURCE	CONTROL OF SECRETION	PRINCIPAL ACTIONS
ADRENAL CORTEX HORMONES		
Mineralocorticoids (mainly aldosterone) from zona glomerulosa cells	Increased blood K^+ level and angiotensin II stimulate secretion.	Increase blood levels of Na^+ and water; decrease blood level of K^+.
Glucocorticoids (mainly cortisol) from zona fasciculata cells	ACTH stimulates release; corticotropin-releasing hormone (CRH) promotes ACTH secretion in response to stress and low blood levels of glucocorticoids.	Increase protein breakdown (except in liver), stimulate gluconeogenesis and lipolysis, provide resistance to stress, dampen inflammation, depress immune responses.
Androgens (mainly dehydroepiandrosterone, or DHEA) from zona reticularis cells 	ACTH stimulates secretion.	Assist in early growth of axillary and pubic hair in both sexes; in females, contribute to libido and are source of estrogens after menopause.
ADRENAL MEDULLA HORMONES		
Epinephrine and norepinephrine from chromaffin cells 	Sympathetic preganglionic neurons release acetylcholine, which stimulates secretion.	Enhance effects of sympathetic division of autonomic nervous system (ANS) during stress.

PANCREATIC ISLETS

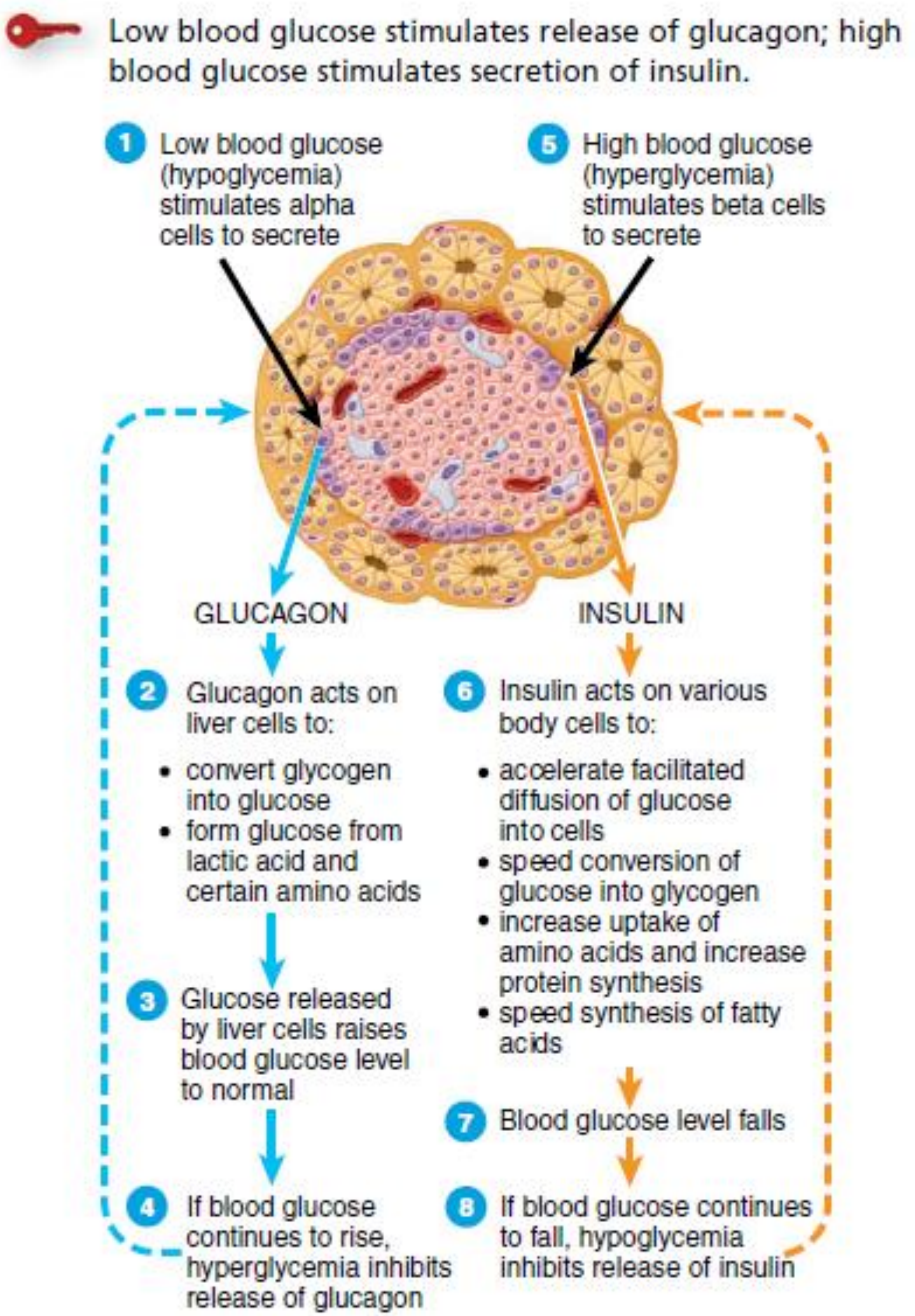
- **The pancreas is both an endocrine gland and an exocrine gland.**
- **The first part of the small intestine, and consists of a head, a body, and a tail.**
- **Roughly 99% of the exocrine cells of the pancreas are arranged in clusters called acini.**
- **The acini produce digestive enzymes, which flow into the gastrointestinal tract through a network of ducts. Scattered among the exocrine acini are 1–2 million tiny clusters of endocrine tissue called pancreatic islets.**

CELL TYPES IN THE PANCREATIC ISLETS

➢ Each pancreatic islet includes four types of hormone-secreting cells.

1. **Alpha or A cells** constitute about 17% of pancreatic islet cells and secrete glucagon.
2. **Beta or B cells** constitute about 70% of pancreatic islet cells and secrete insulin.
3. **Delta or D cells** constitute about 7% of pancreatic islet cells and secrete somatostatin.
4. **F cells** constitute the remainder of pancreatic islet cells and secrete pancreatic polypeptide.

NEGATIVE FEEDBACK REGULATION OF THE SECRETION OF GLUCAGON AND INSULIN



Summary of Pancreatic Islet Hormones

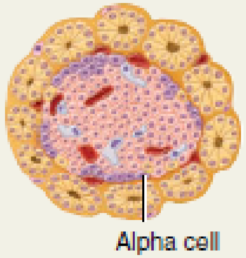
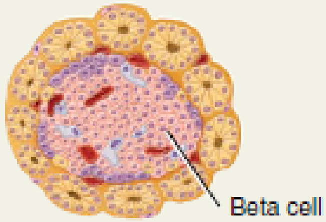
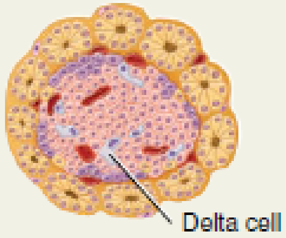
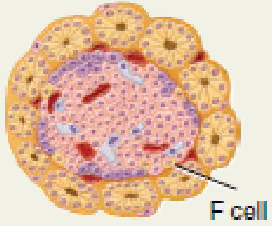
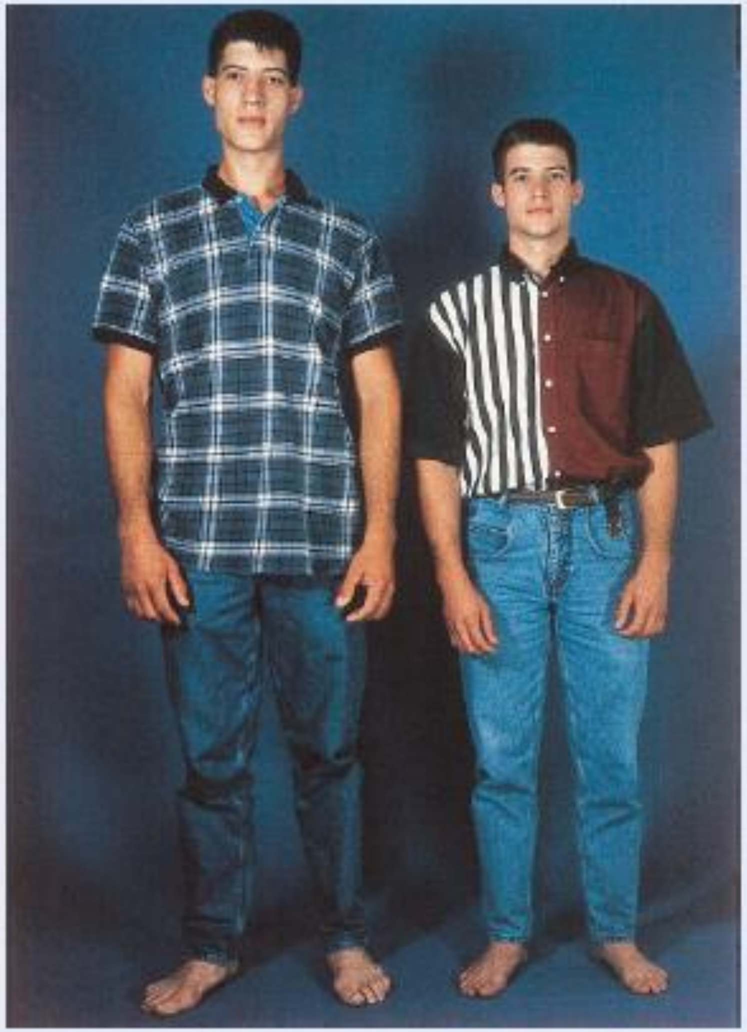
HORMONE AND SOURCE	CONTROL OF SECRETION	PRINCIPAL ACTIONS
Glucagon from alpha cells of pancreatic islets 	Decreased blood level of glucose, exercise, and mainly protein meals stimulate secretion; somatostatin and insulin inhibit secretion.	Raises blood glucose level by accelerating breakdown of glycogen into glucose in liver (glycogenolysis), converting other nutrients into glucose in liver (gluconeogenesis), and releasing glucose into blood.
Insulin from beta cells of pancreatic islets 	Increased blood level of glucose, acetylcholine (released by parasympathetic vagus nerve fibers), arginine and leucine (two amino acids), glucagon, GIP, hGH, and ACTH stimulate secretion; somatostatin inhibits secretion.	Lowers blood glucose level by accelerating transport of glucose into cells, converting glucose into glycogen (glycogenesis), and decreasing glycogenolysis and gluconeogenesis; increases lipogenesis and stimulates protein synthesis.
Somatostatin from delta cells of pancreatic islets 	Pancreatic polypeptide inhibits secretion.	Inhibits secretion of insulin and glucagon; slows absorption of nutrients from gastrointestinal tract.
Pancreatic polypeptide from F cells of pancreatic islets 	Meals containing protein, fasting, exercise, and acute hypoglycemia stimulate secretion; somatostatin and elevated blood glucose level inhibit secretion.	Inhibits somatostatin secretion, gallbladder contraction, and secretion of pancreatic digestive enzymes.

Figure 18.22 **Various endocrine disorders.**

Disorders of the endocrine system often involve hyposecretion or hypersecretion of hormones.



(a) A 22-year-old man with pituitary giantism shown beside his identical twin

(b) Acromegaly (excess hGH during adulthood)

(c) Goiter (enlargement of thyroid gland)

(d) Exophthalmos (excess thyroid hormones, as in Graves disease)

(e) Cushing's syndrome (excess glucocorticoids)

DIABETES INSIPIDUS

- **The most common abnormality associated with dysfunction of the posterior pituitary is diabetes insipidus (DI).**
- **This disorder is due to defects in antidiuretic hormone (ADH) receptors or an inability to secrete ADH.**
- **Neurogenic diabetes insipidus results from hyposecretion of ADH, usually caused by a brain tumor, head trauma, or brain surgery that damages the posterior pituitary or the hypothalamus.**
- **Nephrogenic diabetes insipidus, the kidneys do not respond to ADH. The ADH receptors may be non-functional, or the kidneys may be damaged.**
- **A common symptom of both forms of DI is excretion of large volumes of urine, with resulting dehydration and thirst.**

DIABETES INSIPIDUS

- **Treatment of neurogenic diabetes insipidus involves hormone replacement, usually for life.**

- **Treatment of nephrogenic diabetes insipidus is more complex and depends on the nature of the kidney dysfunction.**

THYROID GLAND DISORDERS

- Thyroid gland disorders affect all major body systems and are among the most common endocrine disorders.
- Congenital hypothyroidism, hyposecretion of thyroid hormones that is present at birth, has devastating consequences if not treated promptly.
- At birth, the baby typically is normal because lipid-soluble maternal thyroid hormones crossed the placenta during pregnancy and allowed normal development.
- Most states require testing of all newborns to ensure adequate thyroid function. If congenital hypothyroidism exists, oral thyroid hormone treatment must be started soon after birth and continued for life.

THYROID GLAND DISORDERS

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THYROID GLAND DISORDERS

- **The most common form of <u>hyperthyroidism is Graves disease</u>, which occurs seven to ten times more often in females than in males, usually before age 40.**
- **Graves disease is an autoimmune disorder in which the person produces antibodies that mimic the action of thyroid-stimulating hormone (TSH).**
- **The antibodies continually stimulate the thyroid gland to grow and produce thyroid hormones.**
- **<u>Treatment may include</u> surgical removal of part or all of the thyroid gland (thyroidectomy), the use of radioactive iodine to selectively destroy thyroid tissue, and the use of antithyroid drugs to block synthesis of thyroid hormones.**

PARATHYROID GLAND DISORDERS

- **Hypoparathyroidism: too little parathyroid hormone—leads to a deficiency of blood calcium, which causes neurons and muscle fibers to depolarize and produce action potentials spontaneously.**

- **This leads to twitches, spasms, and tetany (maintained contraction) of skeletal muscle.**

- **The leading cause of hypoparathyroidism is accidental damage to the parathyroid glands or to their blood supply during thyroidectomy surgery.**

PARATHYROID GLAND DISORDERS

- **Hyperparathyroidism:** **an elevated level of parathyroid hormone, most often is due to a tumor of one of the parathyroid glands**
- **An elevated level of PTH causes excessive resorption of bone matrix, raising the blood levels of calcium and phosphate ions and causing bones to become soft and easily fractured.**
- **High blood calcium level promotes formation of kidney stones.**
- **Fatigue, personality changes, and lethargy are also seen in patients with hyperparathyroidism.**

PANCREATIC ISLET DISORDERS

- **Hyperinsulinemia.**
- **Hyperglycemia.**
- **Hypoglycaemia.**

DIABETES MELLITUS

- It caused by an inability to produce or use insulin.
- **Because insulin is unavailable to aid transport of glucose into body cells, blood glucose level is high and glucose "spills" into the urine (glucosuria).**
- **Hallmarks of diabetes mellitus are the three "polys": polyuria, excessive urine production due to an inability of the kidneys to reabsorb water; polydipsia, excessive thirst; and polyphagia, excessive eating.**
- **Both genetic and environmental factors contribute to onset of the two types of diabetes mellitus—type 1 and type 2—but the exact mechanisms are still unknown.**

TYPE 1 DIABETES

- It is previously known as insulin-dependent diabetes mellitus (IDDM), occurs because the person's immune system destroys the pancreatic beta cells.
- As a result, the pancreas produces little or no insulin.
- Type 1 diabetes usually develops in people younger than age 20 and it persists throughout life. By the time symptoms of type 1 diabetes arise, 80–90% of the islet beta cells have been destroyed.
- Because insulin is not present to aid the entry of glucose into body cells, most cells use fatty acids to produce ATP. Stores of triglycerides in adipose tissue are catabolized to yield fatty acids and glycerol.
- The by-products of fatty acid breakdown—organic acids called ketones or ketone bodies—accumulate. Buildup of ketones causes blood pH to fall, a condition known as ketoacidosis. Unless treated quickly, ketoacidosis can cause death.

TYPE 1 DIABETES

- **Type 1 diabetes is treated through self-monitoring of blood glucose level (up to 7 times daily), regular meals containing 45–50% carbohydrates and less than 30% fats, exercise, and periodic insulin injections (up to 3 times a day).**

TYPE 2 DIABETES

- It is formerly known as non-insulin-dependent diabetes mellitus (NIDDM), is much more common than type 1, representing more than 90% of all cases.

- Type 2 diabetes most often occurs in obese people who are over age 35. However, the number of obese children and teenagers with type 2 diabetes is increasing.
- Clinical symptoms are mild, and the high glucose levels in the blood often can be controlled by diet, exercise, and weight loss. Sometimes, drugs such as glyburide and metformin are used to stimulate secretion of insulin by pancreatic beta cells.

HYPERINSULINISM

- Most often results when a diabetic injects too much insulin.
- The main symptom is hypoglycaemia, decreased blood glucose level, which occurs because the excess insulin stimulates too much uptake of glucose by body cells.
- The resulting hypoglycaemia stimulates the secretion of epinephrine, glucagon, and human growth hormone.
- As a consequence, anxiety, sweating, tremor, increased heart rate, hunger, and weakness occur.

THANK YOU

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