Physiology and Anatomy of the Endocrine System

Prepared by

Dr. Naim Kittana, PhD

An-Najah National University
Faculty of Medicine and Health Sciences
Department of Biomedical Sciences

Introduction

- The nervous and endocrine systems are the major controlling systems of the body.

- The nervous system exerts rapid controls via nerve impulses; the endocrine system exerts more prolonged effects via hormones.

The Endocrine System: An Overview

Hormonally regulated processes include:

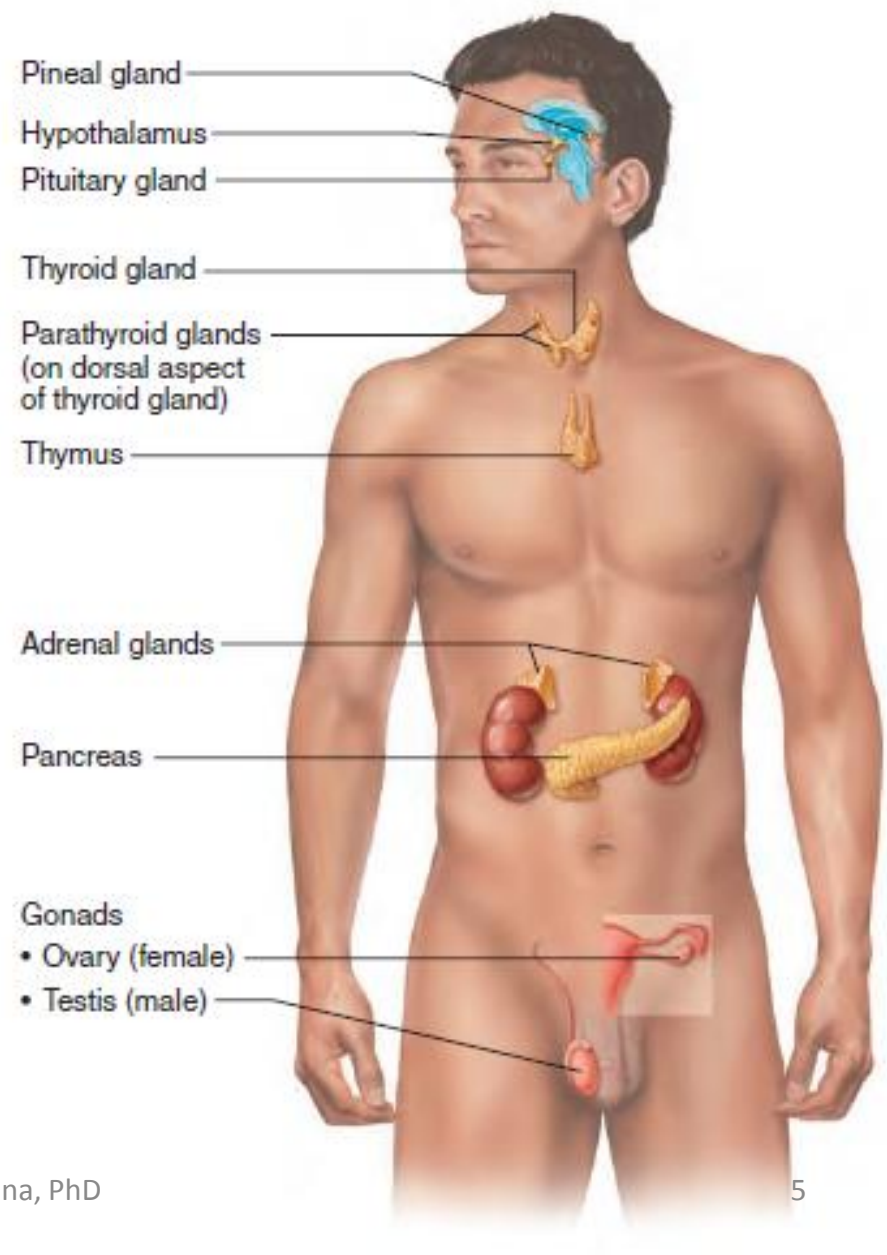
- Reproduction
- Growth and development
- Maintaining electrolyte, water, and nutrient balance
- Regulating cellular metabolism and energy balance
- Mobilizing body defenses.

Endocrine organs

They are ductless, well- vascularized glands that release hormones directly into the blood or lymph.

The endocrine organs include

- Pituitary
- Thyroid
- Parathyroid
- Adrenal
- Pineal glands
- The hypothalamus
  (a neuroendocrine organ)
- The pancreas
- Gonads
- Placenta



Notes

- Local chemical messengers, not generally considered part of the endocrine system, include autocrines, which act on the cells that secrete them, and paracrines, which act on a different cell type nearby.

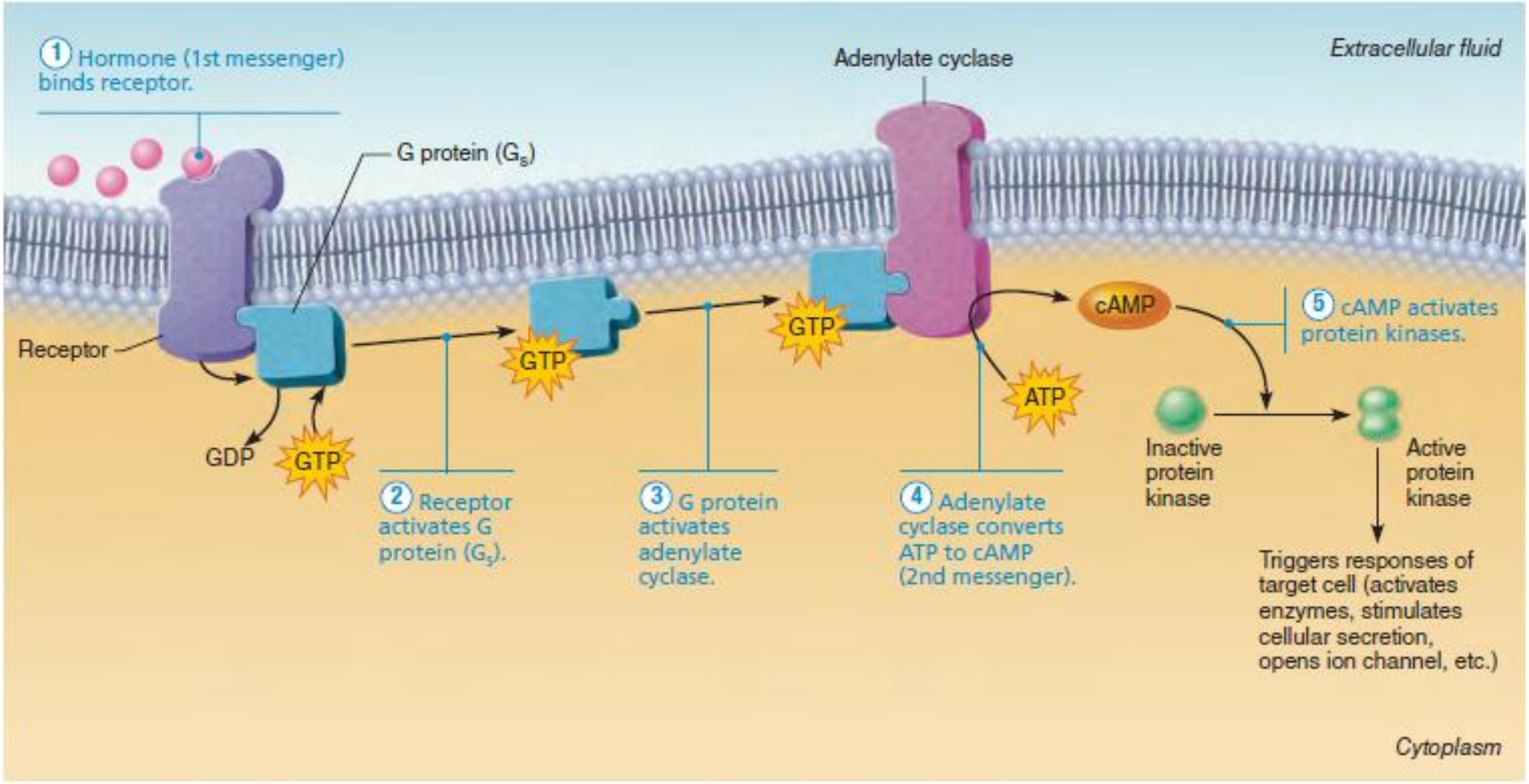
- Most hormones are steroids or amino acid based

Mechanisms of Hormone Action

- Hormones alter cell activity by stimulating or inhibiting characteristic cellular processes of their target cells.

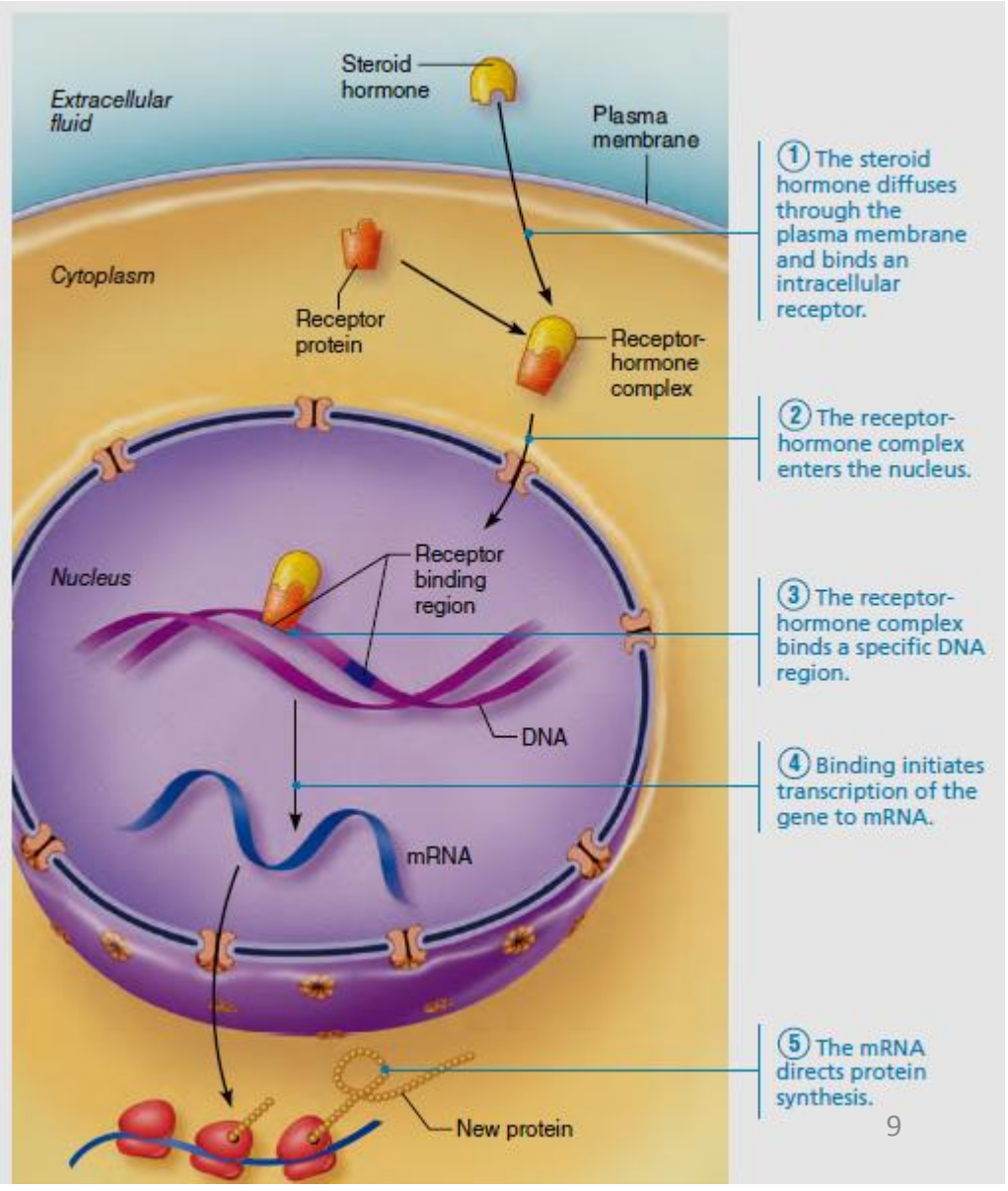
- Cell responses to hormone stimulation may involve:
  - Changes in membrane permeability
  - Enzyme synthesis, activation, or inhibition
  - Secretory activity
  - Mitosis

Plasma Membrane Receptors and Second-Messenger Systems



Intracellular Receptors

- Steroid hormones (and thyroid hormone) enter their target cells and effect responses by activating DNA, which initiates messenger RNA formation leading to protein synthesis.



Target Cell Specificity

- The ability of a target cell to respond to a hormone depends on the presence of receptors, on its plasma membrane or within the cell, to which the hormone can bind.

- Hormone receptors are dynamic structures. High or low levels of stimulating hormones can change the number and/or sensitivity of hormone receptors.

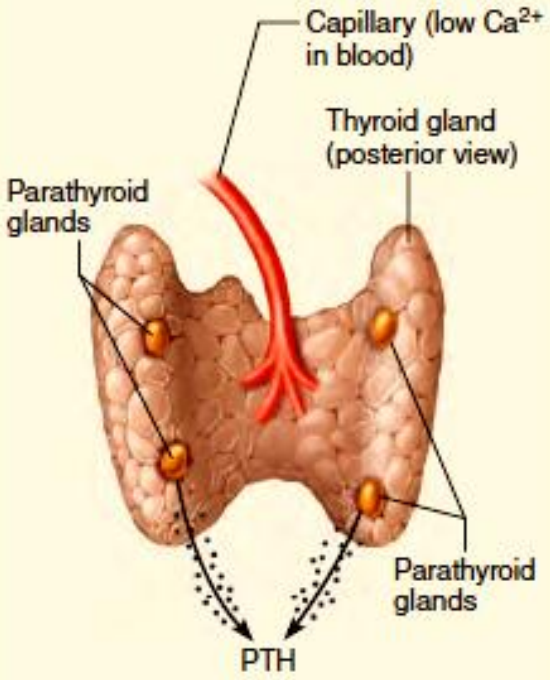
Control of Hormone Release

- Humoral, neural, or hormonal stimuli activate endocrine organs to release their hormones.
- Negative feedback is important in regulating hormone levels in the blood.
- The nervous system, acting through hypothalamic controls, can in certain cases override or modulate hormonal effects

Types of endocrine gland stimuli

(a) Humoral Stimulus

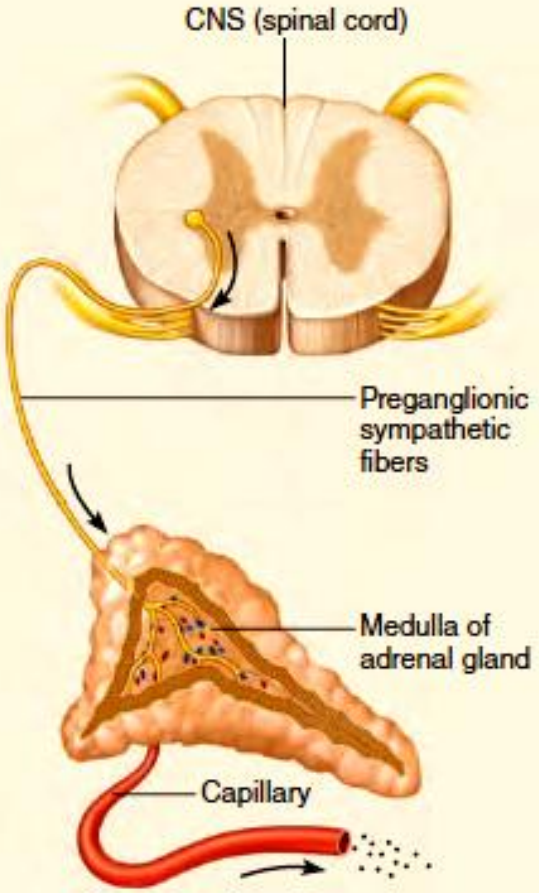
Hormone release caused by altered levels of certain critical ions or nutrients.



Stimulus: Low concentration of Ca^{2+} in capillary blood.
Response: Parathyroid glands secrete parathyroid hormone (PTH), which increases blood Ca^{2+}.

(b) Neural Stimulus

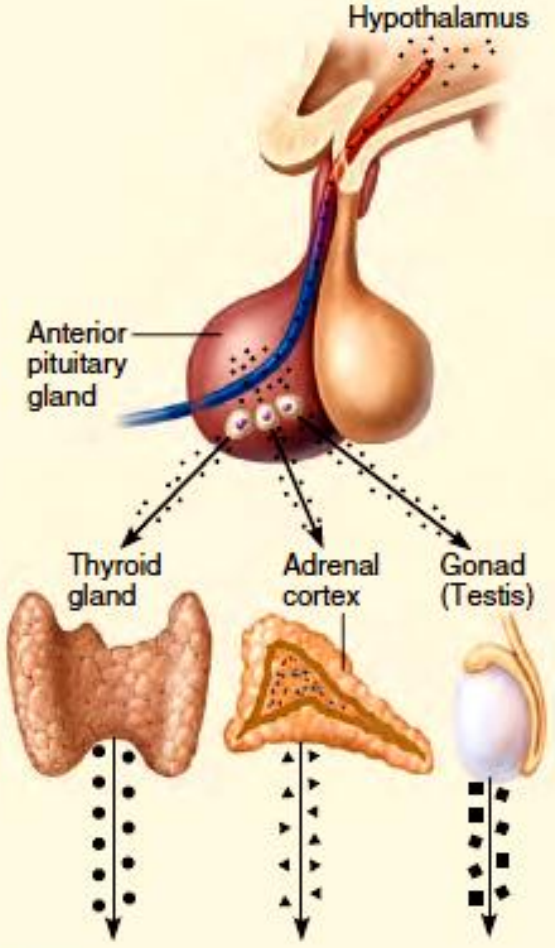
Hormone release caused by neural input.



Stimulus: Action potentials in preganglionic sympathetic fibers to adrenal medulla.
Response: Adrenal medulla cells secrete epinephrine and norepinephrine.

(c) Hormonal Stimulus

Hormone release caused by another hormone (a tropic hormone).



Stimulus: Hormones from hypothalamus.
Response: Anterior pituitary gland secretes hormones that stimulate other endocrine glands to secrete hormones.

Half-Life, Onset, and Duration of Hormone Activity

- Blood levels of hormones reflect a balance between secretion and degradation/excretion.
- The liver and kidneys are the major organs that degrade hormones;
- Breakdown products are excreted in urine and feces.
- Hormone half-life and duration of activity are limited and vary from hormone to hormone.

The Pituitary Gland and Hypothalamus

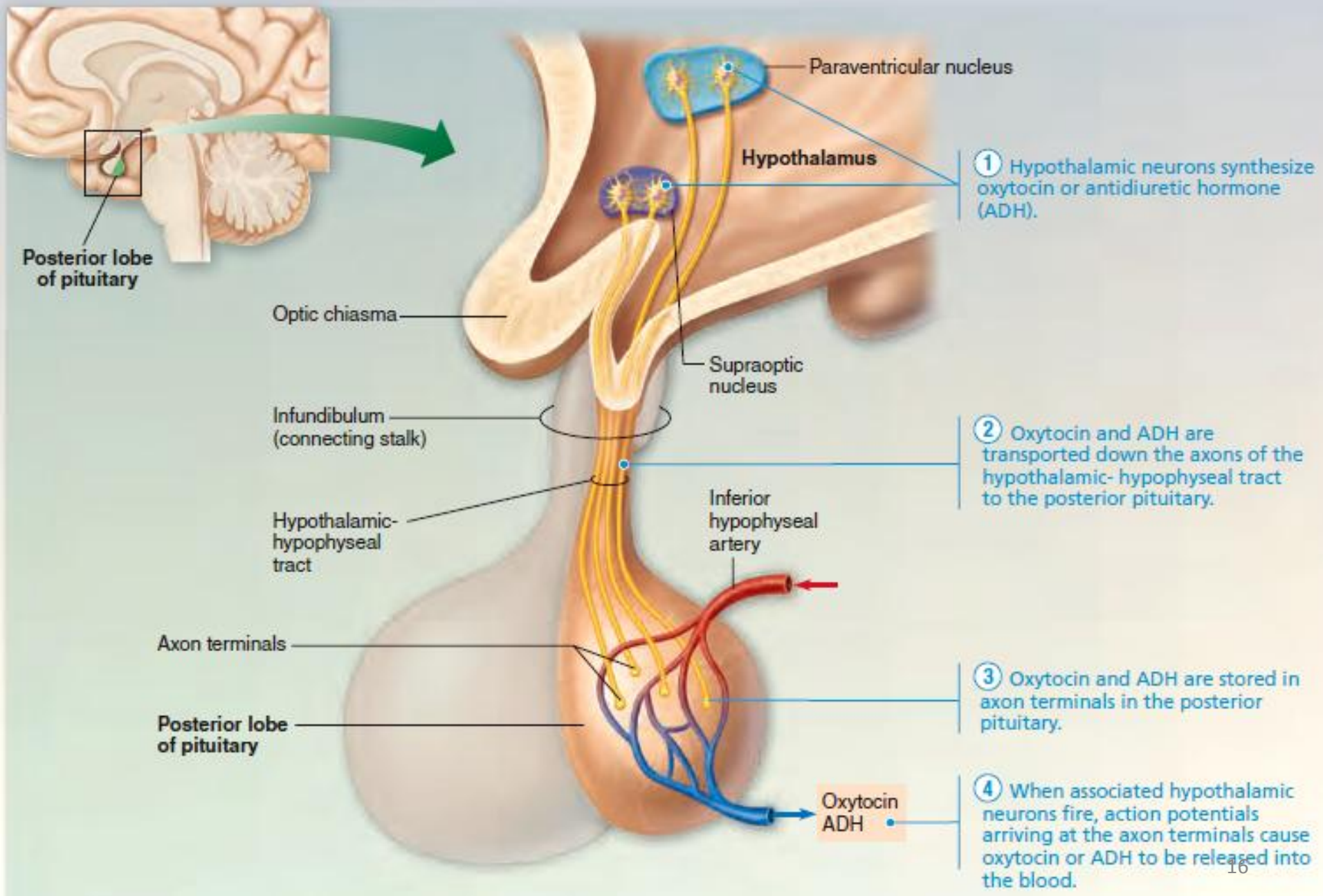
Pituitary-Hypothalamic Relationships

- The pituitary gland hangs from the base of the brain and is enclosed by bone.

- It consists of a hormone-producing glandular portion (anterior pituitary or adenohypophysis) and a neural portion (posterior pituitary or neurohypophysis), which is an extension of the hypothalamus.

- The neurohypophysis includes the infundibulum (stalk) and the posterior pituitary.

Posterior Pituitary: *Action potentials* travel down the axons of hypothalamic neurons, causing hormone release from their axon terminals in the posterior pituitary.



The hypothalamus

(a) synthesizes two hormones that it exports to the posterior pituitary for storage and later release and

(b) regulates the hormonal output of the anterior pituitary via releasing and inhibiting hormones.

The Posterior Pituitary and Hypothalamic Hormones

- The posterior pituitary stores and releases two hypothalamic hormones:
  - Oxytocin
  - Antidiuretic hormone (ADH)

Oxytocin

- It stimulates powerful uterine contractions, which trigger labor and delivery of an infant

- It stimulates milk ejection in nursing women.

➢ Its release is mediated reflexively by the hypothalamus and represents a positive feedback mechanism.

Antidiuretic hormone (ADH)

- It stimulates the kidney tubules to reabsorb and conserve water, resulting in small volumes of highly concentrated urine and decreased plasma solute concentration.

- ADH is released in response to high solute concentrations in the blood and inhibited by low solute concentrations in the blood.

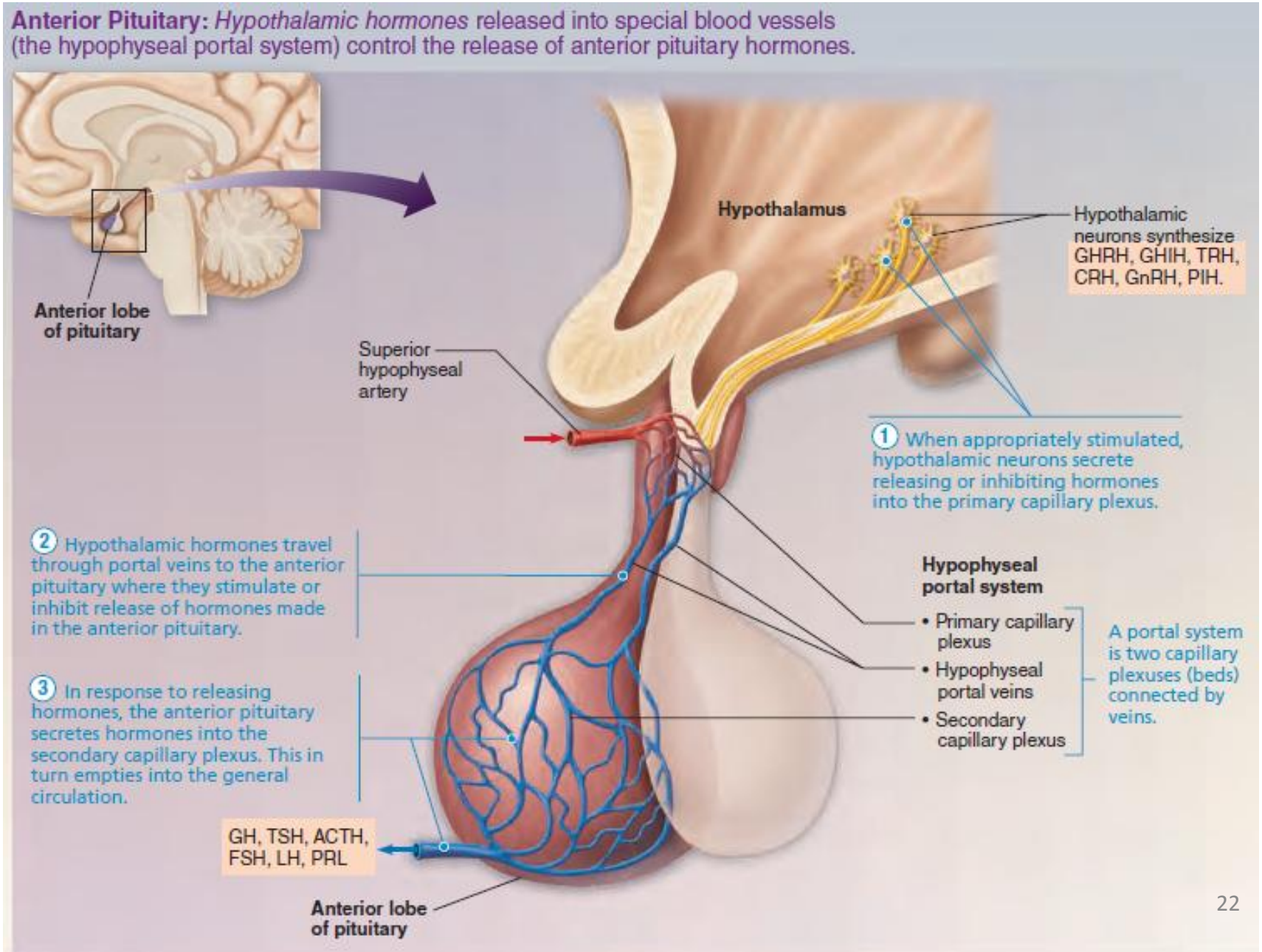
- Hyposecretion results in diabetes insipidus

Anterior Pituitary Hormones

- Four of the six anterior pituitary hormones are tropic hormones that regulate the function of other endocrine organs.

- Most anterior pituitary hormones exhibit a diurnal rhythm of release, which is subject to modification by stimuli influencing the hypothalamus.

Anterior Pituitary Hormones



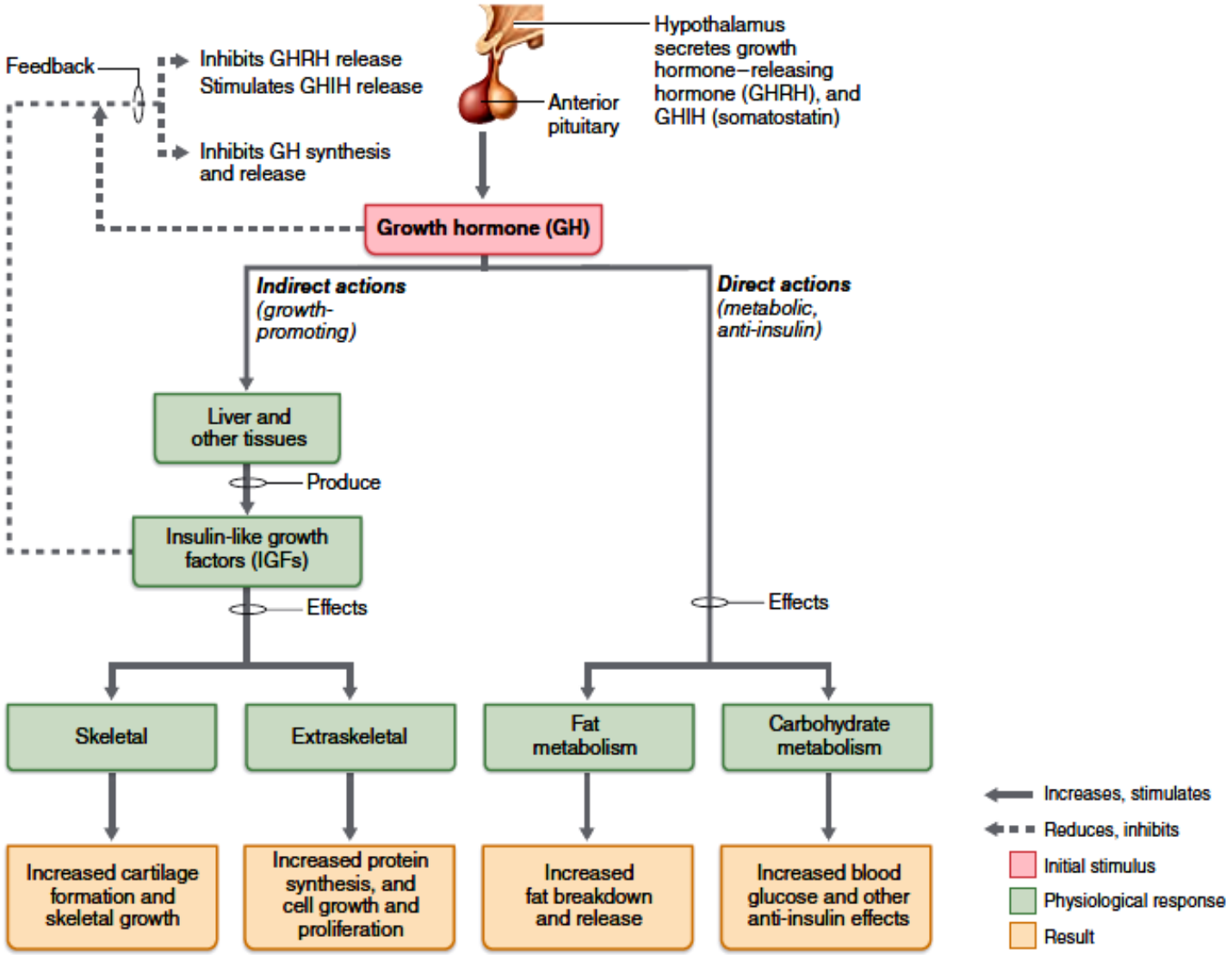
Anterior Pituitary Hormones

- Growth hormone (GH)
- Thyroid-stimulating hormone (TSH)
- Adrenocorticotropic hormone (ACTH)
- The gonadotropins—follicle-stimulating hormone (FSH) and luteinizing hormone (LH)
- Prolactin (PRL)

Growth hormone (GH) (somatotropin)

- It is an anabolic hormone that stimulates growth of all body tissues but especially skeletal muscle and bone.
- It may act directly, or indirectly, via insulin-like growth factors (IGFs).
- GH mobilizes fats, stimulates protein synthesis, and inhibits glucose uptake and metabolism.
- Its secretion is regulated by growth hormone–releasing hormone (GHRH) and growth hormone–inhibiting hormone (GHIH), or somatostatin.

Growth-promoting and metabolic actions of GH



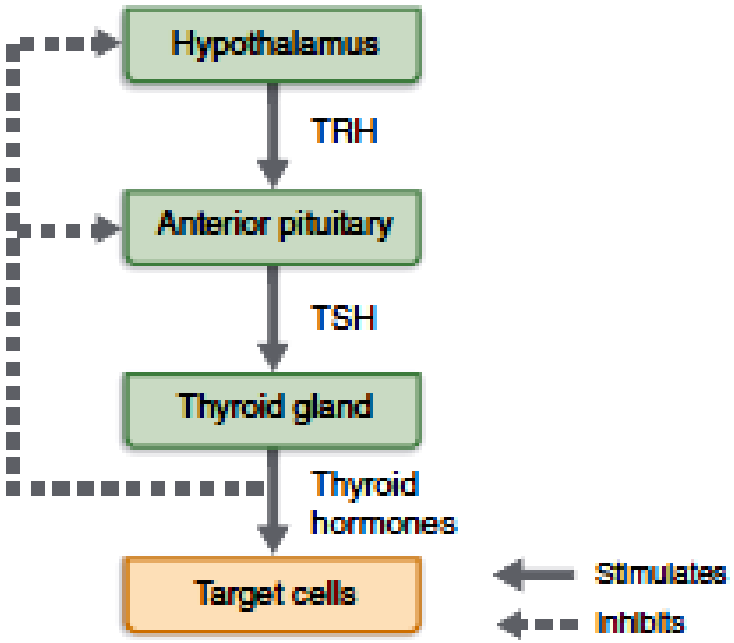
Growth hormone (GH)

- Hypersecretion causes **gigantism** in children and **acromegaly** in adults

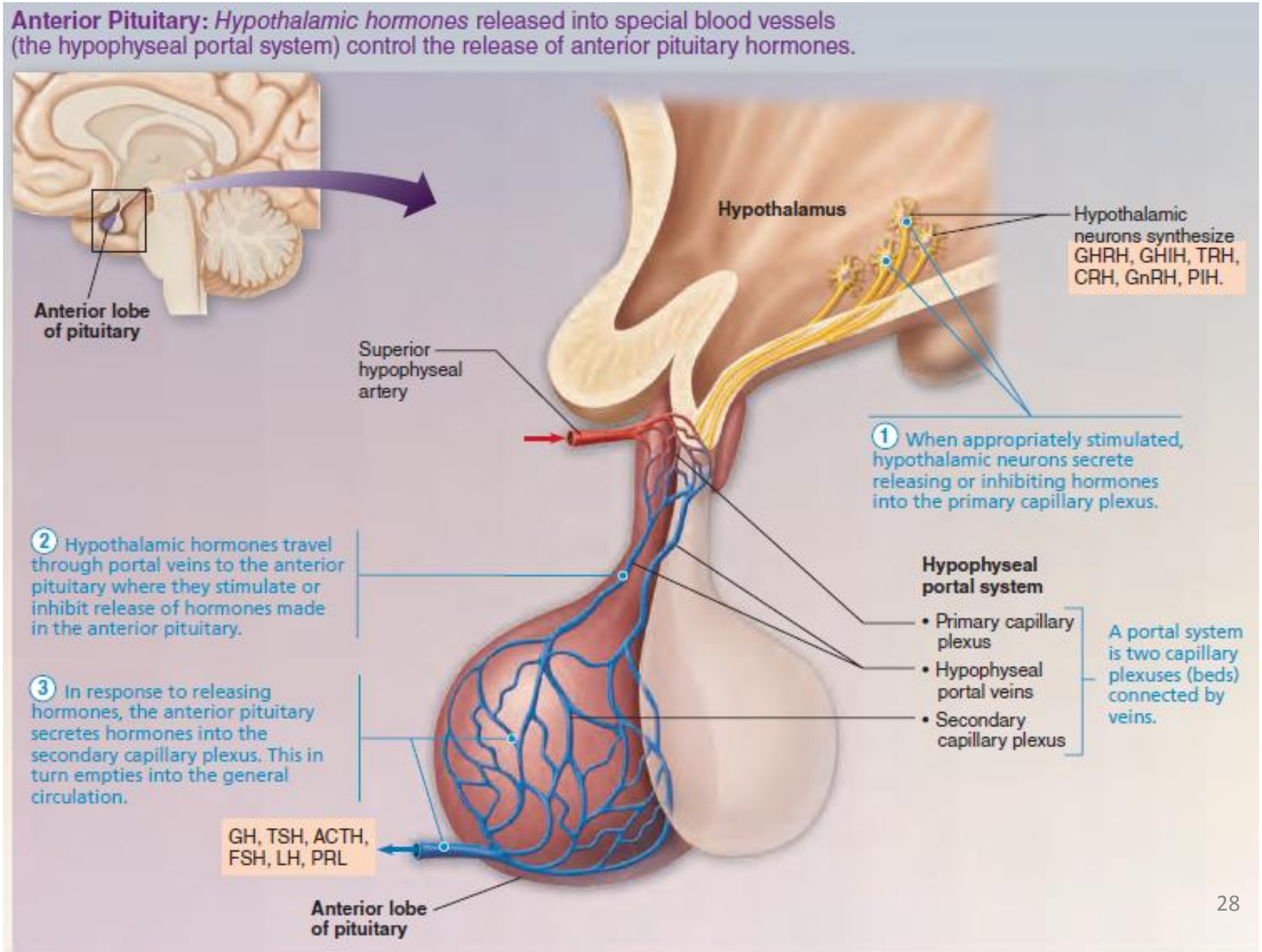
- Hyposecretion in children causes pituitary **dwarfism**.

Thyroid-stimulating hormone (TSH)

- TSH promotes normal development and activity of the thyroid gland.
- Thyrotropin releasing hormone (TRH) stimulates release of TSH
- Negative feedback of thyroid hormone inhibits it.
- GHIH also inhibits TSH secretion



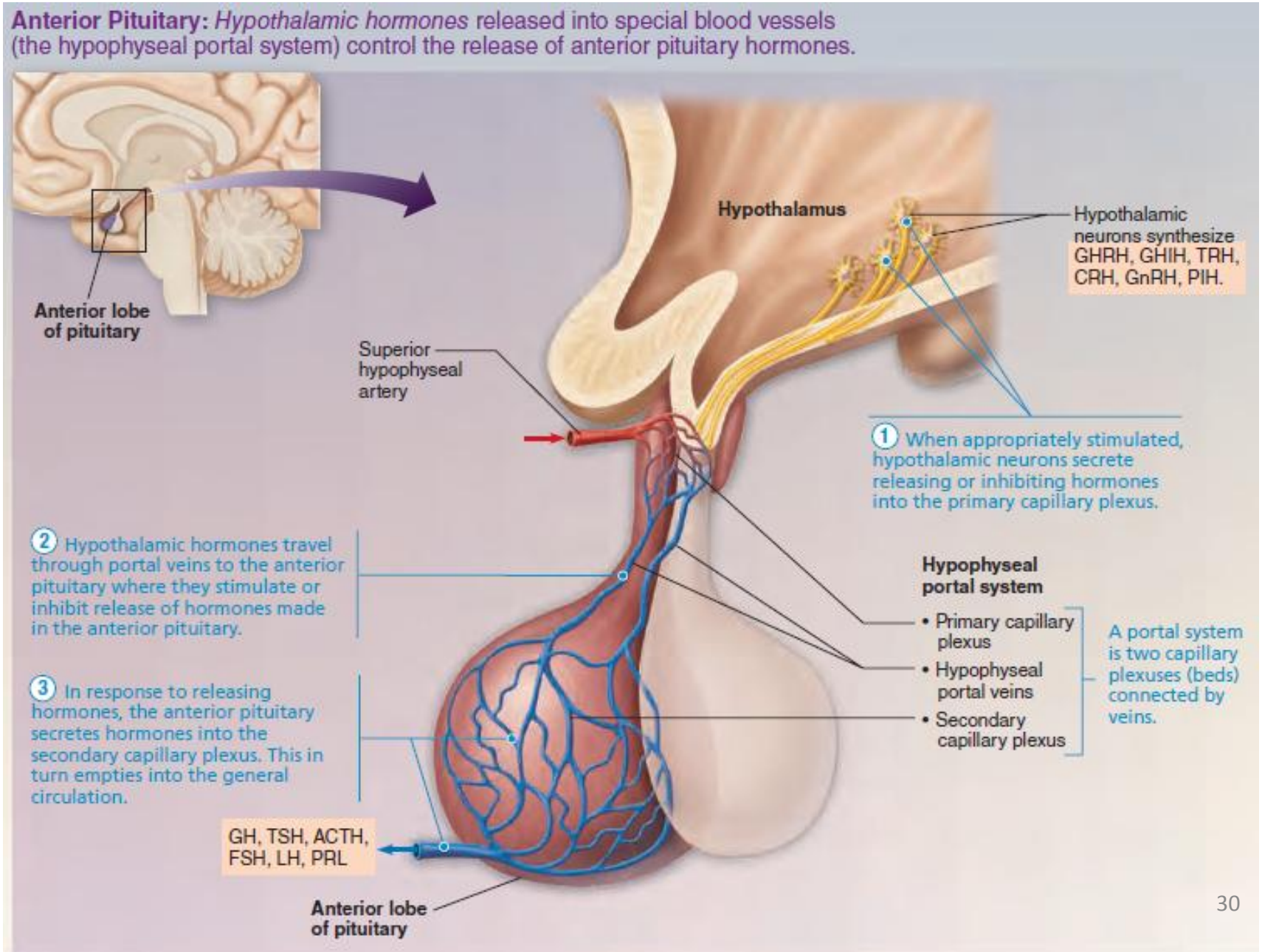
Anterior Pituitary Hormones



Adrenocorticotropic hormone (ACTH)

- It stimulates the adrenal cortex to release corticosteroids.
- Corticotropin-releasing hormone (CRH) triggers ACTH release
- Rising glucocorticoid levels inhibit it.

Anterior Pituitary Hormones



FSH and LH

- The gonadotropins—FSH and LH—regulate the functions of the gonads in both sexes.

- In both sexes, FSH stimulates production of gametes (sperm or eggs), while LH stimulates gonadal hormone production.

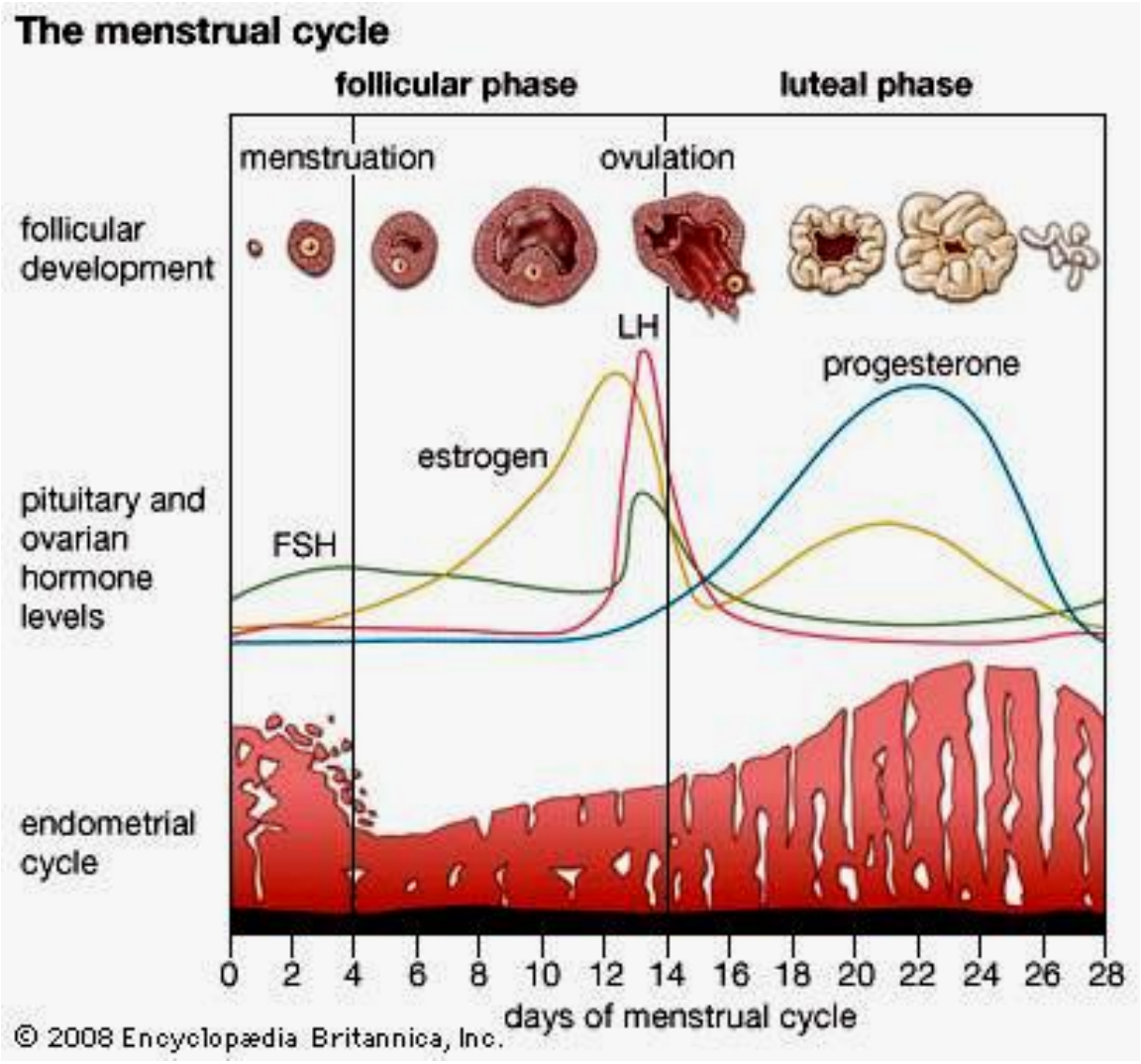
FSH and LH

- In females, LH works with FSH to cause an egg-containing ovarian follicle to mature. LH then triggers ovulation and promotes synthesis and release of ovarian hormones.

- In males, LH stimulates the interstitial cells of the testes to produce the male hormone testosterone.

- Gonadotropin levels rise in response to gonadotropin-releasing hormone (GnRH).

- Negative feedback of gonadal hormones inhibits gonadotropin release.


The menstrual cycle
follicular phase
luteal phase
menstruation
ovulation
follicular development
LH
progesterone
estrogen
pituitary and ovarian hormone levels
FSH
endometrial cycle
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
days of menstrual cycle
© 2008 Encyclopædia Britannica, Inc.

FSH and LH

- Gonadotropins are virtually absent from the blood of prepubertal boys and girls.

- During puberty, the **gonadotropic cells of** the anterior pituitary are activated and gonadotropin levels rise, causing the gonads to mature.

- In both sexes, **gonadotropin releasing hormone (GnRH) produced by the hypothalamus** prompts gonadotropin release.

- Gonadal hormones, produced in response to the gonadotropins, feed back to suppress FSH and LH release.

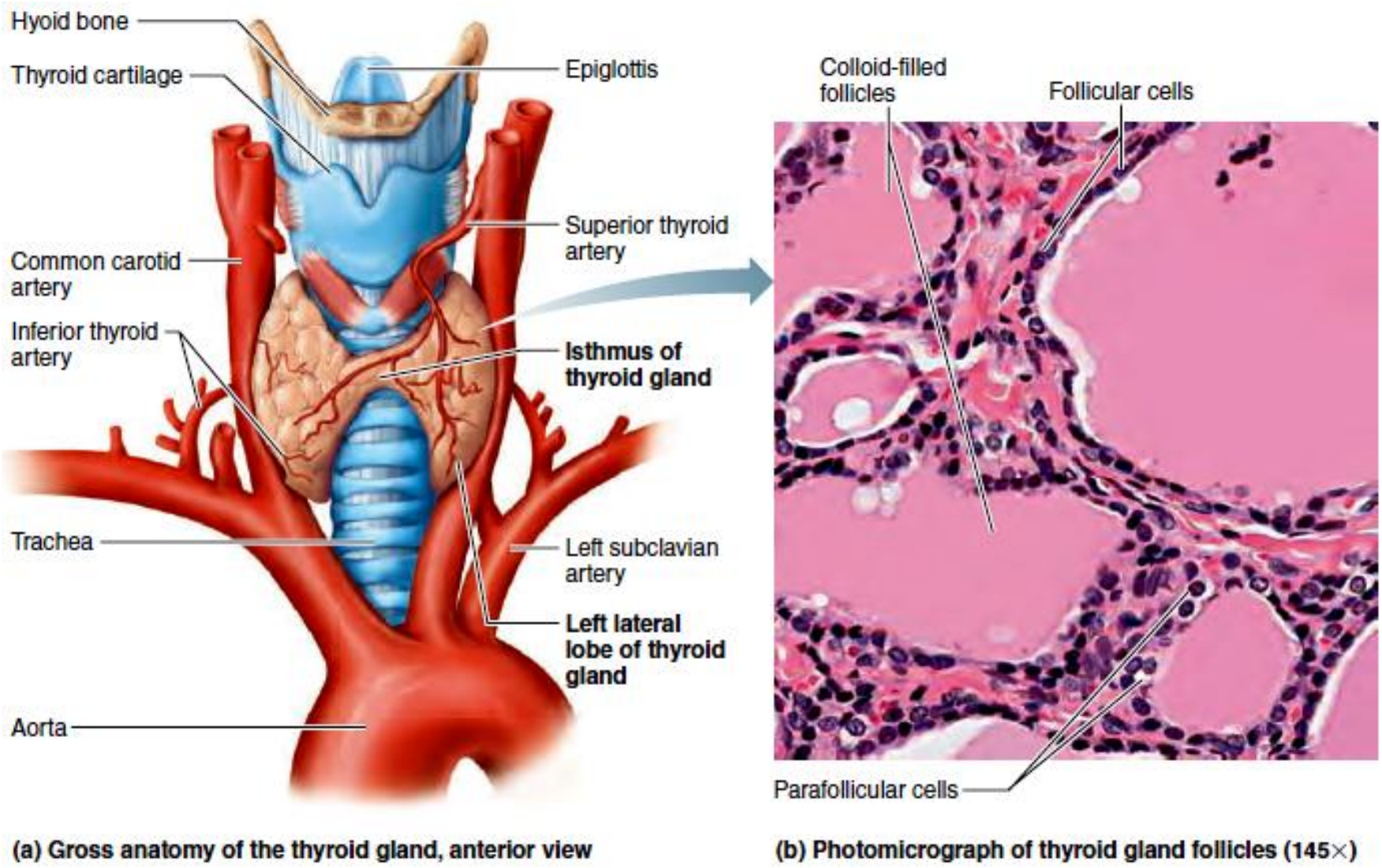
Prolactin (PRL)

- It promotes milk production in humans.

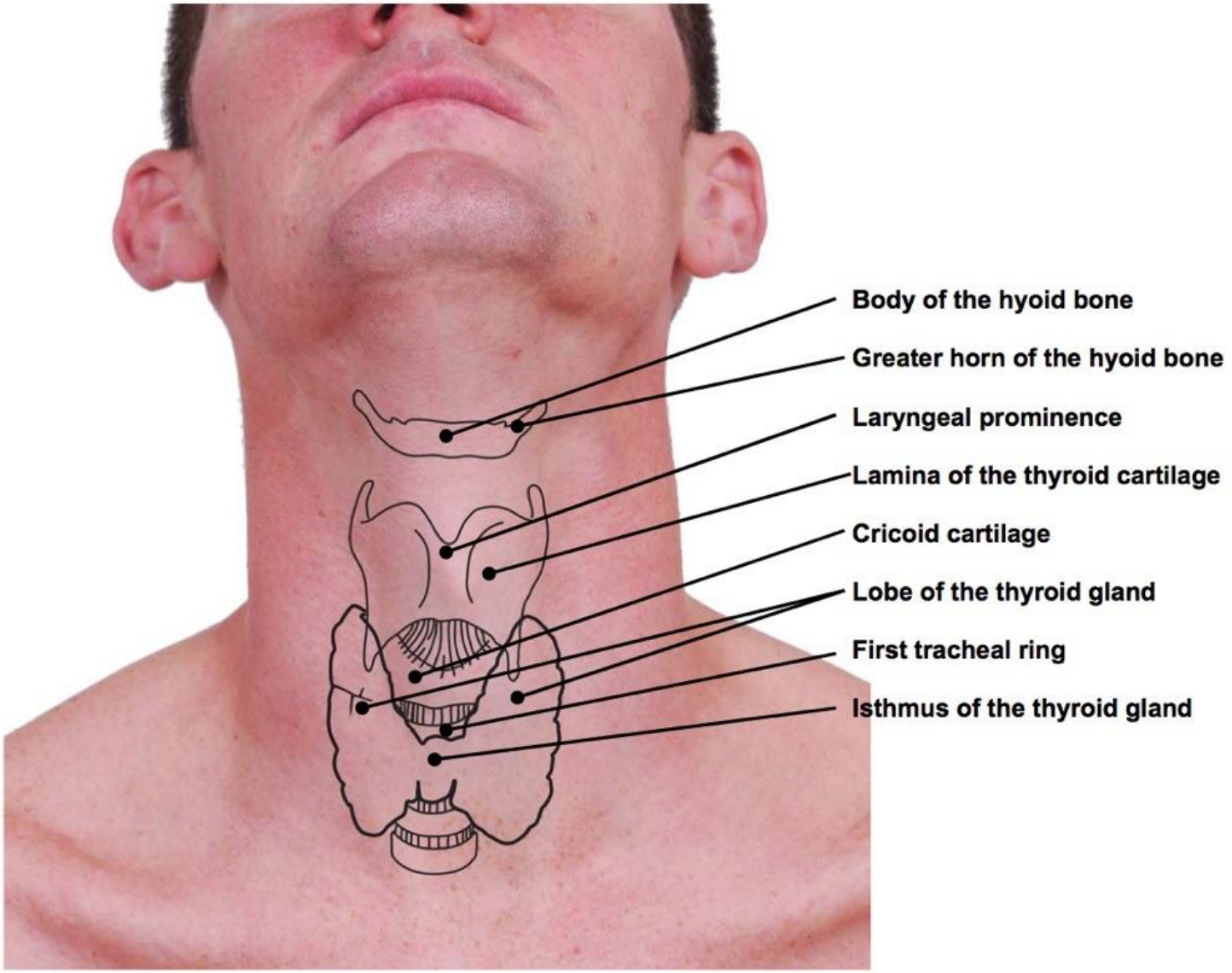
- Its secretion is inhibited by dopamine, that acts as a prolactin-inhibiting hormone (PIH)

- **Hypersecretion of prolactin (hyperprolactinemia) causes:**
  - **Females:** inappropriate lactation, lack of menses and infertility
  - **Males:** Impotence

The Thyroid Gland



The Thyroid Gland



The Thyroid Gland

- The thyroid gland is located in the anterior neck.
- Thyroid follicles store colloid containing thyroglobulin, a glycoprotein from which thyroid hormone is derived.
- Thyroid hormone (TH) includes thyroxine (T4) and triiodothyronine (T3), which increase the rate of cellular metabolism. Consequently, oxygen use and heat production rise.

Steps of thyroid hormone synthesis:

1. Iodide is uptaken in response to TSH hormone
2. Iodide is oxidized by **thyroidal peroxidase** to iodine
3. Tyrosine on thyroglobulin is iodinated and forms MIT & DIT
4. Iodotyrosines condensation

   MIT+DIT→T3; DIT+DIT→T4

The Thyroid Gland

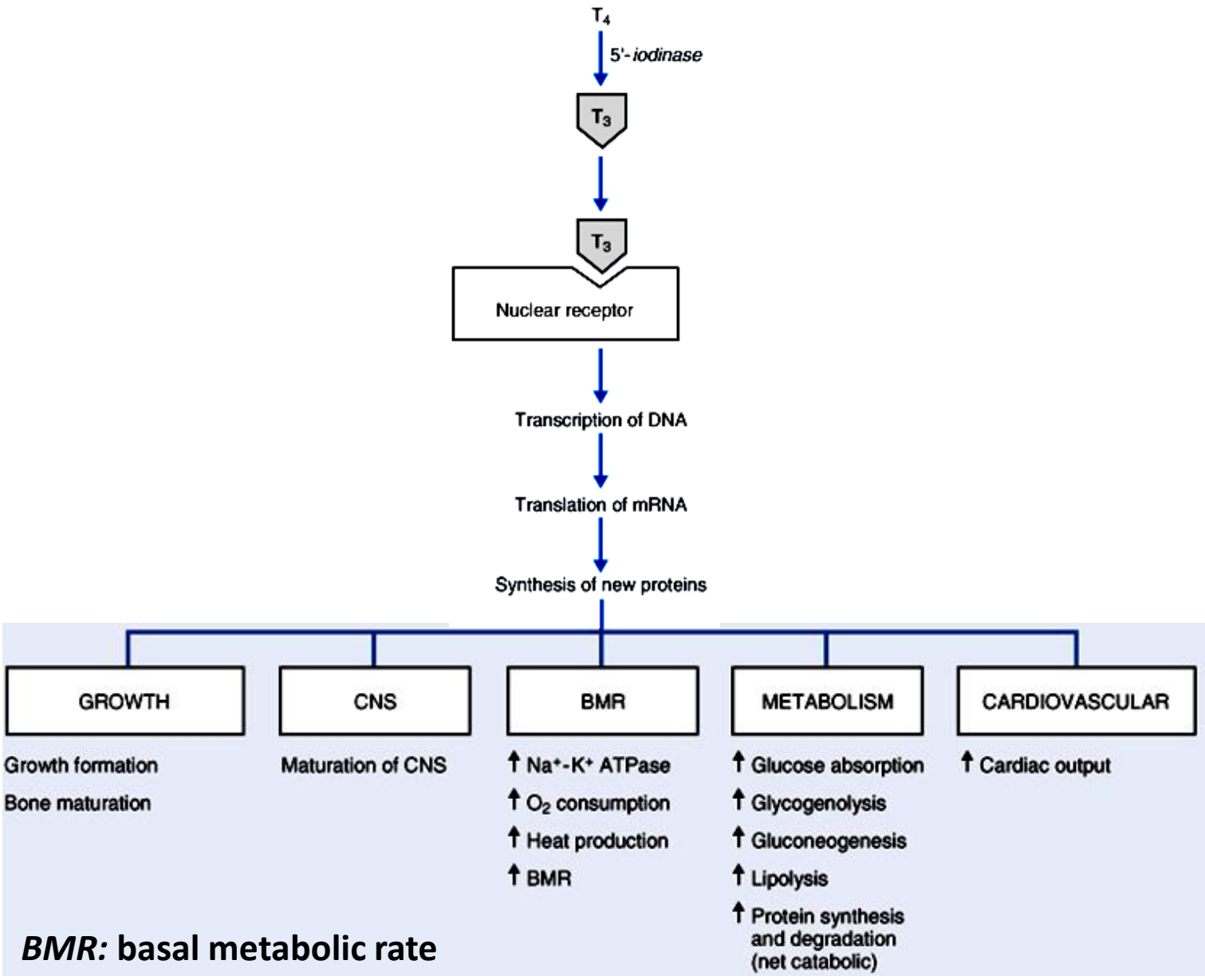
- Secretion of thyroid hormone, prompted by TSH, requires the follicular cells to take up the stored colloid and split the hormones from the colloid for release.

- Rising levels of thyroid hormone feed back to inhibit the anterior pituitary and hypothalamus.

- Most T4 is converted to T3 (the more active form) in the target tissues.

- These hormones act by turning on gene transcription and protein synthesis.

Mechanism of actions of thyroid hormones



BMR: **basal metabolic rate**

Homeostatic Imbalance of the Thyroid Gland

Hypothyroid disorders may result from:

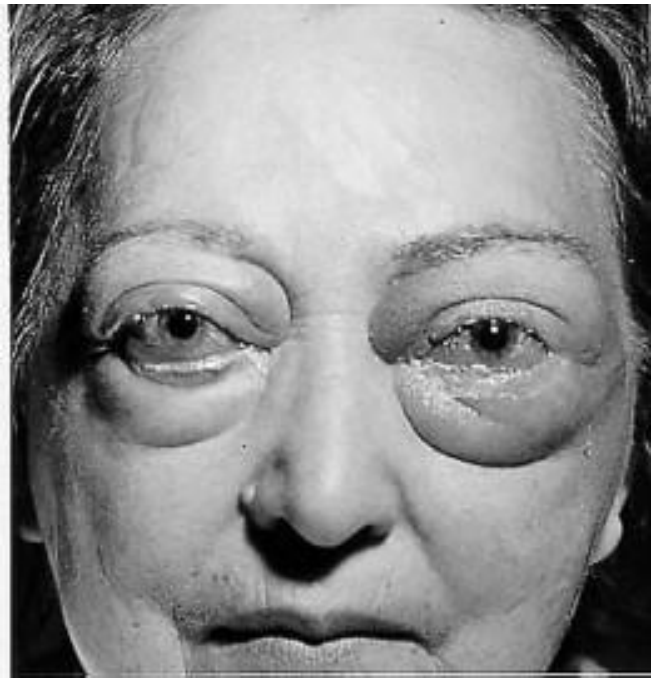
- Thyroid gland defects
- Secondarily from inadequate TSH or TRH release.
- When the thyroid gland is removed surgically
- When dietary iodine is inadequate

- ➢ Hypothyroidism conditions: Myxedema, Goiter, Cretinism
- ➢ Hyperthyroidism condition: Graves' disease

Myxedema

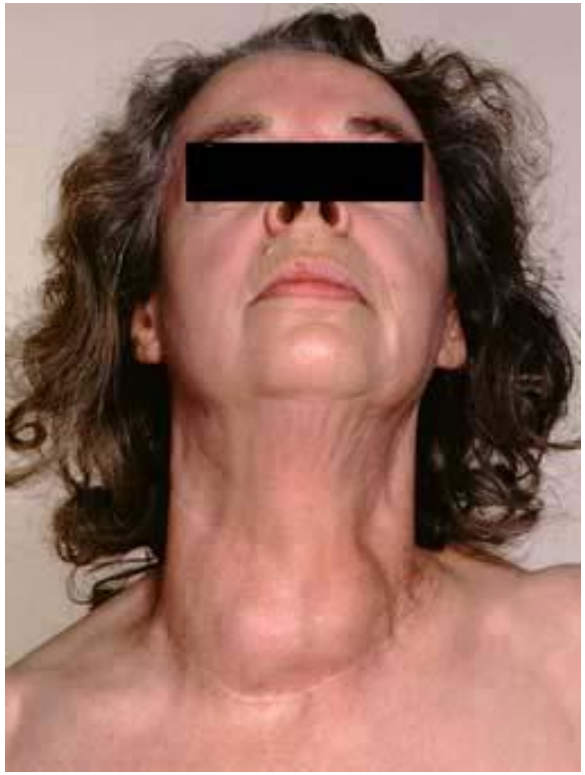
- **Full-blown hypothyroid syndrome In adults.**

- **Symptoms include:**
  - Low metabolic rate
  - Feeling chilled
  - Constipation
  - Thick dry skin
  - Puffy eyes
  - Edema
  - Lethargy
  - Mental sluggishness (but not mental retardation)



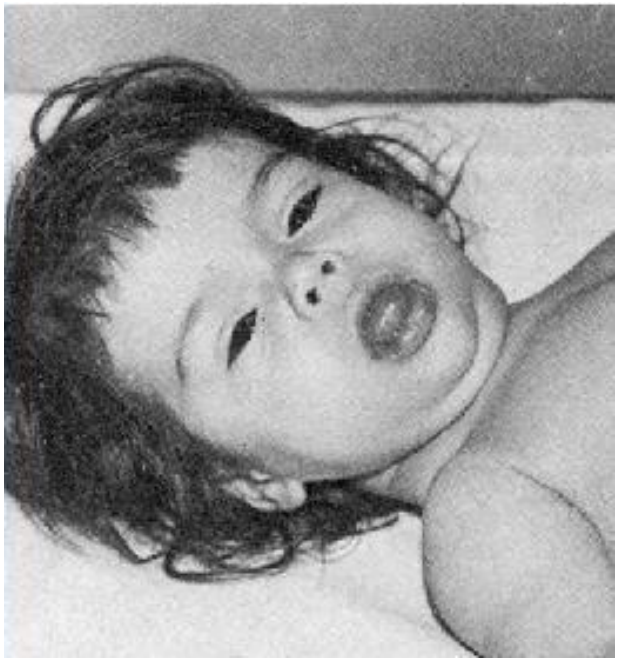
Goiter

- An enlarged protruding thyroid gland
- Occurs if myxedema results from lack of Iodine
- The follicular cells produce colloid but cannot iodinate it and make functional hormones.
- The pituitary gland secretes increasing amounts of TSH in an attempt to stimulate the thyroid to produce TH, but the only result is that the follicles accumulate more and more *unusable colloid.*



Cretinism

- Severe hypothyroidism in infants
- The child is mentally retarded and has a short, disproportionately sized body and a thick tongue and neck
- Thyroid hormone replacement therapy can prevent cretinism if diagnosed early enough



Graves' disease

- The most common hyperthyroid disease
- It is an autoimmune condition, where abnormal antibodies are directed against thyroid follicular cells.
- Rather than marking these cells for destruction as antibodies normally do, these antibodies mimic TSH and continuously stimulate TH release.

Typical symptoms of Graves' disease

- Elevated metabolic rate
- Sweating
- Rapid and irregular heartbeat
- Nervousness
- Weight loss despite adequate food
- Eyeballs may protrude (*exophthalmos)* if the tissue behind the eyes becomes edematous and fibrous

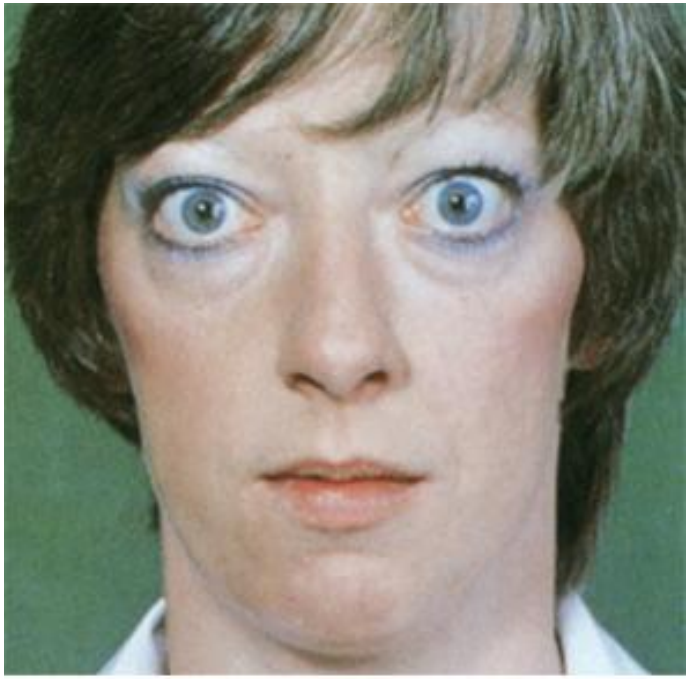
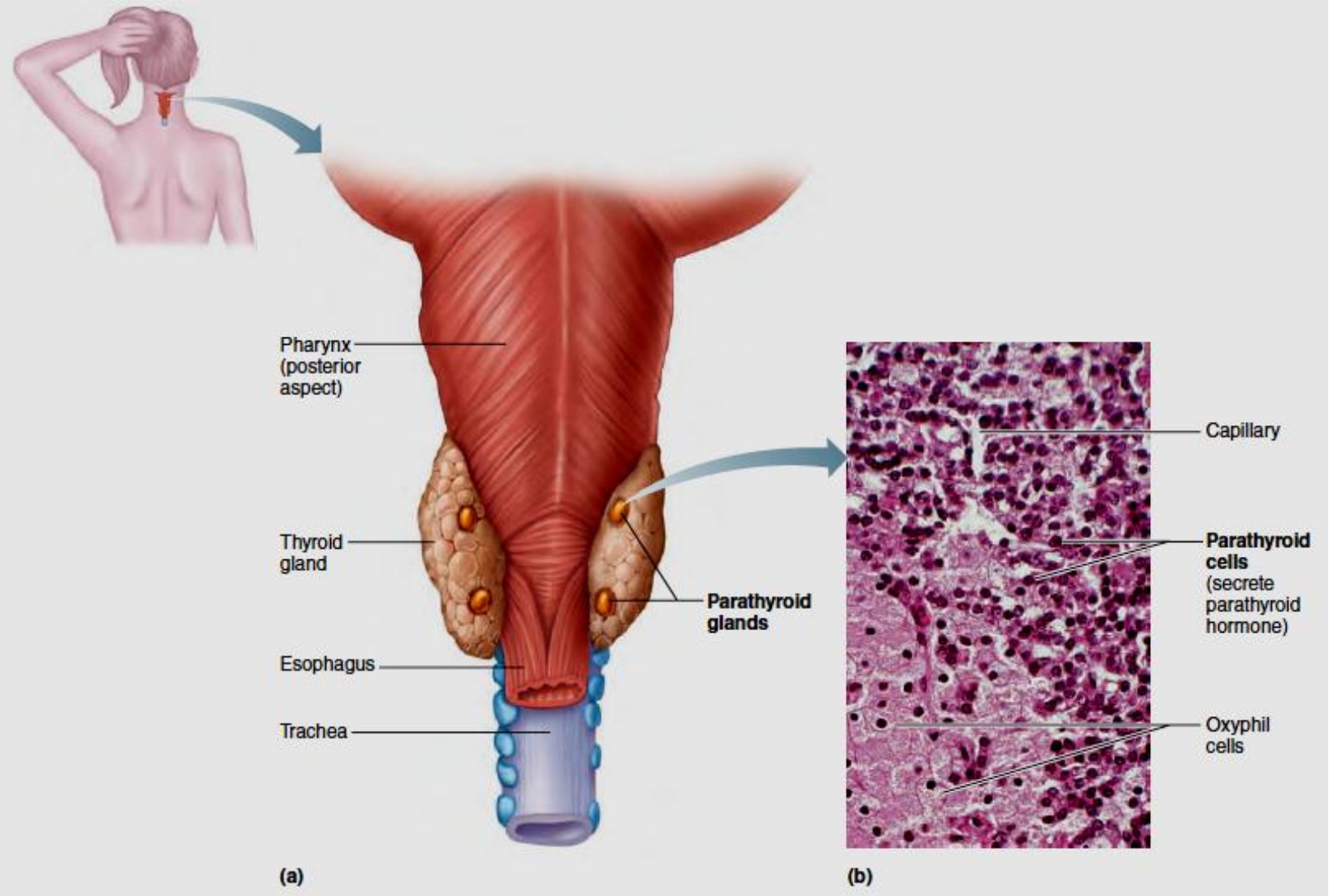


PHOTO RESEARCHERS/BIOPHOTO ASSOCIATES

Parafollicular (C) Cells of the Thyroid Gland

- They produce calcitonin
- It is not normally important in calcium homeostasis
- At pharmacological levels, it inhibits bone matrix resorption and enhances calcium deposit in bone

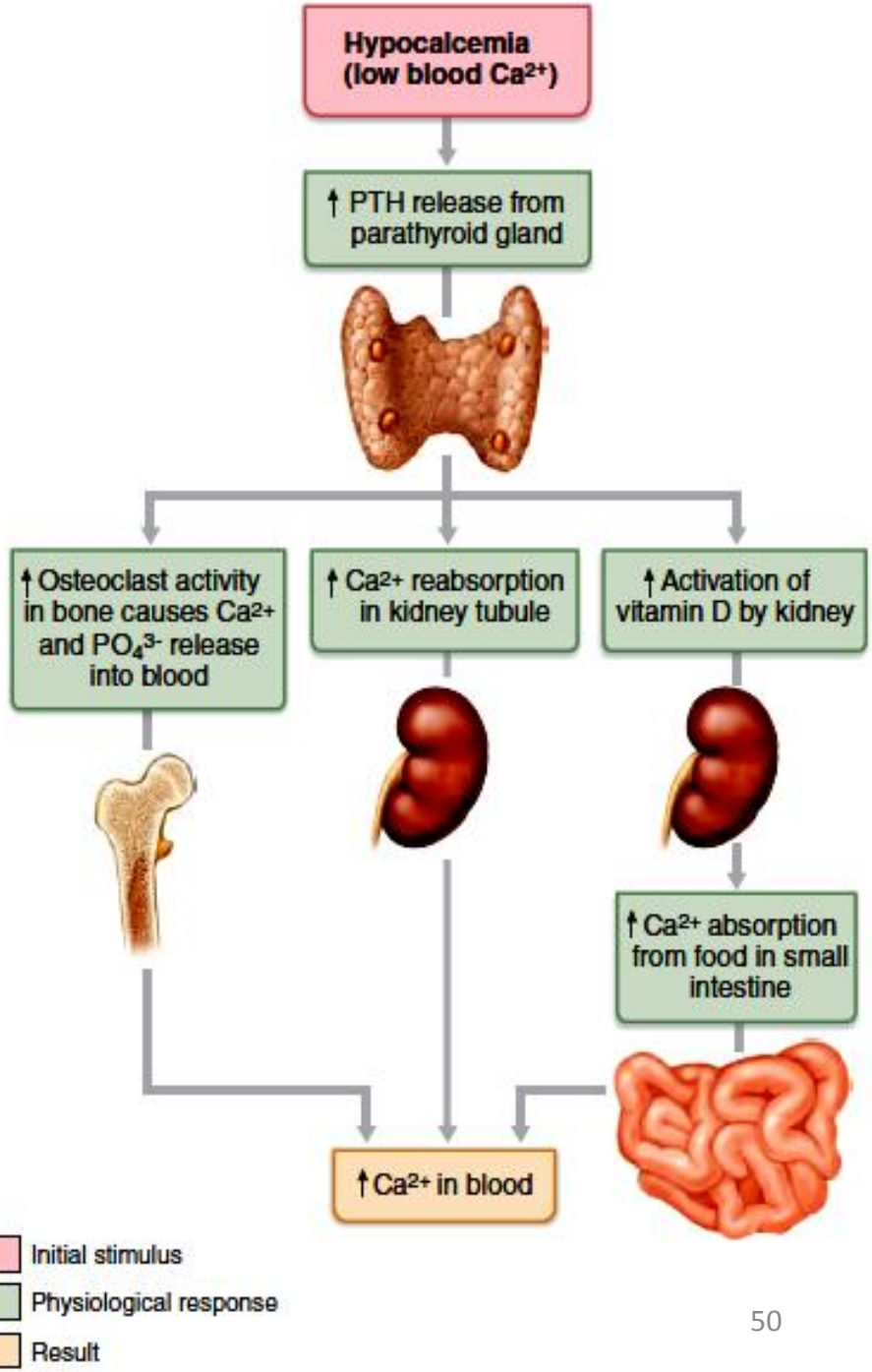
The Parathyroid Glands



(a) The parathyroid glands are located on the posterior aspect of the thyroid gland and may be more inconspicuous than depicted. **(b) Photomicrograph** of parathyroid gland tissue (1603).

The Parathyroid Glands

- They secrete parathyroid hormone (PTH), which increases blood calcium levels.
- It targets bone, the kidneys, and the small intestine (indirectly via vitamin D activation).
- PTH is the key hormone for calcium homeostasis.
- Falling blood calcium levels trigger PTH release; rising blood calcium levels inhibit its release.



Imbalance of PTH

- Hyperparathyroidism results in hypercalcemia and extreme bone wasting

- Hypoparathyroidism leads to hypocalcemia, evidenced by tetany, respiratory paralysis and death

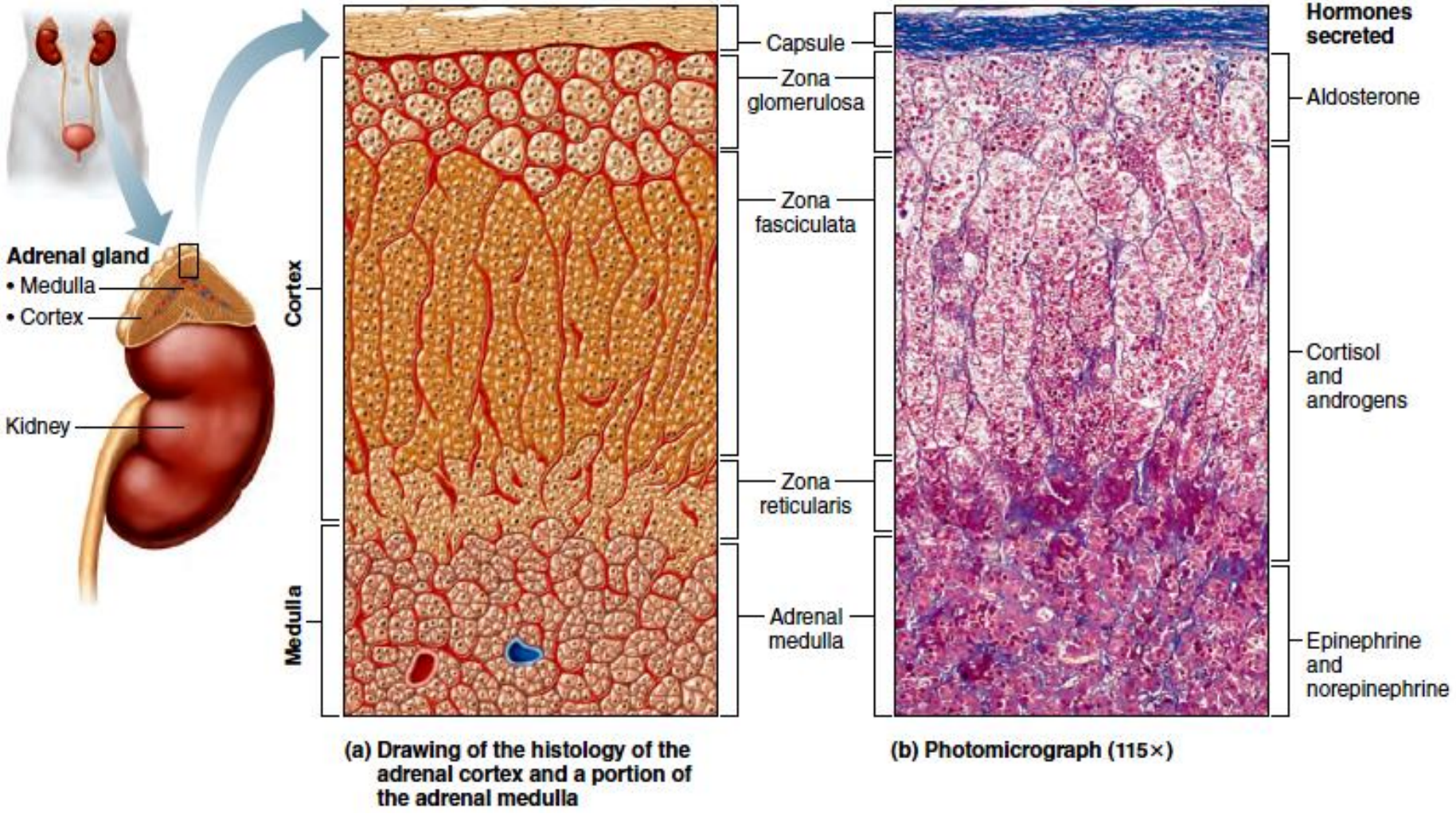
The Adrenal (Suprarenal) Glands

The Adrenal (Suprarenal) Glands

- The paired adrenal (suprarenal) glands sit atop the kidneys.

- Each adrenal gland has two functional portions,
  a) The cortex and
  b) The medulla

The Adrenal (Suprarenal) Glands

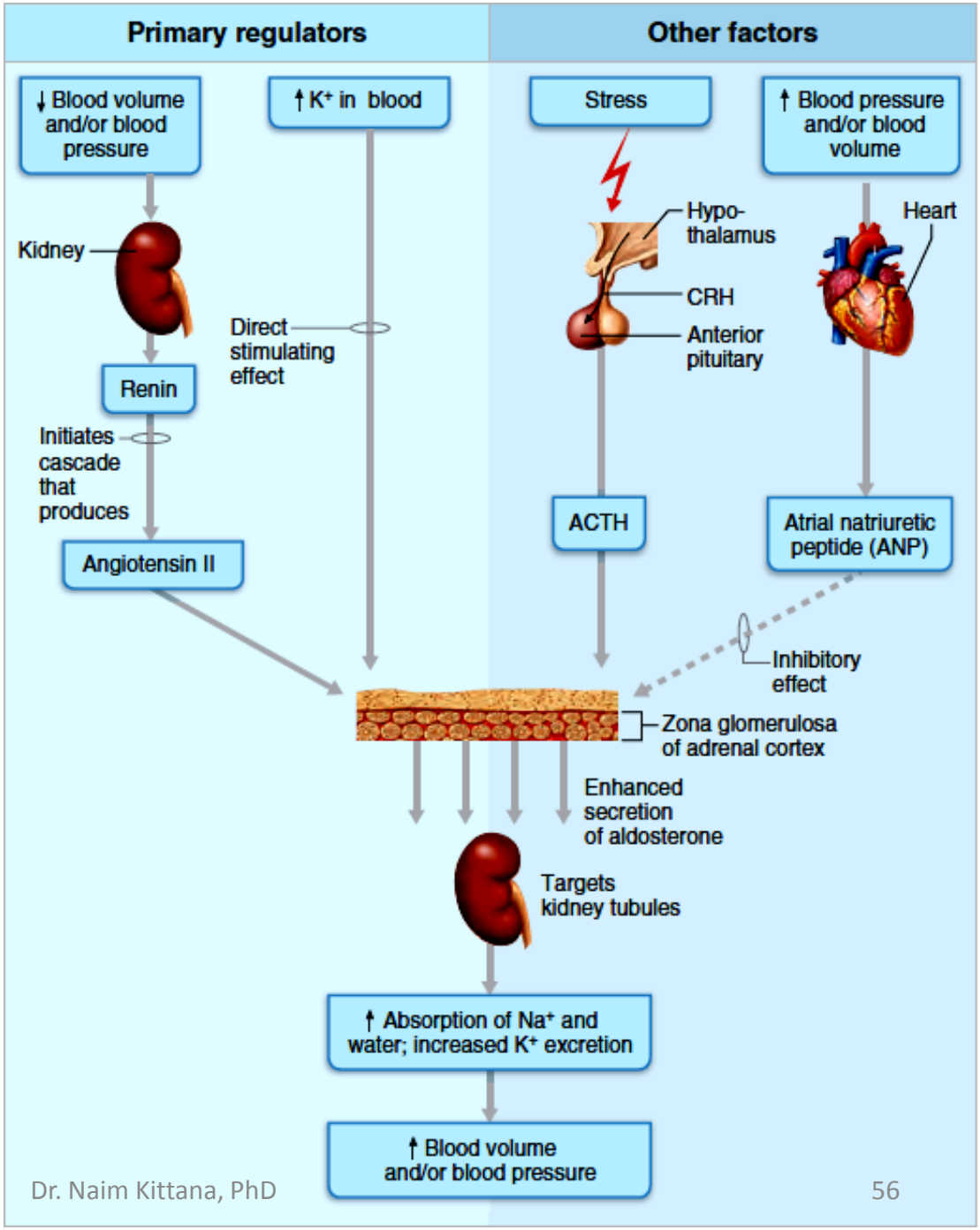


Hormones of the Adrenal Cortex

- **Mineralocorticoids:** help control the balance of minerals and water in the blood.

- **Glucocorticoids:** influence the energy metabolism of most body cells and help resist stressors

Major mechanisms controlling aldosterone release from the adrenal cortex



Homeostatic Imbalance of Aldosterone

- **Aldosteronism:** hypersecretion of aldosterone
- **Cause:** adrenal tumors.
- **Two major sets of problems result:**
  (1) Hypertension and edema due to excessive Na^{2+} and water retention
  (2) K^{+} depletion: as a result, neurons become nonresponsive, leading to muscle weakness and eventually paralysis

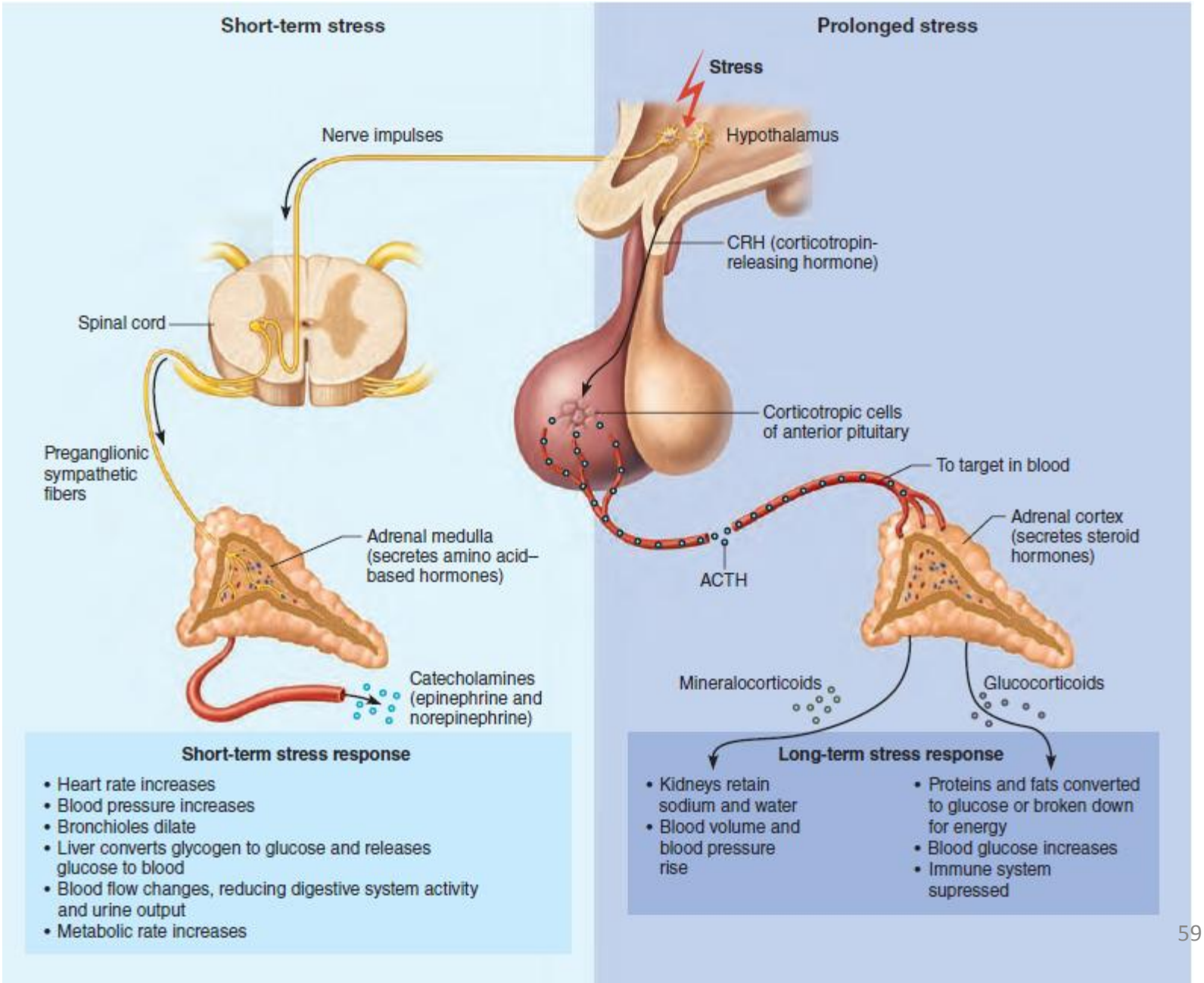
Glucocorticoids

- They include cortisol (hydrocortisone, the main hormone), cortisone, and corticosterone

- **Under normal circumstances:**
  - Help the body adapt to intermittent food intake by keeping blood glucose levels fairly constant
  - Maintain blood pressure by increasing the action of vasoconstrictors.

- **Under severe stress** due to hemorrhage, infection, or physical or emotional trauma evokes a dramatically higher output of Glucocorticoids,

Stress and the adrenal gland



Normal regulation of glucocorticoid levels

- Cortisol secretory bursts, driven by patterns of eating and activity, occur in a definite pattern throughout the day and night.
- Cortisol blood levels peak shortly before we rise in the morning.
- The lowest levels occur in the evening just before and shortly after we fall asleep.
- However, acute stress of any variety interrupts the normal cortisol rhythm

Physiological Effects of Glucocorticoids

- Cortisol rises blood levels of glucose, fatty acids, and amino acids.

- Cortisol's prime metabolic effect is to provoke gluconeogenesis, (formation of glucose from fats and proteins)

- In order to "save" glucose for the brain, cortisol mobilizes fatty acids from adipose tissue and encourages their increased use for energy.

Physiological Effects of Glucocorticoids

- Cortisol induces the breakdown of stored proteins to provide building blocks for repair or to make enzymes for metabolic processes.

- Cortisol enhances the sympathetic nervous system's vasoconstrictive effects, and the rise in blood pressure to help ensure that these nutrients are quickly distributed to cells.

Physiological Effects of Glucocorticoids

- Ideal amounts of glucocorticoids promote normal functions, but too much cortisol exerts significant anti-inflammatory and anti-immune effects

Glucocorticoids Homeostatic Imbalance (Cushing's syndrome)

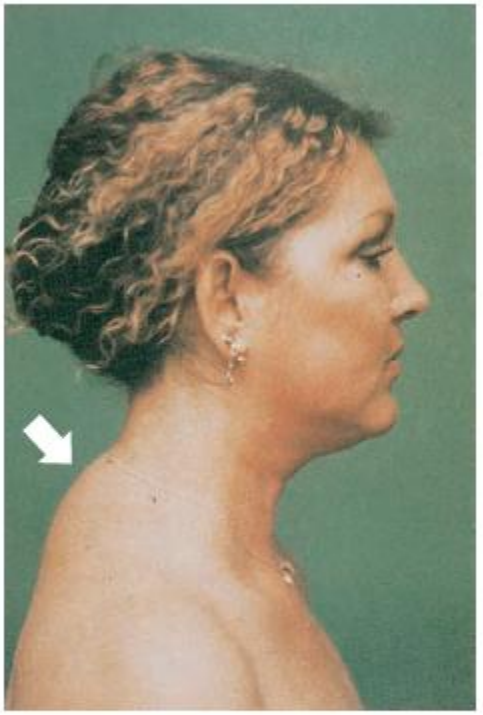
- Results from excess Glucocorticoids secretion

- **Etiology:**
  - ACTH-releasing malignancy of the lungs, pancreas, or kidneys; or by a tumor of the adrenal cortex
  - Drug-induced

Symptoms of Cushing's syndrome:

- Swollen "moon" face
- Redistribution of fat to the abdomen and the posterior neck (causing a "buffalo hump"),
- Hyperglycemia and other metabolic disturbances including steroid-induced diabetes mellitus and weight gain

(a) Patient before onset.



(b) **Same patient with Cushing's syndrome.** The white arrow shows the characteristic "buffalo hump" of fat on the upper back.

Symptoms of Cushing's syndrome:

- Osteoporosis
- Peptic ulcer
- Cataracts and increased intraocular pressure leading to glaucoma
- Edema
- Hypertension
- Increased susceptibility to infection
- Easy bruising and poor wound healing
- Muscle weakness and tissue loss

Glucocorticoids Homeostatic Imbalance (Addison's disease)

- The major hyposecretory disorder of the adrenal cortex
- Involves deficits in both glucocorticoids and mineralocorticoids.
- **Symptoms:**
- Weight loss
- Drop in plasma glucose and sodium levels
- Hyperkalemia (high plasma potassium levels)
- Severe dehydration and hypotension

Corticosteroid replacement therapy is the usual treatment.

Gonadocorticoids (Adrenal Sex Hormones)

- Most gonadocorticoids secreted by the adrenal cortex are weak androgens, or male sex hormones

- Most are converted in tissue cells to more potent male hormones, such as *testosterone, and* some are converted to estrogens.

- The secreted amounts are relatively little

The Adrenal Medulla

- Part of the autonomic nervous system
- Made up of **medullary chromaffin cells**
- **They** synthesize the *catecholamines* ***epinephrine and norepinephrine (NE)*** from tyrosine amino acid
- Approximately 80% is epinephrine and 20% norepinephrine
- Activated by the sympathetic nervous system in response to stress

Physiological effects of sympathetic nervous system

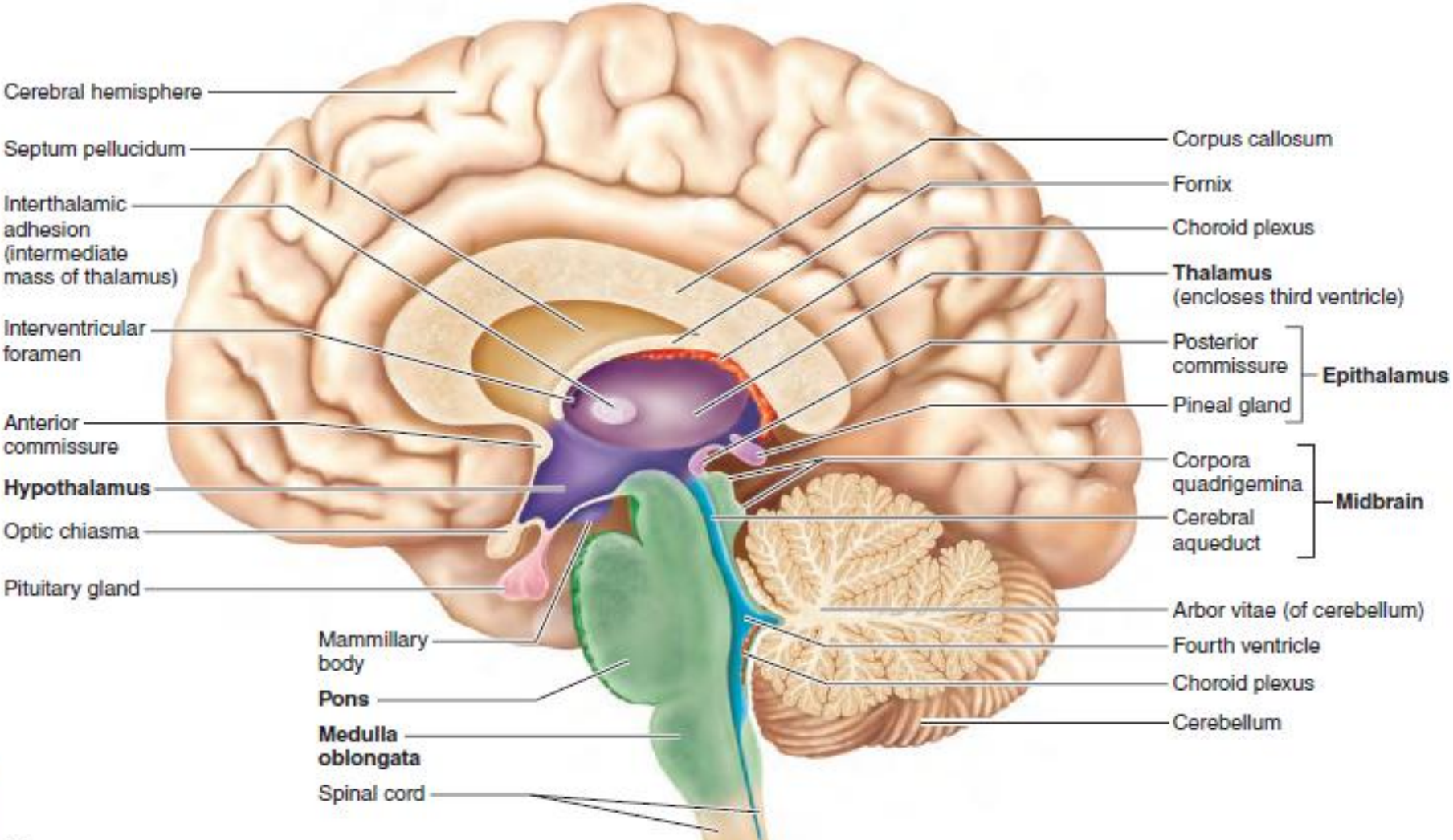
- Blood vessels constrict and the heart beats faster (together raising the blood pressure)
- Blood is diverted from temporarily nonessential organs to the heart and skeletal muscles.
- Blood glucose levels rise

Homeostatic Imbalance of Catecholamines (Pheochromocytoma)

- Medullary chromaffin cell tumor that hypersecret catecholamines

- Produces symptoms of uncontrolled sympathetic nervous system activity:
  - Hyperglycemia (elevated blood glucose),
  - Increased metabolic rate
  - Rapid heartbeat and palpitations
  - Hypertension
  - Intense nervousness, and sweating

The Pineal Gland



The Pineal Gland

- Tiny, pine cone–shaped pineal gland hangs from the roof of the third ventricle in the diencephalon
- Mainly secrets **Melatonin** hormone
- Melatonin concentrations in the blood rise and fall in a diurnal (daily) cycle: Peak levels occur during the night and make us drowsy, and lowest levels occur around noon.
- The pineal gland indirectly receives input from the visual pathways concerning the intensity and duration of daylight

The Pancreas

- Located partially behind the stomach in the abdomen
- is a mixed gland composed of both endocrine and exocrine gland cells
- *Acinar cells,* forming the bulk of the gland, produce an enzyme-rich juice that is carried by ducts to the small intestine during digestion
- Scattered among the acinar cells are approximately a million **pancreatic islets (***islets of Langerhans)* tiny cell clusters that produce pancreatic hormones

Islets of Langerhans

- Contain two major populations of hormone-producing cells:
  - Alpha (a) cells: synthesize glucagon (hyperglycemic hormone)
  - Beta (β) cells: Synthesize insulin (hypoglycemic hormone)

Glucagon

- The major target of glucagon is the liver, where it promotes the rise of blood glucose levels by:
  - Breakdown of glycogen to glucose (*glycogenolysis)*
  - Synthesis of glucose (*gluconeogenesis)*
  - Release of glucose to the blood by liver cells

- Glucagon release is suppressed by rising blood glucose levels and by insulin

Insulin

- Synthesized as part of a larger polypeptide chain called **proinsulin.**

- Enzymes then excise the middle portion of this chain, releasing functional insulin

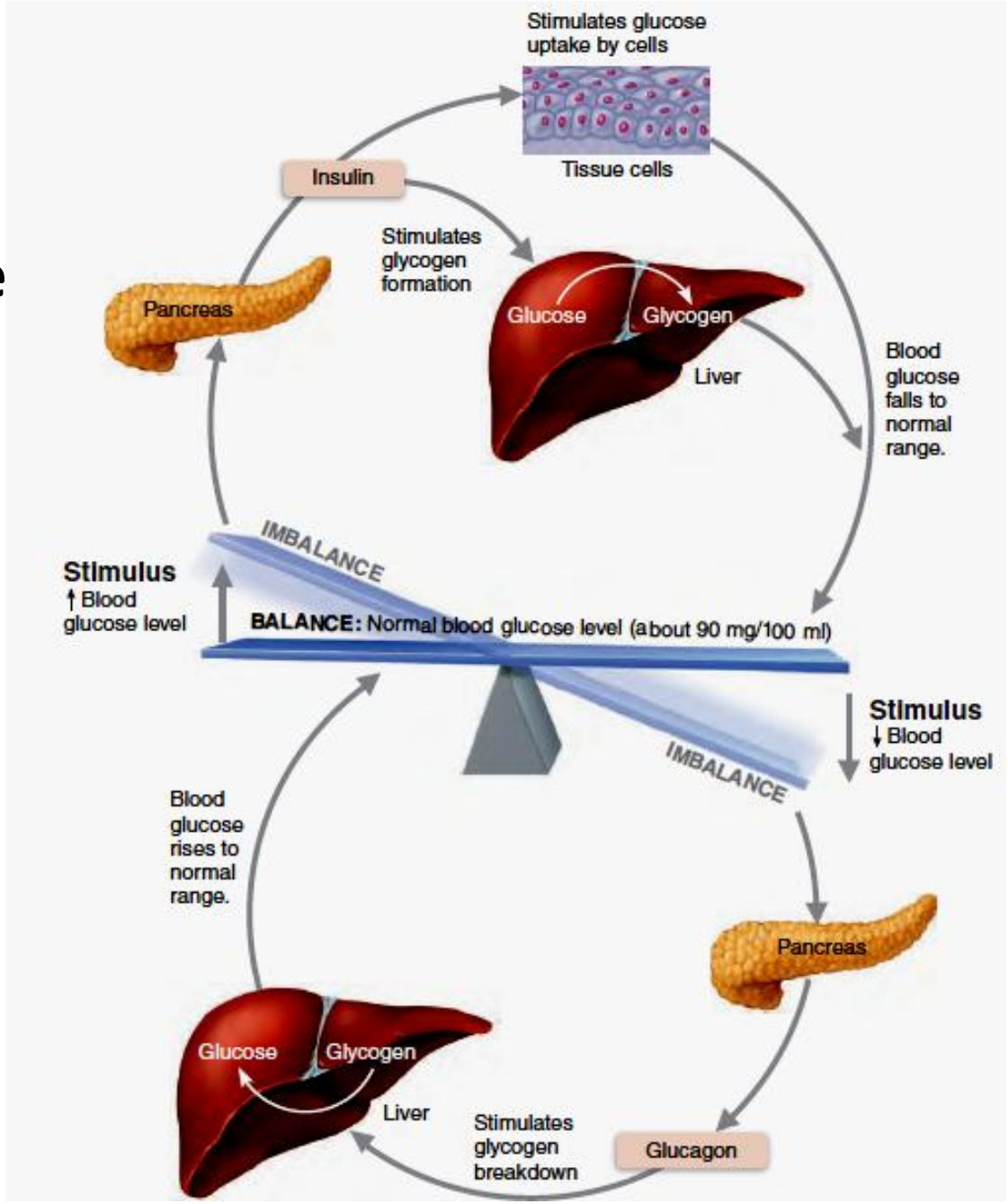
- Main effect is to lower blood glucose levels but it also influences protein and fat metabolism

Circulating insulin lowers blood glucose levels in three ways:

- Enhances membrane transport of glucose (and other simple sugars) into most body cells, especially muscle and fat cells.
- Inhibits the breakdown of glycogen to glucose.
- Inhibits the conversion of amino acids or fats to glucose.

Insulin is NOT needed for glucose entry into liver, kidney, and brain tissue

Insulin and glucagon from the pancreas regulate blood glucose levels



Factors That Influence Insulin Release

- Elevated blood glucose levels
- Rising blood levels of amino acids and fatty acids
- Release of acetylcholine

Homeostatic Imbalance: Diabetes mellitus (DM)

- **Types:**
  - Type 1 DM: When insulin is absent
  - Type 2 DM: If insulin is present, but its effects are deficient

- In either case, blood glucose levels remain high after a meal because glucose is unable to enter most tissue cells.

Signs of DM:

- **Polyuria:** Excessive glucose in the blood leads to excessive glucose in the kidney filtrate where it acts as an osmotic diuretic

- **Polydipsia:** in response to dehydration

- **Polyphagia (excessive hunger)**

- When hyperglycemia becomes excessive, the person begins to feel nauseated

- This precipitates the fight-or-flight response.

- This response results, in all the reactions that normally occur in the hypoglycemic (fasting) state to make glucose available:
  - Glycogenolysis
  - Lipolysis (breakdown of fat)
  - and gluconeogenesis

- When sugars cannot be used as cellular fuel, more fats are mobilized, resulting in high fatty acid levels in the blood, a condition called lipidemia

- In severe cases of DM, blood levels of fatty acids and their metabolites (acetoacetic acid, acetone, and others) rise dramatically (Ketoacidosis)

Consequences of Untreated ketoacidosis

- It disrupts heart activity and oxygen transport
- Causes severe depression of the nervous system
- leads to coma and death

The Gonads

Ovaries

- Oval organs located in the female's abdominopelvic cavity.

- Besides producing ova, or eggs, the ovaries produce several hormones, most importantly estrogens and progesterone

Physiological functions of the ovaries

- **Alone, the estrogens are responsible for:**
  - Maturation of the reproductive organs
  - The appearance of the secondary sex characteristics of females at puberty.

- **Acting with progesterone it promotes :**
  - Breast development and
  - Cyclic changes in the uterine mucosa

Male *testes*

- Located in an extra-abdominal skin pouch called the scrotum

- They produce sperm and male sex hormones, primarily **testosterone**

Physiological functions testosterone:

- Maturation of the male reproductive organs
- The appearance of secondary sex characteristics and sex drive
- Necessary for normal sperm production
- Maintenance of the reproductive organs in their mature functional state in adult males

Table 16.5 Selected Examples of Hormones Produced by Organs Other Than the Major Endocrine Organs

SOURCE	HORMONE	CHEMICAL COMPOSITION	TRIGGER	TARGET ORGAN AND EFFECTS
Adipose tissue	Leptin	Peptide	Secretion proportional to fat stores; increased by nutrient uptake	Brain: suppresses appetite; increases energy expenditure
Adipose tissue	Resistin, adiponectin	Peptides	Secretion proportional to fat stores for resistin, inversely proportional for adiponectin	Fat, muscle, liver: resistin antagonizes insulin's action and adiponectin enhances it
Gastrointestinal (GI) tract mucosa				
▪ Stomach	Gastrin	Peptide	Secreted in response to food	Stomach: stimulates glands to release hydrochloric acid (HCl)
▪ Stomach	Ghrelin	Peptide	Secreted in response to fasting	Hypothalamus and pituitary: stimulates food intake and GH release
▪ Duodenum (of small intestine)	Secretin	Peptide	Secreted in response to food	Pancreas and liver: stimulates release of bicarbonate-rich juice Stomach: inhibits secretory activity
▪ Duodenum	Cholecystokinin (CCK)	Peptide	Secreted in response to food	Pancreas: stimulates release of enzyme-rich juice Gallbladder: stimulates expulsion of stored bile Hepatopancreatic sphincter: causes sphincter to relax, allowing bile and pancreatic juice to enter duodenum
▪ Duodenum (and other gut regions)	Incretins [glucose-dependent insulinotropic peptide (GIP) and glucagon-like peptide 1 (GLP-1)]	Peptide	Secreted in response to glucose in intestinal lumen	Pancreas: enhances glucose-dependent release of insulin and inhibition of glucagon release
Heart (atria)	Atrial natriuretic peptide (ANP)	Peptide	Secreted in response to stretching of atria (by rising blood pressure)	Kidney: inhibits sodium ion reabsorption and renin release Adrenal cortex: inhibits secretion of aldosterone; decreases blood pressure
Kidney	Erythropoietin (EPO)	Glycoprotein	Secreted in response to hypoxia	Red bone marrow: stimulates production of red blood cells
Skeleton	Osteocalcin	Peptide	Unknown; insulin promotes its activation	Increases insulin production and insulin sensitivity
Skin (epidermal cells)	Cholecalciferol (provitamin D_3)	Steroid	Activated by the kidneys to active vitamin D_3 (calcitriol) in response to parathyroid hormone	Intestine: stimulates active transport of dietary calcium across cell membranes of small intestine
Thymus	Thymulin, thymopoietins, thymosins	Peptides	Unknown	Mostly act locally as paracrines; involved in T lymphocyte development and in immune responses

Table 16.3 Adrenal Gland Hormones: Summary of Regulation and Effects

HORMONE	REGULATION OF RELEASE	TARGET ORGAN AND EFFECTS	EFFECTS OF HYPERSECRETION ↑ AND HYPOSECRETION ↓
Adrenocortical Hormones			
Mineralocorticoids (chiefly aldosterone)	**Stimulated** by renin-angiotensin-aldosterone mechanism (activated by decreasing blood volume or blood pressure), elevated blood K^+ levels, and ACTH (minor influence) **Inhibited** by increased blood volume and pressure, and decreased blood K^+ levels	Kidneys: increase blood levels of Na^+ and decrease blood levels of K^+; since water reabsorption accompanies sodium retention, blood volume and blood pressure rise	↑ Aldosteronism ↓ Addison's disease
Glucocorticoids (chiefly cortisol)	**Stimulated** by ACTH **Inhibited** by feedback inhibition exerted by cortisol	Body cells: promote gluconeogenesis and hyperglycemia; mobilize fats for energy metabolism; stimulate protein catabolism; assist body to resist stressors; depress inflammatory and immune responses	↑ Cushing's syndrome ↓ Addison's disease
Gonadocorticoids (chiefly androgens, converted to testosterone or estrogens after release)	**Stimulated** by ACTH; mechanism of inhibition incompletely understood, but feedback inhibition not seen	Insignificant effects in males; contributes to female libido; development of pubic and axillary hair in females; source of estrogen after menopause	↑ Masculinization of females (adrenogenital syndrome) ↓ No effects known
Adrenal Medullary Hormones			
Catecholamines (epinephrine and norepinephrine)	**Stimulated** by preganglionic fibers of the sympathetic nervous system	Sympathetic nervous system target organs: effects mimic sympathetic nervous system activation; increase heart rate and metabolic rate; increase blood pressure by promoting vasoconstriction	↑ Prolonged fight-or-flight response; hypertension ↓ Unimportant

Table 16.1 Pituitary Hormones: Summary of Regulation and Effects

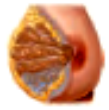
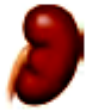
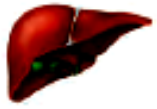
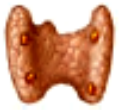
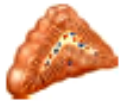
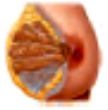
HORMONE (CHEMICAL STRUCTURE AND CELL TYPE)	REGULATION OF RELEASE	TARGET ORGAN AND EFFECTS	EFFECTS OF HYPOSECRETION ↓ AND HYPERSECRETION ↑
Posterior Pituitary Hormones (Made by Hypothalamic Neurons and Stored in Posterior Pituitary			
			
Oxytocin (Peptide, mostly from neurons in paraventricular nucleus of hypothalamus)	**Stimulated** by impulses from hypothalamic neurons in response to cervical/uterine stretching and suckling of infant at breast **Inhibited** by lack of appropriate neural stimuli	  Uterus: stimulates uterine contractions; initiates labor Breast: initiates milk ejection	Unknown
Antidiuretic hormone (ADH) or vasopressin (Peptide, mostly from neurons in supraoptic nucleus of hypothalamus)	**Stimulated** by impulses from hypothalamic neurons in response to increased blood solute concentration or decreased blood volume; also stimulated by pain, some drugs, low blood pressure **Inhibited** by adequate hydration of the body and by alcohol	 Kidneys: stimulate kidney tubule cells to reabsorb water	↓ Diabetes insipidus ↑ Syndrome of inappropriate ADH secretion (SIADH)
Anterior Pituitary Hormones			
			
Growth hormone (GH) (Protein, somatotropic cells)	**Stimulated** by GHRH* release, which is triggered by low blood levels of GH as well as by a number of secondary triggers including hypoglycemia, increases in blood levels of amino acids, low levels of fatty acids, exercise, and other types of stressors **Inhibited** by feedback inhibition exerted by GH and IGFs, and by hyperglycemia, hyperlipidemia, obesity, and emotional deprivation via either increased GHIH* (somatostatin) or decreased GHRH* release	   Liver, muscle, bone, cartilage, and other tissues: anabolic hormone; stimulates somatic growth; mobilizes fats; spares glucose Growth-promoting effects mediated indirectly by IGFs	↓ Pituitary dwarfism in children ↑ Gigantism in children; acromegaly in adults

Table 16.1 *(continued)*

HORMONE (CHEMICAL STRUCTURE AND CELL TYPE)	REGULATION OF RELEASE	TARGET ORGAN AND EFFECTS	EFFECTS OF HYPOSECRETION ↓ AND HYPERSECRETION ↑
Thyroid-stimulating hormone (TSH) (Glycoprotein, thyrotropic cells)	**Stimulated** by TRH* and in infants indirectly by cold temperature **Inhibited** by feedback inhibition exerted by thyroid hormones on anterior pituitary and hypothalamus and by GHIH*	 Thyroid gland: stimulates thyroid gland to release thyroid hormones	↓ Cretinism in children; myxedema in adults ↑ Hyperthyroidism; effects similar to those of Graves' disease, in which antibodies mimic TSH
Adrenocorticotropic hormone (ACTH) (Peptide, corticotropic cells)	**Stimulated** by CRH*; stimuli that increase CRH release include fever, hypoglycemia, and other stressors **Inhibited** by feedback inhibition exerted by glucocorticoids	 Adrenal cortex: promotes release of glucocorticoids and androgens (mineralocorticoids to a lesser extent)	↓ Rare ↑ Cushing's disease
Follicle-stimulating hormone (FSH) (Glycoprotein, gonadotropic cells)	**Stimulated** by GnRH* **Inhibited** by feedback inhibition exerted by inhibin, and estrogen in females and testosterone in males	 Ovaries and testes: in females, stimulates ovarian follicle maturation and estrogen production; in males, stimulates sperm production	↓ Failure of sexual maturation ↑ No important effects
Luteinizing hormone (LH) (Glycoprotein, gonadotropic cells)	**Stimulated** by GnRH* **Inhibited** by feedback inhibition exerted by estrogen and progesterone in females and testosterone in males	 Ovaries and testes: in females, triggers ovulation and stimulates ovarian production of estrogen and progesterone; in males, promotes testosterone production	As for FSH
Prolactin (PRL) (Protein, prolactin cells)	**Stimulated** by decreased PIH*; release enhanced by estrogens, birth control pills, breast-feeding, and dopamine-blocking drugs **Inhibited** by PIH* (dopamine)	 Breast secretory tissue: promotes lactation	↓ Poor milk production in nursing women ↑ Inappropriate milk production (galactorrhea); cessation of menses in females; impotence in males

*Indicates hypothalamic releasing and inhibiting hormones: GHRH – growth hormone–releasing hormone; GHIH – growth hormone–inhibiting hormone; TRH – thyrotropin-releasing hormone; CRH – corticotropin-releasing hormone; GnRH – gonadotropin-releasing hormone; PIH – prolactin-inhibiting hormone