ANATOMY AND PHYSIOLOGY OF ENDOCRINE SYSTEM

Course Name: Anatomy and Physiology 2

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Introduction

- The nervous and endocrine systems act together to coordinate functions of all body systems.
- The nervous system acts through nerve impulses (action potentials) conducted along axons of neurons. At synapses, nerve impulses trigger the release of mediator (messenger) molecules called *neurotransmitters*.
- The endocrine system also controls body activities by releasing mediators, called *hormones*
- The means of control of the two systems are very different.

Introduction (continued)

- 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.

- Several mediators act as both neurotransmitters and hormones.
- One familiar example is norepinephrine, which is released as a neurotransmitter by sympathetic postganglionic neurons and as a hormone by chromaffin cells of the adrenal medullae.

What is an Endocrine Gland?

- **Exocrine glands** (sudoriferous, sebaceous, mucous, and digestive) secrete their products through ducts into body cavities or onto body surfaces.

- **Endocrine glands** (EN-do¯-krin; *endo-* within) secrete their products (hormones) into the interstitial fluid surrounding the secretory cells rather than into ducts. From the interstitial fluid, hormones diffuse into blood capillaries and blood carries them to target cells throughout the body.

- Because of their dependence on the cardiovascular system to distribute their products, endocrine glands are some of the most vascular tissues of the body.

- Considering that most hormones are required in very small amounts, circulating levels typically are low.

Comparison of Control by the Nervous and Endocrine Systems

The endocrine system consists of

1- Endocrine glands (pituitary, thyroid, parathyroid, adrenal, and pineal glands)

2- Other hormone-secreting tissues (hypothalamus, thymus, pancreas, ovaries, testes, kidneys, stomach, liver, small intestine, skin, heart, adipose tissue, and placenta).

- ✓The nervous system controls homeostasis through nerve impulses and neurotransmitters, which act locally and quickly.
- ✓The endocrine system uses hormones, which act more slowly in distant parts of the body.
- ✓The nervous system controls neurons, muscle cells, and glandular cells.

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.**

Hormone Activity

- Hormones affect only specific target cells that have receptors to recognize (bind) a given hormone.

- The **number** of hormone receptors may decrease (down-regulation) or increase (up-regulation).

- Circulating hormones enter the bloodstream; While local hormones (without first entering the bloodstream) are called paracrines (act locally on neighbouring cells), and autocrines (act locally on the same cell that secreted them).

Chemically, hormones are either

1- Lipid-soluble (steroids, thyroid hormones, and nitric oxide); most lipid-soluble hormones are bound to transport proteins synthesized by the liver.

2- Water-soluble (amines; peptides, proteins, and glycoproteins; and eicosanoids). Water-soluble hormone molecules circulate in the watery blood plasma in a “free” form (not attached to plasma proteins).

Mechanisms of Hormone Action

- Lipid-soluble steroid hormones and thyroid hormones affect cell function by altering gene expression

→ (Lipid-soluble hormones bind to receptors inside target cells.)

- Water-soluble hormones alter cell function by activating plasma membrane receptors, which elicit production of a second messenger that activates various enzymes inside the cell

→ (Water-soluble hormones bind to receptors embedded in the plasma membranes of target cells.)

Hormone Interactions

Hormonal interactions can have three types of effects:

→ *Permissive, synergistic, or antagonistic.*

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,

(3) Influences exerted by other hormones.

→A target cell responds more vigorously when the level of a hormone rises or when it has more receptors (upregulation).

Hormone Interactions (continued)
1- Permissive effect

- *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**.
- For example, epinephrine alone only weakly stimulates lipolysis (the breakdown of triglycerides), but when small amounts of thyroid hormones (T3 and T4) are present, the same amount of epinephrine stimulates lipolysis much more powerfully.
- Sometimes the permissive hormone increases the number of receptors for the other hormone, and sometimes it promotes the synthesis of an enzyme required for the expression of the other hormone's effects.

Hormone Interactions (continued)
2- Synergistic effect
3- Antagonistic 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**.
- For example, normal development of oocytes in the ovaries requires both follicle-stimulating hormone from the anterior pituitary and estrogens from the ovaries. Neither hormone alone is sufficient.

- When one hormone opposes the actions of another hormone, the two hormones are said to have **antagonistic effects**.
- An example of an antagonistic pair of hormones is insulin, which promotes synthesis of glycogen by liver cells, and glucagon, which stimulates breakdown of glycogen in the liver

Homeostatic Control of Hormone Secretion

Hormone secretion is controlled by:

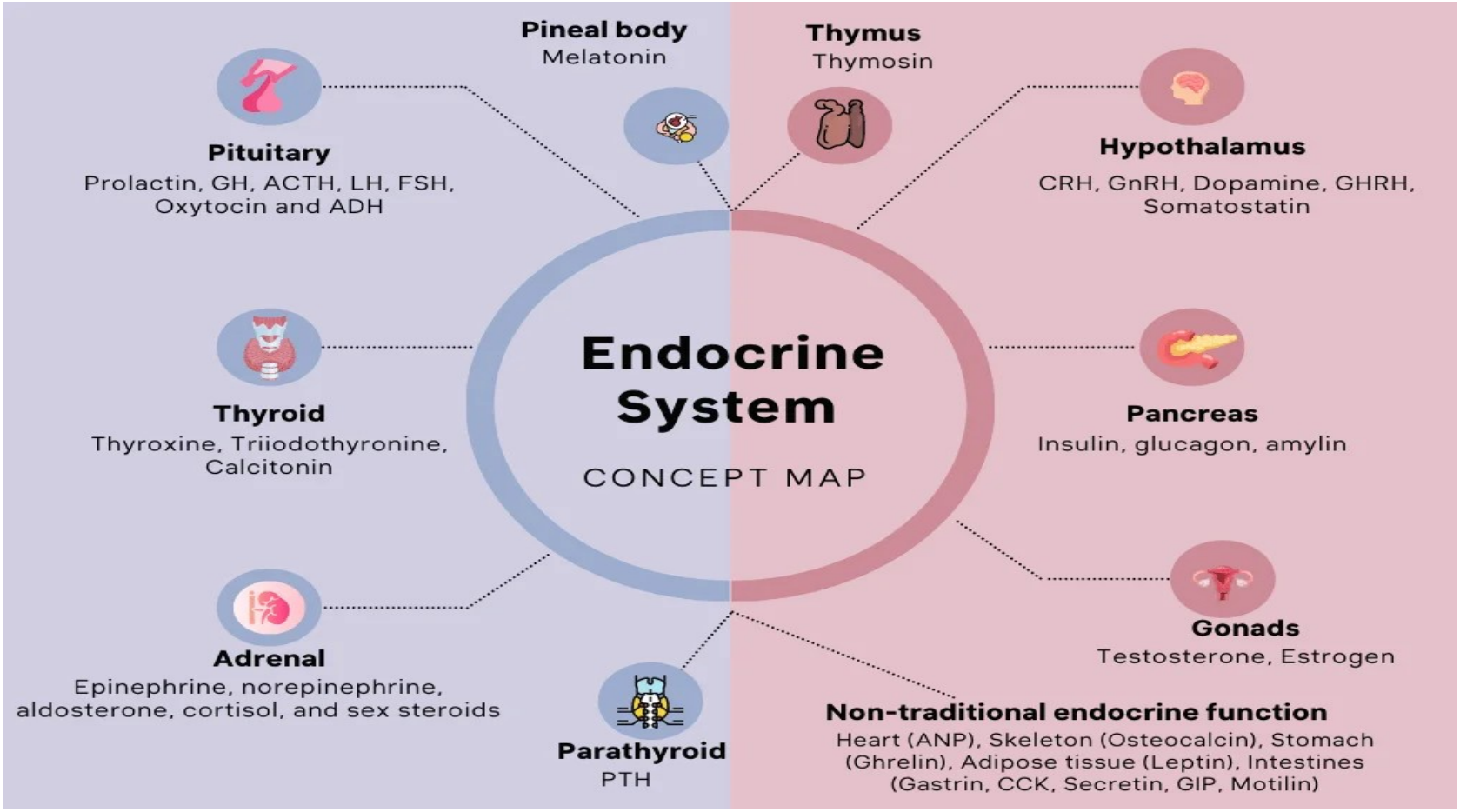
1- Signals from the nervous system,

2- Chemical changes in blood,

3- Other hormones.

- ✓**MOSTLY, negative feedback systems regulate the secretion of many hormones.**
- ✓Few operate via positive feedback → example, during childbirth, the hormone oxytocin stimulates contractions of the uterus, and uterine contractions in turn stimulate more oxytocin release, a positive feedback effect

GLANDS



https://myendoconsult.com/learn/endocrine-system-concept-map/

1. Hypothalamus
2 . Pituitary Gland

- ✓**The hypothalamus** is the major integrating link between the nervous and endocrine systems.
- ✓The hypothalamus and pituitary gland regulate virtually all aspects of growth, development, metabolism, and homeostasis.
- ✓**The pituitary gland** is located in the hypophyseal fossa and is divided into two main portions: the anterior pituitary (glandular portion) and the posterior pituitary (nervous portion).
- ✓Secretion **of anterior pituitary** hormones is stimulated by releasing hormones and suppressed by inhibiting hormones from the hypothalamus.
- ✓The blood supply to the anterior pituitary is from the superior hypophyseal arteries. Hypothalamic releasing and inhibiting hormones enter the primary plexus and flow to the secondary plexus in the anterior pituitary by the hypophyseal portal **veins**.
- ✓**The posterior pituitary** contains axon terminals of neurosecretory cells whose cell bodies are in the hypothalamus.
- ✓Hormones made by the hypothalamus and stored in the posterior 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.

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 insulin-like 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 and Testis	➢ In <u>females</u>, initiates development of oocytes and induces ovarian secretion of estrogens. ➢ In <u>males</u>, stimulates testes to produce sperm.

Summary of the Principal Actions of Anterior Pituitary Hormones (CONTINUED)		
HORMONE	**TARGET TISSUES**	**PRINCIPAL ACTIONS**
Luteinizing hormone (LH)	Ovary and 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	Adrenal cortex	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.

Summary of Posterior Pituitary Hormones

HORMONE AND TARGET TISSUES	CONTROL OF SECRETION	PRINCIPAL ACTIONS
Oxytocin (OT) 1. Uterus 2. Mammary glands	Neurosecretory cells of hypothalamus secrete OT in response to uterine distension and lactation.	1. Stimulates contraction of smooth muscle cells of uterus during childbirth; 2. Stimulates contraction of myoepithelial cells in mammary glands to cause milk ejection.
Antidiuretic hormone (ADH) or vasopressin 1. Kidneys 2. Sudoriferous (sweat) glands 3. 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: 1. Decreasing urine volume; 2. Decreases water loss through perspiration; 3. Raises blood pressure by constricting arterioles.

3. Thyroid Gland

- ✓The thyroid gland is located inferior to the larynx.
- ✓It consists of thyroid *follicles* composed of follicular cells, which secrete the thyroid hormones thyroxine (T4) and triiodothyronine (T3), and *parafollicular* cells, which secrete calcitonin (CT)

Thyroid hormones

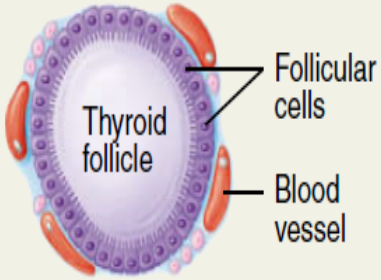
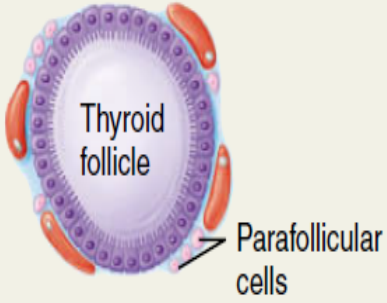
- ✓Are synthesized from iodine and tyrosine within thyroglobulin (TGB).
- ✓They are transported in the blood bound to plasma proteins, mostly thyroxine-binding globulin (TBG).
- ✓Secretion is controlled by TRH from the hypothalamus and thyroid-stimulating hormone (TSH) from the anterior pituitary.
- ✓Thyroid hormones regulate oxygen use and metabolic rate, cellular metabolism, and growth and development.

Calcitonin (CT)

- ✓Can lower the blood level of calcium ions (Ca2) and promote deposition of Ca2 into bone matrix.
- ✓Secretion of CT is controlled by the Ca2 level in the blood.

TABLE 18.6

Summary of Thyroid Gland Hormones

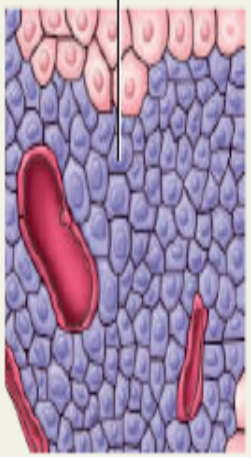
HORMONE AND SOURCE	CONTROL OF SECRETION	PRINCIPAL ACTIONS
T_3 (triiodothyronine) and T_4 (thyroxine) or thyroid hormones from follicular cells 	Secretion is increased by thyrotropin-releasing hormone (TRH), which stimulates release of thyroid-stimulating hormone (TSH) in response to low thyroid hormone 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.

4. Parathyroid Glands

- ✓The parathyroid glands are embedded in the **posterior** surfaces of the **lateral lobes** of the thyroid gland.
- ✓They consist of chief cells and oxyphil cells.
- ✓**Parathyroid hormone (PTH)** regulates the homeostasis of calcium, magnesium, and phosphate ions by increasing blood calcium and magnesium levels and decreasing blood phosphate levels.
- ✓PTH secretion is controlled by the level of calcium in the blood.

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.

5. Adrenal Glands

- ✓ The adrenal glands are located superior to the kidneys. They consist of an outer adrenal cortex and inner adrenal medulla.

The adrenal cortex is divided into a zona glomerulosa, a zona fasciculata, and a zona reticularis;

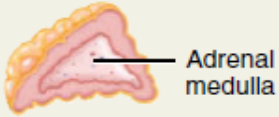
- ✓ Cortical secretions include mineralocorticoids, glucocorticoids, and androgens.
- ✓ *Mineralocorticoids* (mainly aldosterone) increase sodium and water reabsorption and decrease potassium reabsorption. Secretion is controlled by the renin–angiotensin–aldosterone (RAA) pathway and by K level in the blood.
- ✓ *Glucocorticoids* (mainly cortisol) promote protein breakdown, gluconeogenesis, and lipolysis; help resist stress; and serve as anti-inflammatory substances. Their secretion is controlled by ACTH.
- ✓ *Androgens* secreted by the adrenal cortex stimulate growth of axillary and pubic hair, aid the prepubertal growth spurt, and contribute to libido.

The adrenal medulla consists of chromaffin cells and large blood vessels.

- ✓ The adrenal medulla secretes epinephrine and norepinephrine (NE), which are released during stress and produce effects similar to sympathetic responses.

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.
		

6. Pancreatic Islets

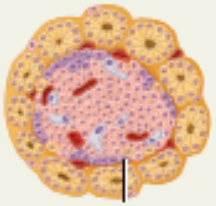
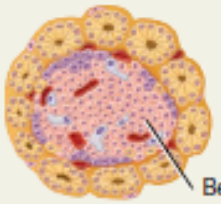
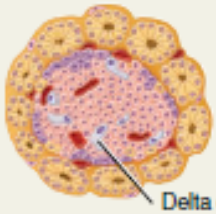
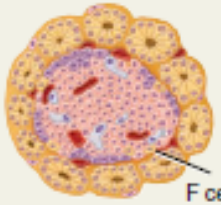
- ✓The pancreas lies in the curve of the duodenum.
- ✓It has both endocrine and exocrine functions.

- ✓**The endocrine portion** consists of pancreatic islets or islets of Langerhans, made up of four types of cells: alpha, beta, delta, and F cells.

- ✓Alpha cells secrete glucagon, beta cells secrete insulin, delta cells secrete somatostatin, and F cells secrete pancreatic polypeptide.
- ✓Glucagon increases blood glucose level; insulin decreases blood glucose level. Secretion of both hormones is controlled by the level of glucose in the blood.

TABLE 18.9

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.

7. Ovaries
8. Testes

The ovaries

- ✓Located in the pelvic cavity and produce estrogens, progesterone, and inhibin.
- ✓These sex hormones govern the development and maintenance of female secondary sex characteristics, reproductive cycles, pregnancy, lactation, and normal female reproductive functions.

The testes

- ✓Lie inside the scrotum and produce testosterone and inhibin.
- ✓These sex hormones govern the development and maintenance of male secondary sex characteristics and normal male reproductive functions.

TABLE 18.10

Summary of Hormones of the Ovaries and Testes

HORMONE	PRINCIPAL ACTIONS
OVARIAN HORMONES	
Estrogens and progesterone  Ovary	Together with gonadotropic hormones of anterior pituitary, regulate female reproductive cycle, maintain pregnancy, prepare mammary glands for lactation, and promote development and maintenance of female secondary sex characteristics.
Relaxin (RLX)	Increases flexibility of pubic symphysis during pregnancy; helps dilate uterine cervix during labor and delivery.
Inhibin	Inhibits secretion of FSH from anterior pituitary.
TESTICULAR HORMONES	
Testosterone  Testis	Stimulates descent of testes before birth; regulates sperm production; promotes development and maintenance of male secondary sex characteristics.
Inhibin	Inhibits secretion of FSH from anterior pituitary.

9. Pineal Gland
10.Thymus Gland

The pineal gland

- ✓It is attached to the roof of the third ventricle of the brain.
- ✓It consists of secretory cells called pinealocytes, neuroglia, and endings of sympathetic postganglionic axons.
- ✓The pineal gland secretes melatonin, which contributes to setting the body's biological clock (controlled in the suprachiasmatic nucleus).
- ✓During sleep, plasma levels of melatonin increase.

The thymus gland

- ✓Secretes several hormones related to immunity.
- ✓Thymosin, thymic humoral factor (THF), thymic factor (TF), and thymopoietin promote the maturation of T cells.

Other Endocrine Tissues and Organs, Eicosanoids, and Growth Factors

- ✓Body tissues other than those normally classified as endocrine glands contain endocrine tissue and secrete hormones; they include the gastrointestinal tract, placenta, kidneys, skin, and heart.
- ✓Prostaglandins and leukotrienes are eicosanoids that act as local hormones in most body tissues.
- ✓Growth factors are local hormones that stimulate cell growth and division.

TABLE 18.11

Summary of Hormones Produced by Other Organs and Tissues That Contain Endocrine Cells

HORMONE	PRINCIPAL ACTIONS
GASTROINTESTINAL TRACT	
Gastrin	Promotes secretion of gastric juice; increases movements of the stomach.
Glucose-dependent insulinotropic peptide (GIP)	Stimulates release of insulin by pancreatic beta cells.
Secretin	Stimulates secretion of pancreatic juice and bile.
Cholecystokinin (CCK)	Stimulates secretion of pancreatic juice; regulates release of bile from gallbladder; causes feeling of fullness after eating.
PLACENTA	
Human chorionic gonadotropin (hCG)	Stimulates corpus luteum in ovary to continue production of estrogens and progesterone to maintain pregnancy.
Estrogens and progesterone	Maintain pregnancy; help prepare mammary glands to secrete milk.
Human chorionic somatomammotropin (hCS)	Stimulates development of mammary glands for lactation.
KIDNEYS	
Renin	Part of reaction sequence that raises blood pressure by bringing about vasoconstriction and secretion of aldosterone.
Erythropoietin (EPO)	Increases rate of red blood cell formation.
Calcitriol* (active form of vitamin D)	Aids in absorption of dietary calcium and phosphorus.
HEART	
Atrial natriuretic peptide (ANP)	Decreases blood pressure.
ADIPOSE TISSUE	
Leptin	Suppresses appetite; may increase FSH and LH activity.

*Synthesis begins in the skin, continues in the liver, and ends in the kidneys.

Aging and the Endocrine System

- ✓ Although some endocrine glands shrink as we get older, their performance may or may not be compromised.
- ✓ Production of human growth hormone, thyroid hormones, cortisol, aldosterone, and estrogens decreases with advancing age.
- ✓ With aging, the blood levels of TSH, LH, FSH, and PTH rise.
- ✓ The pancreas releases insulin more slowly with age, and receptor sensitivity to glucose declines.
- ✓ After puberty, thymus size begins to decrease, and thymic tissue is replaced by adipose and areolar connective tissue.

Reference:

1. Principles of Anatomy and Physiology, 16th Edition by Gerard J. Tortora, Bryan H. Derrickson, Publisher: Wiley, (2020), ISBN: 978-1-119-66268-6