10

The Endocrine System
The Endocrine System

OUTLINE:

- Functions and Mechanisms of Hormones
- Hypothalamus and Pituitary Gland
- Thyroid Gland
- Parathyroid Glands
- Adrenal Glands
- Pancreas
- Thymus Gland
- Pineal Gland
- Locally Acting Chemical Messengers
Functions and Mechanisms of Hormones

- The main function of the endocrine system is to coordinate body systems and maintain homeostasis.
  - The endocrine system
    - Works with the nervous system
    - Is a more leisurely system of communication than the nervous system
    - Endocrine glands contain secretory cells that release their products, called hormones, into extracellular fluid where they diffuse into the bloodstream
    - Hormones are one type of chemical messenger of the body
Figure 10.1 An endocrine gland.

The hormone diffuses from the extracellular fluid into the bloodstream.

The hormone travels throughout the body.

Capillary

Hormone
The major endocrine glands are
- Pituitary
- Thyroid
- Parathyroids
- Adrenals
- Pineal
Functions and Mechanisms of Hormones

- Organs with some endocrine tissue include
  - Hypothalamus
  - Thymus
  - Pancreas
  - Ovaries
  - Testes
  - Heart
  - Placenta
  - Stomach
  - Intestines
  - Kidneys
Figure 10.2 The endocrine system.
Functions and Mechanisms of Hormones

- Hormones travel in the bloodstream

- Although hormones come into contact with virtually all cells, they typically affect a particular type of cell, called a target cell.

- Target cells have receptors, which are protein molecules that recognize and bind specific hormones.

- Cells other than target cells lack the correct receptors and are unaffected by the hormone.

- The mechanism by which a hormone influences target cells depends on the chemical makeup of the hormone.
Functions and Mechanisms of Hormones

- Two main types of hormones
  - Lipid-soluble
  - Water-soluble
- Lipid-soluble hormones include steroid hormones
  - Derived from cholesterol
Functions and Mechanisms of Hormones

- The main organs and glands that secrete steroid hormones are
  - Ovaries
  - Testes
  - Adrenal glands
Lipid-soluble hormones

- Move easily through any target cell’s plasma membrane
- Once inside the target cell, the steroid hormone combines with receptor molecules
- In the nucleus, the hormone-receptor complex attaches to DNA and activates certain genes to synthesize specific proteins
Figure 10.3 Mode of action of some lipid-soluble hormones.
Functions and Mechanisms of Hormones

- Water-soluble hormones
  - Made of amino acids
  - Cannot pass through the lipid bilayer of the plasma membrane
  - Considered first messengers
  - Exert their effects indirectly by binding to receptors on the surface of the target cell
  - This stimulates second messengers within the cell that carry out the effect of the hormone
Functions and Mechanisms of Hormones

- One common second messenger is cyclic adenosine monophosphate (cAMP)
  - Hormones bind to a receptor site on the target cell membrane, prompting the conversion of ATP to cAMP within the cell
  - Then cAMP activates an enzyme within the cell (a protein kinase), which in turn activates another enzyme, and so on
Figure 10.4 *Mode of action of some water-soluble hormones.*
Functions and Mechanisms of Hormones

- Summary of lipid-soluble versus water-soluble hormones
  - Lipid-soluble hormones move into a cell and stimulate the synthesis of proteins
  - Water-soluble proteins activate proteins already present in the cell, and they do this without ever entering the cell
- Research now indicates that steroid hormones may have additional mechanisms of action, including interacting with membrane receptors
How Hormones Influence Target Cells

The mechanisms by which hormones exert their characteristic effects on target cells is dependent upon the type of hormone and the type of cell that is responsive to that hormone. Lipid-soluble hormones usually act inside the cell, while lipid-insoluble hormones act at the cell surface. This tutorial contrasts these two modes of hormone action.

Press "PLAY" to begin Animation.
Feedback Mechanisms and Secretion of Hormones

- Negative feedback mechanism
  - Increased blood level of the hormone inhibits its further release
  - Alternatively, some endocrine glands are sensitive to the particular condition they regulate rather than to the level of hormone they produce
    - Example: the pancreas stops secreting insulin when levels of blood glucose decline
Feedback Mechanisms and Secretion of Hormones

Hormonal Feedback Loops

Hormones are chemical signals produced by endocrine glands that circulate through body fluids and affect distant target cells. This tutorial describes the different types of feedback loop mechanisms that control hormonal levels in the body to maintain homeostasis.

Press "PLAY" to begin Animation.
Feedback Mechanisms and Secretion of Hormones

- Positive feedback mechanism
  - Outcome of a process further stimulates the process
  - Example: oxytocin and the uterine contractions of childbirth
  - Less common than negative feedback
Figure 10.5 **The positive feedback cycle.**

- **Step 1:** The head of the baby stretches the cervix of the mother’s uterus.
- **Step 2:** In response to the stretching, nerve impulses are sent to the hypothalamus.
- **Step 3:** The hypothalamus signals the posterior pituitary to release OT.
- **Step 4:** The posterior pituitary releases OT, which travels in the blood to muscles of the uterus.
- **Step 5:** The uterus responds to OT by contracting more vigorously.
- **Step 6:** Uterine contractions increase dilation of the cervix, which stimulates further release of OT, which stimulates even more frequent and vigorous contractions.
- At birth, stretching of the cervix lessens and the positive feedback cycle is broken.
Interactions Between Hormones

- **Antagonistic**
  - The effect of one hormone opposes that of another hormone

- **Synergistic**
  - The response of a tissue to a combination of hormones is much greater than its response to either individual hormone

- **Permissive**
  - One hormone must be present for another hormone to exert its effects
Hypothalamus and Pituitary Gland

- Pituitary gland
  - Located at the base of the brain
  - Consists of two lobes
    - Anterior: circulatory connection to hypothalamus
    - Posterior: neural connection to hypothalamus
  - The anterior pituitary is connected to the hypothalamus, which synthesizes and secretes releasing and inhibiting hormones
    - Releasing hormones stimulate hormone secretion by the anterior pituitary
    - Inhibiting hormones inhibit hormone secretion by the anterior pituitary
Figure 10.6 The two lobes of the pituitary gland and the hormones they secrete.
Hypothalamus and Pituitary Gland

- The anterior pituitary gland synthesizes and secretes six main hormones:
  - Growth hormone (GH)
  - Prolactin (PRL)
  - Thyroid-stimulating hormone (TSH)
  - Adrenocorticotropic hormone (ACTH)
  - Follicle-stimulating hormone (FSH)
  - Luteinizing hormone (LH)
Anterior Lobe

- Two hormones of the hypothalamus regulate the synthesis and release of GH
  - Growth hormone-releasing hormone (GHRH) stimulates the release of GH
  - Growth hormone-inhibiting hormone (GHIH) inhibits the release of GH
Anterior Lobe

- Growth hormone (GH): stimulates the rate of cell division and an increase in cell size
  - Target cells include bone, muscle, and cartilage
- Disorders
  - Gigantism: abnormally high production of GH in childhood, when the bones are still capable of lengthening
  - Acromegaly: high levels of GH in adulthood, when the bones can thicken but not lengthen
  - Pituitary dwarfism: insufficient production of GH in childhood. In contrast to other forms of dwarfism, can be treated by administering GH in childhood
Figure 10.7 Robert Wadlow, a pituitary giant.
Figure 10.8 Acromegaly. Excess secretion of GH in adulthood.
Figure 10.9 Pituitary dwarfism.
Anterior Lobe

- Prolactin (PRL)
  - In females, stimulates the mammary glands to produce milk
    - In excess can cause infertility and lactation when birth has not occurred
  - In males, involved in the production of mature sperm in the testes
    - In excess can lead to sterility
Anterior Lobe

- Tropic hormones
  - Hormones that influence the secretion of hormones by other glands
  - Include the following hormones of the anterior pituitary
    - TSH
    - ACTH
    - FSH
    - LH
Anterior Lobe

- Thyroid-stimulating hormone (TSH)
  - Acts on the thyroid gland to stimulate the synthesis and release of thyroid hormones

- Adrenocorticotropic hormone (ACTH)
  - Controls the synthesis and secretion of glucocorticoid hormones from the cortex of the adrenal glands

- Follicle-stimulating hormone (FSH)
  - In females, promotes development of egg cells and secretion of estrogen
  - In males, promotes the production of sperm
Anterior Lobe

- Luteinizing hormone (LH)
  - In females, causes ovulation and the secretion of estrogen and progesterone
  - In males, stimulates the production and secretion of testosterone
Posterior Lobe

- Cells within the posterior lobe of the pituitary gland do not produce any hormones
  - Neurons of the hypothalamus manufacture antidiuretic hormone (ADH) and oxytocin (OT)
  - ADH and OT travel down the nerve cells (neurosecretory cells) into the posterior pituitary, where they are stored and released
The Hypothalamus and Pituitary

The hypothalamus and the pituitary gland work together to coordinate many of the actions of the endocrine system. In this activity, you will learn how the hypothalamus controls hormonal release by the pituitary gland.

Press "PLAY" to begin Animation.
Posterior Lobe

- Antidiuretic hormone (ADH or vasopressin)
  - Causes the kidneys to remove water from the fluid destined to become urine
  - A deficiency of ADH results in diabetes insipidus
    - Excessive urine production and dehydration
    - Can be treated by administering ADH in a nasal spray

- Oxytocin (OT)
  - In females, stimulates the uterine contractions of childbirth and milk ejection from the mammary glands
  - In males, may facilitate sexual behavior and the transport of sperm
Figure 10.10 The steps and role of oxytocin.

Step 1: Sucking by the infant stimulates nerve receptors in the nipple.

Step 2: The resulting impulses travel along nerves to the hypothalamus.

Step 3: The hypothalamus signals the posterior pituitary to release OT.

Step 4: OT travels via the bloodstream to the mammary glands.

Step 5: Milk is ejected from the mammary glands.
Thyroid Gland

- Shield-shaped structure at the front of the neck
  - Hormones produced
    - Thyroid hormone (TH)
    - Calcitonin (CT)
Thyroid Gland

- Thyroid hormone (TH)
  - Includes thyroxine ($T_4$) and triiodothyronine ($T_3$)
  - Produced in the follicular cells
- Broad effects
  - Regulates metabolic rate and production of heat
  - Maintains blood pressure
  - Promotes normal functioning of several organ systems
Figure 10.11 *Location and structure of the thyroid gland.*

(a) The thyroid gland lies over the trachea, just below the larynx.

(b) Diagram showing thyroid tissue. Follicular cells produce the precursor to thyroid hormone, and the parafollicular cells produce calcitonin.
Thyroid Gland

- Simple goiter
  - An enlarged thyroid gland
  - Can result from a diet deficient in iodine, which is needed for the production of TH
  - Can be treated by iodine supplements or administration of TH
Thyroid Gland

- Cretinism
  - Too little TH during fetal development or infancy
  - Dwarfism and delayed mental and sexual development
- Myxedema
  - Too little TH in adulthood
  - Fluid accumulation in facial tissues and a decrease in alertness, body temperature, and heart rate
Figure 10.12 *Disorders of the thyroid gland.*

(a) Simple goiter  
(b) Cretinism  
(c) Exophthalmos
Thyroid Gland

- **Graves’ disease**
  - Oversecretion of TH
  - An autoimmune disorder in which antibodies mimic the action of TSH
  
- **Symptoms include**
  - Increased metabolic rate and heart rate
  - Sweating, nervousness, and weight loss
  - Exophthalmos (protruding eyes from fluid accumulation)
Thyroid Gland

- Calcitonin (CT)
  - Produced by parafollicular cells
  - Lowers the level of calcium in the blood
    - Stimulates absorption of calcium by bone
    - Inhibits breakdown of bone
    - Increases excretion of calcium in the urine
Parathyroid Glands

- Parathyroid glands
  - Four small round masses at the back of the thyroid gland
  - Secrete parathyroid hormone (PTH, also called parathormone)
Parathyroid Glands

- **Parathyroid Hormone (PTH)**
  - Increases levels of calcium in the blood
    - Stimulates osteoclasts to break down bone, releasing calcium into the blood
    - Stimulates kidneys to remove calcium from the fluid destined to become urine, returning it to the blood
    - Stimulates rate at which calcium is absorbed from the gastrointestinal tract
    - Inhibits osteoblasts
Parathyroid Glands

- Undersecretion of PTH
  - Can result in nervousness and muscle spasms

- Oversecretion of PTH
  - Pulls calcium from bone tissue, causing weakened bones and elevated blood calcium levels
  - Can lead to kidney stones, calcium deposits in soft tissue, and decreased activity of the nervous system
Figure 10.13 Regulation of calcium levels in the blood.

- Blood calcium rises above normal:
  - Bones release calcium.
  - Kidneys reabsorb calcium.
  - Intestines absorb calcium.

- Normal Blood Calcium

- High Blood Calcium

- Low Blood Calcium

- Bones take up calcium.

- Blood calcium falls below normal.

- Parathyroid glands release PTH.
Adrenal Glands

- Located at the top of the kidneys
- Composed of two regions
  - Adrenal cortex (outer region) secretes
    - Gonadocorticoids
    - Glucocorticoids
    - Mineralocorticoids
  - Adrenal medulla (inner region) secretes
    - Epinephrine (adrenaline)
    - Norepinephrine (noradrenaline)
Figure 10.14 **Location and structure of an adrenal gland.**

(a) Each adrenal gland sits on top of a kidney.

(b) A section through the adrenal gland reveals two regions, the outer adrenal cortex and the inner adrenal medulla. These regions secrete different hormones.
Adrenal Glands

- **Gonadocorticoids: androgens and estrogens**
  - Secreted by the adrenal cortex in both males and females
- **Mineralocorticoids: mineral homeostasis and water balance**
  - **Aldosterone**
    - Acts on cells of the kidneys to
      - Increase reabsorption of sodium ions into the blood
      - Promote the excretion of potassium ions in the urine
Adrenal Glands

- Addison’s Disease
  - Caused by the undersecretion of cortisol and aldosterone
  - Appears to be an autoimmune disorder in which the cells of the adrenal cortex are perceived as foreign
  - Results in bronzing of the skin, weight loss, fatigue, electrolyte imbalance, poor appetite, and poor resistance to stress
  - May be caused by inadequate secretion of ACTH
Figure 10.15 *John F. Kennedy suffered from Addison’s disease.*
Adrenal Glands

- Glucocorticoids
  - Affect glucose homeostasis
  - Act on the liver to promote the conversion of fat and protein into intermediate substances that are eventually converted to glucose
  - Inhibit the inflammatory response
Adrenal Glands

- Cushing’s Syndrome
  - Characterized by redistribution of body fat and fluid accumulation in the face
  - Caused by prolonged exposure to high levels of cortisol
    - May result from
      - A tumor on either the adrenal cortex or anterior pituitary
      - The use of glucocorticoid hormones to treat asthma, lupus, or rheumatoid arthritis
Figure 10.16 Cushing’s syndrome.

(a) Patient with Cushing’s syndrome  
(b) Same patient after treatment
Adrenal Medulla

- Produces epinephrine (adrenaline) and norepinephrine (noradrenaline)
- Both of these hormones are used in our response to danger, preparing us for fight-or-flight
Adrenal Medulla

- Hormonal response to stress
- General Adaptation Syndrome (GAS)
  - A series of physiological adjustments made by our bodies in response to extreme and prolonged stress
    - Three phases
      - Alarm
      - Resistance
      - Exhaustion
Adrenal Medulla

- Hormonal response to stress
  - Alarm
    - Fight-or-flight response
  - Resistance
    - Glucocorticoids from adrenal cortex are the main hormones
    - Body’s protein and fat reserves mobilized
    - Body fluids conserved
  - Exhaustion
    - Organs are unable to meet the heavy demands of the resistance phase, and they begin to fail
Adrenal Medulla
Pancreas

- Located behind the stomach
- Endocrine cells occur in pancreatic islets (also called islets of Langerhans)
- Produces glucagon and insulin hormones
  - **Glucagon**
    - Increases glucose in the blood
    - Prompts the liver to convert glycogen to glucose and to form glucose from lactic acid and amino acids
Pancreas

- **Insulin**
  - Decreases glucose in the blood
  - Stimulates transport of glucose into muscle cells, white blood cells, and connective tissue cells
  - Inhibits the breakdown of glycogen to glucose
  - Prevents the conversion of amino acids and fatty acids to glucose
Figure 10.17 *Location and structure of the pancreas.*

(a) The pancreas is located behind the stomach. The pancreatic duct carries digestive enzymes, not hormones.

(b) Section of pancreatic tissue showing endocrine cells in clusters called pancreatic islets. Surrounding the islets are exocrine cells.
Figure 10.18 Regulation of glucose level in the blood.

- Pancreas secretes insulin.
- Liver stops breakdown of glycogen to glucose.
- Muscle cells take up glucose.
- Adipose tissue uses glucose to form fat.

Blood glucose rises above normal.
Blood glucose falls below normal.
Liver breaks down glycogen to glucose.
Pancreas secretes glucagon.

(after meals)
(between meals)
Pancreas

- Metabolic disorders
  - Diabetes mellitus
    - A group of metabolic disorders characterized by abnormally high levels of glucose in the blood
    - Caused by problems with either insulin production or insulin function
Thymus Gland

- Lies on top of the heart
- Secretes hormones that promote the maturation of T lymphocytes
  - Thymopoietin
  - Thymosin
Pineal Gland

- Located at the center of the brain
- Produces melatonin
  - Levels of circulating melatonin are greater at night than during daylight hours
  - The pineal gland receives input from the visual pathways
    - Light inhibits secretion of melatonin
  - Promotes sleep, reduces jet lag, may slow aging
Pineal Gland

- Too much melatonin can result in seasonal affective disorder (SAD)
  - Associated with winter and short days
  - Treatment includes repeated exposure to very bright light to inhibit melatonin secretion
Locally Acting Chemical Messengers

- Local signaling molecules act very quickly on adjacent cells
  - Neurotransmitters
  - Growth factors
  - Nitric oxide (NO)
  - Prostaglandins
    - Lipid molecules continually released by the plasma membranes of most cells
    - At least 16 different prostaglandin molecules function within the human body
Locally Acting Chemical Messengers

- Prostaglandins have very diverse effects and influence the following
  - Reproductive system (e.g., menstrual cramps)
  - Inflammatory response
  - Blood clotting
  - Body temperature
You Should Now Be Able To:

- Know the functions and mechanisms of hormones
- Know the main hormones and their actions for the main seven glands:
  - Hypothalamus and pituitary gland
  - Thyroid gland
  - Parathyroid glands
  - Adrenal glands
  - Pancreas
  - Thymus gland
  - Pineal gland
- Understand how chemical messengers locally act