The Endocrine System

Overview of the Endocrine System
Properties of the Endocrine System
• Regulates longer term metabolic processes
• Shares some features with nervous system
• Releases hormones from endocrine cells
  • Hormones are chemicals
  • Hormones alter metabolism of many cells
  • Release regulated by negative feedback
  • Hormones act on target cells

Overview of the Endocrine System
An Overview of the Endocrine System

Overview of the Endocrine System
The Structure of Hormones
• Three chemical families
  • Amino acid derivatives
    • E.g., epinephrine, thyroid hormones
  • Peptides and proteins
    • Chains of amino acids
    • E.g., insulin, ADH
  • Lipid derivatives
    • Steroids (e.g., testosterone)
    • Eicosanoids (e.g., prostaglandins)

Overview of the Endocrine System
• Target Cells
  Peripheral cells that can respond to a particular hormone
• Hormone receptor
  A protein in the cell membrane, or within the cytoplasm or nucleus, to which a hormone specifically binds to trigger its actions on a target cell.

Overview of the Endocrine System
The Role of Target Cell Receptors in Hormonal Action

Overview of the Endocrine System
Classes of Hormone Receptor
- **Extracellular** Receptors
  - Located in cell membrane
  - Targeted by
    - Amino acid derivatives
    - Peptides
    - Eicosanoids
  - Operates through a *second messenger* such as *cyclic-AMP*

**Overview of the Endocrine System**

Classes of Hormone Receptors
- **Intracellular** Receptors
  - Located in cytoplasm or nucleus
  - Targeted by steroid and thyroid hormones
  - Operates through changes in gene expression
  - Thyroid hormones also act on mitochondria

**Overview of the Endocrine System**

Mechanisms of Hormone Action

**Overview of the Endocrine System**

Hormone Secretion and Distribution
- Hormones directly enter capillaries
- Distributed widely in the circulation
  - Most hormones travel free in solution
  - Steroid, thyroid hormones bind to blood proteins for transport
- Hormones are inactivated by
  - Binding to cell receptors
  - Removal by liver, kidney cells
  - Breakdown by extracellular enzymes

**Overview of the Endocrine System**

**Key Note**
Hormones coordinate cells on a sustained basis. They circulate in the blood and bind to specific receptors on or in target cells. They alter membrane permeability, activate or inactivate key enzymes, or change genetic activity.

**Overview of the Endocrine System**

Control of Endocrine Secretion
- **Humoral** (fluid) stimuli
  - E.g., blood level of Ca\(^{2+}\) directly controls *parathyroid hormone* and *calcitonin* release
- Hormonal stimuli
• E.g., thyroid stimulating hormone triggers thyroid hormone release
• Neural stimuli
  • E.g., epinephrine release from adrenal gland

Overview of the Endocrine System
Hypothalamus and Endocrine Control
• Three mechanisms of action
  • Hypothalamus secretes hormones as an endocrine organ
  • Hypothalamus secretes regulatory hormones to control pituitary gland endocrine cells
  • Autonomic centers exert direct neural control of adrenal medullae

Overview of the Endocrine System
Three Mechanisms of Hypothalamic Control over Endocrine Organs
The Pituitary Gland
Pituitary Gland
• Also called the hypophysis
• Releases nine important hormones
  • All are peptide hormones
  • All bind to membrane (extracellular) receptors
  • Most use cyclic-AMP as second messenger

The Pituitary Gland
The Location and Anatomy of the Pituitary Gland
The Pituitary Gland
Anterior Pituitary Gland
• Controlled by regulatory hormones from hypothalamic neurons
• Hypophyseal portal system transports hypothalamic hormones directly to anterior pituitary target cells
• Regulated by negative feedback control

The Pituitary Gland
The Hypophyseal Portal System and the Blood Supply to the Pituitary Gland
The Pituitary Gland
Anterior Pituitary Hormones
• Thyroid-Stimulating Hormone (TSH)
  • Triggers thyroid hormone release
• Adrenocorticotropic Hormone (ACTH)
  • Stimulates glucocorticoid release from adrenal gland
• Follicle-Stimulating Hormone (FSH)
• Stimulates estrogen secretion, egg production (females), sperm production (males)

**The Pituitary Gland**

Anterior Pituitary Hormones (continued)

- **Luteinizing Hormone (LH)**
  - Triggers ovulation, *progestin* production (females), *androgen* production (males)
- **Prolactin (PRL)**
  - Stimulates mammary gland development and milk secretion
- **Growth hormone (hGH)**
  - Stimulates cell growth via *somatomedins* released from liver
- **Melanocyte Stimulating Hormone (MSH)**

**The Pituitary Gland**

Negative Feedback Control of Endocrine Secretion

**The Pituitary Gland**

Negative Feedback Control of Endocrine Secretion

**The Pituitary Gland**

Posterior Pituitary Gland

- Releases hormones from hypothalamic axons
- **Antidiuretic Hormone (ADH)**
  - Reduces water loss in the urine
  - Increases thirst
- **Oxytocin**
  - Stimulates uterine contraction, milk delivery
  - Stimulates prostate gland smooth muscle

**The Pituitary Gland**

Pituitary Hormones and Their Targets

**The Pituitary Gland**

**Key Note**

Hypothalamic regulatory factors control the anterior pituitary (source of seven hormones). Most of these control other glands (thyroid, adrenal, gonads). It also produces growth hormone. The posterior pituitary releases two hormones produced in the hypothalamus, ADH (restricts water loss) and oxytocin (stimulates contractions in the mammary glands and uterus, and the prostate gland).

**The Thyroid Gland**

Anatomy of the Thyroid Gland

- Lies near *thyroid* cartilage of larynx
- Consists of two lobes connected by the *isthmus*
• Has a rich blood supply
• Contains numerous thyroid follicles
  • Produce, store, release thyroid hormones

**The Thyroid Gland**

Thyroid Follicles and Thyroid Hormones
• Follicles produce and store colloid
• Production requires adequate iodine in the diet
• Occurs in two forms, thyroxine ($T_4$) and triiodothyronine ($T_3$)
• Increases metabolism and heat production (calorigenic effect)
• Required for normal development

**The Thyroid Gland**

The Thyroid Gland

**The Thyroid Gland**

C Cells of the Thyroid Gland
• C cells scattered outside of follicle epithelium
• Also called parafollicular cells
• Secrete calcitonin
  • Lowers blood $Ca^{2+}$ levels
  • Inhibits osteoclasts of bone
  • Increases urinary calcium loss
  • Triggered by high blood $Ca^{2+}$ level

**The Parathyroid Glands**
• Four glands embedded on thyroid posterior
• Chief cells produce parathyroid hormone
• Low blood $Ca^{2+}$ triggers secretion
• PTH speeds bone breakdown by osteoclasts, increases dietary absorption; slows loss in kidney
• PTH raises blood $Ca^{2+}$

**The Parathyroid Glands**

The Parathyroid Glands

**The Parathyroid Glands**

**The Parathyroid Glands**

**Key Note**

The thyroid gland produces (1) hormones that adjust tissue metabolic rates, and (2) a hormone that usually plays a minor role in calcium ion homeostasis by opposing the action of parathyroid hormone.

**The Adrenal Glands**

Adrenal Gland Anatomy
• Lie along superior border of each kidney
• Surrounded by fibrous capsule
• Made of two parts
  • Adrenal cortex (outer)
  • Adrenal medulla (inner)

The Adrenal Glands

The Adrenal Gland

The Adrenal Glands

Adrenal Cortex
• Makes steroid hormones (corticosteroids)
  • Glucocorticoids (e.g., cortisol)
    • Stimulated by ACTH
    • Affect glucose metabolism
  • Mineralocorticoids (e.g., aldosterone)
    • Stimulated by angiotensin II
    • Restricts loss of water, Na⁺ in urine, sweat, digestive tract, saliva
  • Androgens (male hormone)

The Adrenal Glands

The Adrenal Gland

The Adrenal Glands

Adrenal Medulla
• Produces two related hormones
  • Epinephrine (adrenaline)
  • Norepinephrine (noradrenaline)
• Innervated by preganglionic nerve fibers
• Axons stimulate hormone secretion
• Increases heart rate and force, releases glucose, fatty acids into blood, opens airways

The Adrenal Glands

The Adrenal Glands

Key Note
The adrenal glands produce hormones that adjust metabolic activities at specific sites, affecting either the pattern of nutrient utilization, mineral ion balance, or the rate of energy consumption by active tissues.

The Pineal Gland
The Pineal Gland
- Synthesizes melatonin
  - Inhibits reproductive function
  - Protects neural tissue from free radicals
  - Establishes daily wake-sleep cycle

The Pancreas
Overview of the Pancreas
- Lies behind stomach and beneath liver
- Has both **exocrine** and **endocrine** cells
- Endocrine cells organized into *islets of Langerhans*
- Islet cells secrete **insulin** and **glucagon**
  - *Insulin* produced by *beta* cells
  - *Glucagon* produced by *alpha* cells
- Exocrine cells secrete enzyme-rich digestive fluid

The Pancreas
The Endocrine Pancreas

The Pancreas
The Endocrine Pancreas

The Pancreas
Actions of Insulin and Glucagon
- **Insulin**
  - Lowers blood glucose concentration
  - Increases glucose uptake, storage, and use by target cells
  - Targets liver, muscle, fat cells
- **Glucagon**
  - Raises blood glucose concentration
  - Increases *glycogen* breakdown and glucose synthesis
  - Targets liver cells

Endocrine Tissues of Other Organs
- **Intestines**
  - Secretes hormones to control digestion
- **Kidneys**
  - Secretes three hormones
    - **Calcitriol**—Stimulates calcium and phosphate absorption in intestine
    - **Erythropoietin** (EPO)—Stimulates red blood cell production by bone marrow
    - **Renin**—Enzyme that leads to *angiotensin II* that triggers *aldosterone* from adrenal cortex
Endocrine Tissues of Other Organs

- **Heart**
  - Specialized muscle cells secrete *atrial natriuretic peptide* (ANP) to lower blood volume or blood pressure

- **Thymus**
  - Secretes *thymosins* that control immune system defenses

- **Adipose tissue** (fat cells)
  - Secretes *leptin* to control appetite
  - Secretes *resistin* to reduce insulin response

Endocrine Tissues of Other Organs

- **Testis** (male gonad)
  - Interstitial cells secrete *androgens* (*testosterone*)
  - Sustentacular cells secrete *inhibin*

- **Ovary** (female gonad)
  - Follicle cells secrete *estrogens* and *inhibin*
  - Corpus luteum cells secrete estrogens and *progesterone*

- **Placenta**
  - Secretes several hormones in pregnancy

Patterns of Hormonal Interaction

Kinds of Interaction between Hormones

- **Antagonistic** (opposing effect)
  - E.g., calcitonin versus PTH
- **Synergistic** (additive effect)
  - E.g., hGH and cortisol on glucose sparing
- **Permissive** effect
  - E.g., epinephrine and thyroid hormones
- **Integrative** effect
  - E.g., calcitriol and PTH on calcium levels

Patterns of Hormonal Interaction

Hormones Needed for Normal Growth

- Growth Hormone
- Thyroid Hormones
- Insulin
- Parathyroid Hormone
- Calcitriol
- Reproductive Hormones

Patterns of Hormonal Interaction

Hormones and Stress
• **Stress**—Any condition that threatens *homeostasis*
• General Adaptation Syndrome to stress
  • Alarm phase (sympathetic ANS response)
  • Resistance phase (glucocorticoid response)
  • Exhaustion phase (organ system failure)

**Patterns of Hormonal Interaction**
The General Adaptation Syndrome

**Patterns of Hormonal Interaction**
The General Adaptation Syndrome

**Patterns of Hormonal Interaction**
The General Adaptation Syndrome

**Patterns of Hormonal Interaction**
Hormones and Behavior

  • Sex hormones
    • Testosterone fosters aggressiveness
    • Estrogen fosters sexual receptivity
  • Thyroid hormones
    • Excess leads to nervousness, restlessness
    • Deficiency leads to sluggishness
  • Antidiuretic hormone
    • Leads to feeling of thirst, water intake

**Patterns of Hormonal Interaction**
Hormones and Aging

  • Many hormones unaffected by age
  • Reduced or absent reproductive hormones
  • hGH, insulin release reduced
    • Leads to loss of bone density, muscle mass
  • Tissue response to ADH, glucocorticoids declines

**The Integumentary System**

  • Protects superficial endocrine organs; epidermis synthesizes vitamin D₃
  • Sex hormones stimulate sebaceous gland activity, influence hair growth, fat distribution, and apocrine sweat gland activity; PRL stimulates development of mammary glands; adrenal hormones alter dermal blood flow, stimulate release of lipids from adipocytes; MSH stimulates melanocyte activity

**The Skeletal System**

  • Protects endocrine organs, especially in brain, chest, and pelvic cavity
• Skeletal growth regulated by several hormones; calcium mobilization regulated by parathyroid hormone and calcitonin; sex hormones speed growth and closure of epiphyseal cartilages at puberty and help maintain bone mass in adults

The Muscular System
• Skeletal muscles provide protection for some endocrine organs
• Hormones adjust muscle metabolism, energy production, and growth; regulate calcium and phosphate levels in body fluids; speed skeletal muscle growth

The Nervous System
• Hypothalamic hormones directly control pituitary secretions and indirectly control secretions of other endocrine organs; controls adrenal medullae; secretes ADH and oxytocin
• Several hormones affect neural metabolism; hormones help regulate fluid and electrolyte balance; reproductive hormones influence CNS development and behaviors

The Cardiovascular System
• Circulatory system distributes hormones throughout the body; heart secretes ANP
• Erythropoietin regulates production of RBCs; several hormones elevate blood pressure; epinephrine elevates heart rate and contraction force

The Lymphatic System
• Lymphocytes provide defense against infection and, with other WBCs, assist in repair after injury
• Glucocorticoids have anti-inflammatory effects; thymosins stimulate development of lymphocytes; many hormones affect immune function

The Respiratory System
• Provides oxygen and eliminates carbon dioxide generated by endocrine cells
• Epinephrine and norepinephrine stimulate respiratory activity and dilate respiratory passageways

The Digestive System
• Provides nutrients to endocrine cells; endocrine cells of pancreas secrete insulin and glucagon; liver produces angiotensinogen
• E and NE stimulate constriction of sphincters and depress activity along digestive tract; digestive tract hormones coordinate secretory activities along tract

The Urinary System
• Kidney cells (1) release renin and erythropoietin when local blood pressure declines and (2) produce calcitriol
• Aldosterone, ADH, and ANP adjust rates of fluid and electrolyte reabsorption in kidneys

**The Reproductive System**
• Steroid sex hormones and inhibin suppress secretory activities in hypothalamus and pituitary
• Hypothalamic regulatory hormones and pituitary hormones regulate sexual development and function; oxytocin stimulates uterine and mammary gland smooth muscle contractions