Chapter 45

Hormones and the Endocrine System
Overview: The Body’s Long-Distance Regulators

• Animal **hormones** are chemical signals that are secreted into the circulatory system and communicate regulatory messages within the body.

• Hormones reach **all parts of the body**, but only target cells are equipped to respond.

• Insect metamorphosis is regulated by hormones.
Two systems coordinate communication throughout the body: the endocrine system and the nervous system

The endocrine system secretes hormones that coordinate slower but longer-acting responses including reproduction, development, energy metabolism, growth, and behavior.

The nervous system conveys high-speed electrical signals along specialized cells called neurons; these signals regulate other cells.
Types of Secreted Signaling Molecules

- Secreted chemical signals include
  - Hormones
  - Local regulators
  - Neurotransmitters
  - Neurohormones
  - Pheromones
Hormones - Endocrine

- Endocrine signals (hormones) are secreted into extracellular fluids and travel via the bloodstream.

- **Endocrine glands** are ductless and secrete hormones directly into surrounding fluid.

- Hormones mediate responses to environmental stimuli and regulate growth, development, and reproduction.

- **Exocrine glands** have ducts and secrete substances onto body surfaces or into body cavities (for example, tear ducts).
Local Regulators

- **Local regulators** are chemical signals that travel over short distances by diffusion.
- Local regulators help regulate blood pressure, nervous system function, and reproduction.
- Local regulators are divided into two types:
  - **Paracrine** signals act on cells near the secreting cell.
  - **Autocrine** signals act on the secreting cell itself.
(a) Endocrine signaling

(b) Paracrine signaling

(c) Autocrine signaling
Neurotransmitters and Neurohormones

- Neurons (nerve cells) contact target cells at synapses
- At synapses, neurons often secrete chemical signals called neurotransmitters that diffuse a short distance to bind to receptors on the target cell
- Neurotransmitters play a role in sensation, memory, cognition, and movement
- **Neurohormones** are a class of hormones that originate from neurons in the brain and diffuse through the bloodstream
(d) Synaptic signaling

(e) Neuroendocrine signaling
Pheromones are chemical signals that are released from the body and used to communicate with other individuals in the species.

- Pheromones mark trails to food sources, warn of predators, and attract potential mates.
Chemical Classes of Hormones

• Three major classes of molecules function as hormones in vertebrates:
  – Polypeptides (proteins and peptides)
  – Amines derived from amino acids
  – Steroid hormones
• Lipid-soluble hormones (steroid hormones) pass easily through cell membranes, while water-soluble hormones (polypeptides and amines) do not.

• The solubility of a hormone correlates with the location of receptors inside or on the surface of target cells.
Cellular Response Pathways

- Water and lipid soluble hormones differ in their paths through a body
- Water-soluble hormones are secreted by exocytosis, travel freely in the bloodstream, and bind to cell-surface receptors
- Lipid-soluble hormones diffuse across cell membranes, travel in the bloodstream bound to transport proteins, and diffuse through the membrane of target cells
Signaling by any of these hormones involves three key events:

- Reception
- Signal transduction
- Response
• The hormone epinephrine has multiple effects in mediating the body’s response to short-term stress

• Epinephrine binds to receptors on the plasma membrane of liver cells

• This triggers the release of messenger molecules that activate enzymes and result in the release of glucose into the bloodstream
Multiple Effects of Hormones

- The same hormone may have different effects on target cells that have
  - Different receptors for the hormone
  - Different signal transduction pathways
  - Different proteins for carrying out the response

- A hormone can also have different effects in different species!!!
Glycogen deposits

(a) Liver cell

(b) Skeletal muscle blood vessel

(c) Intestinal blood vessel

Vessel dilates.

Vessel constricts.

Epinephrine

β receptor

β receptor

α receptor

Epinephrine

Epinephrine

Same receptors but different intracellular proteins (not shown)

Different receptors

Glycogen breaks down and glucose is released.
In paracrine signaling, nonhormonal chemical signals called local regulators elicit responses in nearby target cells.

Types of local regulators:

- Cytokines and growth factors
- Nitric oxide (NO)
- Prostaglandins - help regulate aggregation of platelets, an early step in formation of blood clots
Major endocrine glands:
- Adrenal glands
- Hypothalamus
- Pineal gland
- Pituitary gland
- Thyroid gland
- Parathyroid glands
- Pancreas
- Kidney
- Ovaries
- Testes

Organs containing endocrine cells:
- Thymus
- Heart
- Liver
- Stomach
- Kidney
- Small intestine

Hormones are assembled into regulatory pathways.
• Hormones are released from an endocrine cell, travel through the bloodstream, and interact with the receptor or a target cell to cause a physiological response
A **negative feedback** loop inhibits a response by reducing the initial stimulus. Negative feedback regulates many hormonal pathways involved in homeostasis.
Insulin and Glucagon: Control of Blood Glucose

- **Insulin** and **glucagon** are antagonistic hormones that help maintain glucose homeostasis.

- The **pancreas** has clusters of endocrine cells called **islets of Langerhans** with alpha cells that produce glucagon and beta cells that produce insulin.
Target Tissues for Insulin and Glucagon

• Insulin reduces blood glucose levels by
  – Promoting the cellular uptake of glucose
  – Slowing glycogen breakdown in the liver
  – Promoting fat storage

• Glucagon increases blood glucose levels by
  – Stimulating conversion of glycogen to glucose in the liver
  – Stimulating breakdown of fat and protein into glucose
Maintenance of glucose homeostasis by insulin and glucagon

Blood glucose level (about 90 mg/100 mL)

STIMULUS: Blood glucose level falls.

Alpha cells of pancreas release glucagon.

Liver breaks down glycogen and releases glucose.

Body cells take up more glucose.

Homeostasis: Blood glucose level declines.

Blood glucose level rises.

Liver takes up glucose and stores it as glycogen.

Beta cells of pancreas release insulin into the blood.

STIMULUS: Blood glucose level rises.

Insulin

Body cells take up more glucose.

STIMULUS: Blood glucose level falls.

Insulin

Body cells take up more glucose.

Alpha cells of pancreas release glucagon.

Liver breaks down glycogen and releases glucose.
Diabetes Mellitus - perhaps the best-known endocrine disorder

- **Diabetes mellitus** is caused by a deficiency of insulin or a decreased response to insulin in target tissues.
- It is marked by elevated blood glucose levels.
- **Type I diabetes mellitus** (insulin-dependent) is an **autoimmune disorder** in which the immune system destroys pancreatic beta cells.
- **Type II diabetes mellitus** (non-insulin-dependent) involves insulin deficiency or reduced response of target cells due to change in insulin receptors.
Coordination of Endocrine and Nervous Systems in Invertebrates

- In insects, molting and development are controlled by a combination of hormones:
  - A brain hormone stimulates release of ecdysone from the prothoracic glands
  - Juvenile hormone promotes retention of larval characteristics
  - Ecdysone promotes molting (in the presence of juvenile hormone) and development (in the absence of juvenile hormone) of adult characteristics
Fig. 45-13-3

Ecdysone

Brain

PTTH

Neurosecretory cells

Corpus cardiacum

Corpus allatum

Prothoracic gland

Ecdysone

Juvenile hormone (JH)

Brain

Low JH

EARLY LARVA

LATER LARVA

PUPA

ADULT

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Coordination of Endocrine and Nervous Systems in Vertebrates

- The **hypothalamus** receives information from the nervous system and initiates responses through the endocrine system.

- Attached to the hypothalamus is the **pituitary gland** composed of the posterior pituitary and anterior pituitary.

- The **posterior pituitary** stores and secretes hormones that are made in the hypothalamus.

- The **anterior pituitary** makes and releases hormones under regulation of the hypothalamus.
The two hormones released from the posterior pituitary act directly on nonendocrine tissues.
- **Oxytocin** induces uterine contractions and the release of milk
- Suckling sends a message to the hypothalamus via the nervous system to release oxytocin, which further stimulates the milk glands
- This is an example of **positive feedback**, where the stimulus leads to an even greater response
- **Antidiuretic hormone (ADH)** enhances water reabsorption in the kidneys
Fig. 45-16

Pathway

Stimulus

Sensory neuron

Hypothalamus/posterior pituitary

Neurosecretory cell

Blood vessel

Target cells

Response

Example

Suckling

Posterior pituitary secretes oxytocin (■)

Smooth muscle in breasts

Milk release

Positive feedback

+
Anterior Pituitary Hormones

• Hormone production in the anterior pituitary is controlled by releasing and inhibiting hormones from the hypothalamus

• For example, the production of thyrotropin releasing hormone (TRH) in the hypothalamus stimulates secretion of the thyroid stimulating hormone (TSH) from the anterior pituitary
Hypothalamic releasing and inhibiting hormones

Neurosecretory cells of the hypothalamus

Portal vessels

Endocrine cells of the anterior pituitary

Pituitary hormones

Hormone Pathway:

- **FSH and LH**
  - Target: Testes or ovaries

- **TSH**
  - Target: Thyroid

- **ACTH**
  - Target: Adrenal cortex

- **Prolactin**
  - Target: Mammary glands, Melanocytes

- **MSH**
  - Target: Liver, bones, other tissues

- **GH**
  - Target: Liver, bones, other tissues

Hormones with Tropic Effects:
- FSH
- LH
- TSH
- ACTH

Hormones with Nontropic Effects:
- Prolactin
- MSH

Hormones with Nontropic and Tropic Effects:
- GH
Hormone Cascade Pathways

• A hormone can stimulate the release of a series of other hormones, the last of which activates a nonendocrine target cell; this is called a hormone cascade pathway.

• The release of thyroid hormone results from a hormone cascade pathway involving the hypothalamus, anterior pituitary, and thyroid gland.

• Hormone cascade pathways are usually regulated by negative feedback.
Tropic Hormones

• A **tropic hormone** regulates the function of endocrine cells or glands

• The four strictly tropic hormones are
  – Thyroid-stimulating hormone (TSH)
  – Follicle-stimulating hormone (FSH)
  – Luteinizing hormone (LH)
  – Adrenocorticotropic hormone (ACTH)
Nontropic Hormones

- Nontropic hormones target nonendocrine tissues
- Nontropic hormones produced by the anterior pituitary are
  - **Prolactin (PRL)** stimulates lactation in mammals but has diverse effects in different vertebrates
  - **Melanocyte-stimulating hormone (MSH)** influences skin pigmentation in some vertebrates and fat metabolism in mammals
Growth Hormone

- **Growth hormone (GH)** is secreted by the anterior pituitary gland and has tropic and nontropic actions.
- It promotes growth directly and has diverse metabolic effects.
- It stimulates production of growth factors.
- An excess of GH can cause gigantism, while a lack of GH can cause dwarfism.
Thyroid Hormone: Control of Metabolism and Development

- The thyroid gland consists of two lobes on the ventral surface of the trachea.
- It produces two iodine-containing hormones: triiodothyronine ($T_3$) and thyroxine ($T_4$).
• Thyroid hormones stimulate metabolism and influence development and maturation

• Hyperthyroidism, excessive secretion of thyroid hormones, causes high body temperature, weight loss, irritability, and high blood pressure

• Graves’ disease is a form of hyperthyroidism in humans

• Hypothyroidism, low secretion of thyroid hormones, causes weight gain, lethargy, and intolerance to cold
Adrenal Hormones: Response to Stress

• The adrenal glands are adjacent to the kidneys
• Each adrenal gland actually consists of two glands: the *adrenal medulla* (inner portion) and *adrenal cortex* (outer portion)
Catecholamines from the Adrenal Medulla

- The adrenal medulla secretes epinephrine (adrenaline) and norepinephrine (noradrenaline)

- These hormones are members of a class of compounds called catecholamines

- They are secreted in response to stress-activated impulses from the nervous system

- They mediate various fight-or-flight responses
Steroid Hormones from the Adrenal Cortex

- The adrenal cortex releases a family of steroids called **corticosteroids** in response to stress.
- These hormones are triggered by a hormone cascade pathway via the hypothalamus and anterior pituitary.
- Humans produce two types of corticosteroids: glucocorticoids and mineralocorticoids.
• **Glucocorticoids**, such as cortisol, influence glucose metabolism and the immune system

• **Mineralocorticoids**, such as aldosterone, affect salt and water balance

• The adrenal cortex also produces small amounts of steroid hormones that function as sex hormones
The gonads, testes and ovaries, produce most of the sex hormones: androgens, estrogens, and progestins.

All three sex hormones are found in both males and females, but in different amounts.
• The testes primarily synthesize androgens, mainly testosterone, which stimulate development and maintenance of the male reproductive system.

• Testosterone causes an increase in muscle and bone mass and is often taken as a supplement to cause muscle growth, which carries health risks.
• **Estrogens**, most importantly estradiol, are responsible for maintenance of the female reproductive system and the development of female secondary sex characteristics.

• In mammals, progestins, which include progesterone, are primarily involved in preparing and maintaining the uterus.

• Synthesis of the sex hormones is controlled by FSH and LH from the anterior pituitary.
Melatonin and Biorhythms

• The **pineal gland**, located in the brain, secretes **melatonin**

• Light/dark cycles control release of melatonin

• Primary functions of melatonin appear to relate to biological rhythms associated with reproduction
You should now be able to:

1. Distinguish between the following pairs of terms: hormones and local regulators, paracrine and autocrine signals

2. Explain how the antagonistic hormones insulin and glucagon regulate carbohydrate metabolism

3. Distinguish between type 1 and type 2 diabetes
5. Explain how the hypothalamus and the pituitary glands interact and how they coordinate the endocrine system

6. Explain the role of tropic hormones in coordinating endocrine signaling throughout the body

7. List and describe the functions of hormones released by the following: anterior and posterior pituitary lobes, thyroid glands, parathyroid glands, adrenal medulla, adrenal cortex, gonads, pineal gland