CHAPTER 10

The Endocrine System
Chapter 10 Learning Outcomes

• 10-1
  • Explain the role of intercellular communication in homeostasis, and describe the complementary roles of the endocrine and nervous systems.

• 10-2
  • Contrast the major structural classes of hormones, and explain the general mechanisms of hormonal action on target organs.

• 10-3
  • Describe the location, hormones, and functions of the pituitary gland.

• 10-4
  • Describe the location, hormones, and functions of the thyroid gland.

• 10-5
  • Describe the location, hormones, and functions of the parathyroid glands.
Chapter 10 Learning Outcomes

• 10-6
  • Describe the location, hormones, and functions of the adrenal glands.

• 10-7
  • Describe the location of the pineal gland, and discuss the functions of the hormone it produces.

• 10-8
  • Describe the location, hormones, and functions of the pancreas.

• 10-9
  • Discuss the functions of the hormones produced by the kidneys, heart, thymus, testes, ovaries, and adipose tissue.
Chapter 10 Learning Outcomes

• 10-10
  • Explain how hormones interact to produce coordinated physiological responses, and describe how the endocrine system responds to stress and is affected by aging.

• 10-11
  • Give examples of interactions between the endocrine system and other organ systems.
Intercellular Communication (10-1)

- Preserves homeostasis
- Mostly done through chemical messages
- Distant communication is coordinated by endocrine and nervous systems
  - Nervous system is fast
    - Specific and short duration
  - Endocrine system is slower
    - Releases hormones into bloodstream that bind to target cells, longer duration
Nervous and Endocrine Systems Comparison (10-1)

- Both rely on release of chemicals that bind to specific receptors on target cells
- Both share chemical messengers
  - Epinephrine (E) and norepinephrine (NE), hormones released from adrenal medulla
  - NE, a neurotransmitter when released in synapses
Nervous and Endocrine Systems Comparison (10-1)

- Both are regulated by negative feedback mechanisms
- Both coordinate and regulate activities of other cells, tissues, organs, and systems to maintain homeostasis
1. List four similarities between the nervous and endocrine systems.
The Endocrine System (10-2)

- Includes all **endocrine cells** and tissues
- Cells are glandular and secretory
- Secretions enter the ECF
- Cytokines are local chemical messengers
- **Hormones** are chemical messengers secreted into the blood and transported to target cells
The Structure of Hormones (10-2)

- **Amino acid derivatives**
  - All derived from amino acid tyrosine
  - $E$, $NE$, *thyroid hormones*, *melatonin*

- **Peptide hormones**
  - Largest group
  - Includes *ADH*, *oxytocin*, hypothalamic, pituitary, pancreatic hormones
The Structure of Hormones (10-2)

• *Lipid derivatives*
  
  • Most derived from cholesterol
  
  • **Steroid hormones** released by reproductive organs and adrenal cortex
    
    • For example, testosterone, estrogen
  
  • *Eicosanoids* coordinate local cellular functions
    
    • For example, *prostaglandins*
Hypothalamus
Production of ADH, oxytocin, and regulatory hormones

Pituitary Gland
Anterior lobe:
ACTH, TSH, GH, PRL, FSH, LH, and MSH
Posterior lobe:
Release of ADH and oxytocin

Thyroid Gland
Thyroxine (T4)
Triiodothyronine (T3)
Calcitonin (CT)

Adrenal Glands
Adrenal medulla:
Epinephrine (E)
Norepinephrine (NE)
Adrenal cortex:
Cortisol, corticosterone, aldosterone, androgens

Pancreas (Pancreatic Islets)
Insulin
Glucagon

Pineal Gland
Melatonin

Parathyroid Glands
(located on the posterior surface of the thyroid gland)
Parathyroid hormone (PTH)

Organs with Secondary Endocrine Functions
Heart: Secretes
• Atrial natriuretic peptide (ANP)

Thymus: (Undergoes atrophy during adulthood)
Secretes thymosins

Adipose Tissue: Secretes
• Leptin

Digestive Tract: Secretes numerous hormones involved in the coordination of system functions, glucose metabolism, and appetite

Kidneys: Secrete
• Erythropoietin (EPO)
• Calcitriol

Gonads:
Testes (male):
Androgens (especially testosterone), inhibin
Ovaries (female):
Estrogens, progestins, inhibin

Figure 10-1 Organs and Tissues of the Endocrine System.
Mechanisms of Hormonal Action (10-2)

- Hormones alter operations of target cells
  - Change identities, activities, locations, or quantities of structural proteins and enzymes
  - Sensitivity of target cell to hormone depends on specific receptors
  - Receptors are located either on plasma membrane or inside the cell
Figure 10-2 The Role of Target Cell Receptors in Hormonal Action.

- Endocrine cells release hormone.
- Hormone is distributed throughout the body.
- Hormone enters the bloodstream.

**NEURAL TISSUE**
No binding, no hormonal effects.

**SKELETAL MUSCLE TISSUE**
Binding occurs, hormonal effects appear.
Hormonal Action at the Plasma Membrane (10-2)

- Receptors on plasma membrane
  - E, NE, and peptide hormones are not lipid soluble
  - Cannot diffuse through the plasma membrane
  - Must use a receptor on outside of membrane
  - Effect is not direct, they are first messengers that activate second messengers in the cytoplasm
  - Action is linked by G protein, an enzyme complex
Cyclic-AMP Second Messenger System (10-2)

- Or cAMP
  - First messenger activates a G protein
  - Which activates enzyme **adenylate cyclase**
  - Which converts ATP to second messenger, cAMP
  - Which activates *kinase* enzymes inside cell
  - Which *phosphorylates* another molecule
  - Produces amplification of signal
Intracellular Receptors (10-2)

- Receptors inside cytoplasm or nucleus
  - For thyroid and steroid hormones, lipid soluble
  - Forms hormone-receptor complex
  - Activates or inactivates specific genes
  - Alters rate of mRNA transcription
  - Changes structure or function of cell
Nonsteroidal hormones, such as epinephrine (E), norepinephrine (NE), peptide hormones, and eicosanoids, bind to membrane receptors and activate G proteins. They exert their effects on target cells through a second messenger, such as cAMP, which alters the activity of enzymes present in the cell.
Steroid hormones enter a target cell by diffusion. Thyroid hormones are transported across the target cell's plasma membrane. Steroid hormones bind to receptors in the cytoplasm or nucleus. Thyroid hormones either bind to receptors in the nucleus or to receptors on mitochondria. In the nucleus, both steroid and thyroid hormone-receptor complexes directly affect gene activity and protein synthesis. Thyroid hormones also increase the rate of ATP production in the cell.
Hormone Secretion and Distribution (10-2)

- Rapidly enter blood and distributed throughout body
- Freely circulating hormones are short-lived and inactivated when:
  1. They diffuse to target cells and bind to receptors
  2. They are absorbed and broken down in liver and kidney
  3. They are broken down by enzymes in plasma or interstitial fluid
Hormone Secretion and Distribution (10-2)

- Hormones bound to transport proteins stay in circulation longer (steroid and thyroid hormones)
- Each hormone has an equilibrium between bound and free forms
Control of Endocrine Activity (10-2)

- Hormonal secretion under negative feedback control is based on three types of stimuli

1. *Humoral stimuli*
   - Changes in ECF composition

2. *Hormonal stimuli*
   - Changes in circulating hormone levels

3. *Neural stimuli*
   - Neural stimulation of a neuroglandular junction
The Hypothalamus and Endocrine Control (10-2)

- Coordinating centers in hypothalamus regulate nervous and endocrine systems
- The hypothalamus
  1. Acts as an endocrine gland, synthesizing ADH and oxytocin
  2. Secretes **releasing** and **inhibiting regulatory hormones** to control anterior pituitary secretions
  3. Contains ANS centers that control adrenal medullae through sympathetic innervation
2. Define hormone.

3. What is the primary factor that determines each cell's sensitivities to hormones?

4. How would the presence of a molecule that blocks adenylate cyclase affect the activity of a hormone that produces cellular effects through cAMP?

5. Why is cAMP described as a second messenger?

6. What are the three types of stimuli that control hormone secretion?
The Pituitary Gland (10-3)

- Also called the **hypophysis**
  - Protected by the *sella turcica* of the sphenoid bone
  - Hangs from hypothalamus by **infundibulum**
- Anterior and posterior have very different structure
- Secretes nine hormones
  - All are unique peptides or small proteins
  - All use cAMP second messenger mechanism
Figure 10-5  The Location and Anatomy of the Pituitary Gland.

- **Relationship of the pituitary gland to the hypothalamus**
  - Anterior lobe
  - Posterior lobe
  - Third ventricle
  - Infundibulum
  - HYPOTHALAMUS
  - Optic chiasm
  - Mamillary body
  - Sphenoid (sella turcica)

- **Tissue organization of the anterior and posterior lobes of the pituitary gland**
  - Anterior lobe
  - Posterior lobe
  - Pituitary gland
  - Secretes other pituitary hormones
  - Secretes MSH
  - Releases ADH and oxytocin

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The Anterior Lobe of the Pituitary Gland (10-3)

- Contains epithelial endocrine cells
- Cells are surrounded by complex capillary bed
- Capillaries are part of hypophyseal portal system
  - A portal system is two capillary beds in series connected by a communicating blood vessel
The Hypophyseal Portal System (10-3)

• Blood arrives through hypophyseal artery
• Branches into hypophyseal (1st) capillary bed
• Regulatory hormones of hypothalamus diffuse into capillaries and travel through portal veins
• Regulatory hormones diffuse onto target cells in anterior lobe
• Anterior lobe cells secrete hormones into (2nd) capillaries
Figure 10-6 The Hypophyseal Portal System and the Blood Supply to the Pituitary Gland.

Hypothalamic nuclei producing ADH and oxytocin

Hypothalamic neurons producing regulatory hormones

HYPOTHALAMUS

Mamillary body

Optic chiasm

Capillary beds

ANTERIOR LOBE OF PITUITARY GLAND

Hypophyseal artery

Infundibulum

Portal veins

POSTERIOR LOBE OF PITUITARY GLAND

Endocrine cells

Hypophyseal veins
The Seven Anterior Lobe Hormones (10-3)

1. Thyroid-stimulating hormone (TSH)
2. Adrenocorticotropic hormone (ACTH)
3. Follicle-stimulating hormone (FSH)
4. Luteinizing hormone (LH)
5. Prolactin (PRL)
6. Growth hormone (GH)
7. Melanocyte-stimulating hormone (MSH)
Thyroid-Stimulating Hormone (10-3)

- Also called *thyrotropin*
  - Released in response to *thyrotropin-releasing hormone (TRH)* from hypothalamus
  - Triggers release of thyroid hormones from thyroid glands
  - Increases in thyroid hormones cause decrease in TRH and TSH secretion
Adrenocorticotropic Hormone (10-3)

- Also called corticotropin
  - Stimulates secretion of steroid hormones, called glucocorticoids, from adrenal cortex
  - Corticotropin-releasing hormone (CRH) from the hypothalamus triggers release of ACTH
  - Increases in glucocorticoids feed back to inhibit ACTH and CRH secretion
  - The gonadotropins, or sex hormones, are triggered by gonadotropin-releasing hormone (GnRH) from hypothalamus
Follicle-Stimulating Hormone and Luteinizing Hormone (10-3)

- **Follicle-stimulating hormone (FSH)**
  - Promotes follicle (and egg) development in females
  - Promotes sperm production in males

- **Luteinizing hormone (LH)**
  - Induces *ovulation* and secretion of *progestins* in females
  - Stimulates production of *androgens* such as *testosterone* in males
Prolactin (10-3)

- Stimulates mammary gland development
- In pregnancy and nursing, stimulates production of milk
Growth Hormone (10-3)

- Also called *human growth hormone* (*hGH*) and *somatotropin*
  - Stimulates cell growth and replication of all cells, but especially skeletal muscle and chondrocytes
  - Stimulates liver to release *somatomedins*, which trigger an increase in amino acid uptake by cells following a meal
  - Has multiple metabolic influences
Melanocyte-Stimulating Hormone (10-3)

- Increases activity of melanocytes in skin
  - Appears to be nonfunctional in adults
  - Is active in:
    - Fetal development
    - Very young children
    - Pregnancy
    - Certain diseases
A typical pattern of regulation when multiple endocrine organs are involved. The hypothalamus produces a releasing hormone (RH) to stimulate hormone production by other glands; control occurs by negative feedback.
Variations on the theme outlined in part (a). Left: The regulation of prolactin (PRL) production by the anterior lobe. In this case, the hypothalamus produces both a releasing factor (PRF) and an inhibiting hormone (PIH); when one is stimulated, the other is inhibited. Right: the regulation of growth hormone (GH) production by the anterior lobe; when GH–RH release is inhibited, GH–IH release is stimulated.
The Two Posterior Lobe Hormones (10-3)

- Hormones diffuse down axons of hypothalamic neurons that extend into posterior lobe, then into capillaries

1. Antidiuretic hormone (ADH)
2. Oxytocin (OXT)
Antidiuretic Hormone (10-3)

• Also called *vasopressin*
  • Stimulated by increase in ECF osmolarity or decrease in blood volume and pressure
  • Primary target is kidney to decrease water loss
  • Triggers *vasoconstriction* to increase blood pressure
Oxytocin (10-3)

- In women stimulates contraction of uterine muscles during labor and delivery
- Also stimulates contraction of cells surrounding milk secretory cells in mammary glands
- Appears to play unclear role in sexual arousal
Figure 10-8 Pituitary Hormones and Their Targets.

Hypothalamus

**Direct Control by Nervous System**

**Indirect Control through Release of Regulatory Hormones**

Regulatory hormones are released into the hypophyseal portal system for delivery to the anterior lobe of the pituitary gland.

**Direct Release of Hormones**

Sensory Osmoreceptor stimulation

KEY TO PITUITARY HORMONES:

- ACTH: Adrenocorticotropic hormone
- TSH: Thyroid-stimulating hormone
- GH: Growth hormone
- PRL: Prolactin
- FSH: Follicle-stimulating hormone
- LH: Luteinizing hormone
- MSH: Melanocyte-stimulating hormone
- ADH: Antidiuretic hormone
- OXT: Oxytocin

Adrenal gland

- Epinephrine and norepinephrine

Thyroid gland

- Thyroid hormones ($T_3$, $T_4$)

Liver

- Somatomedins

Adrenal medulla

- ACTH

Adrenal cortex

- Glucocorticoids (cortisol, corticosterone)

Anterior lobe of pituitary gland

- Adrenal gland
- Thyroid gland
- Liver
- Mammary glands
- Testes of male
- Ovaries of female
- Melanocytes (uncertain significance in healthy adults)
- Females: Uterine smooth muscle and mammary glands
- Males: Smooth muscle in ductus deferens and prostate gland

Posterior lobe of pituitary gland

- ADH
- OXT

Kidneys

- Inhibin
- Testosterone
- Estrogen
- Progesterone
- Inhibin

Bone, muscle, other tissues

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Table 10-1 The Pituitary Hormones

<table>
<thead>
<tr>
<th>Pituitary Lobe/Hormone</th>
<th>Target</th>
<th>Hormonal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANTERIOR LOBE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thyroid-stimulating hormone (TSH)</td>
<td>Thyroid gland</td>
<td>Secretion of thyroid hormones</td>
</tr>
<tr>
<td>Adrenocorticotropic hormone (ACTH)</td>
<td>Adrenal cortex</td>
<td>Glucocorticoid secretion (cortisol, corticosterone)</td>
</tr>
<tr>
<td><strong>Gonadotropins:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follicle-stimulating hormone (FSH)</td>
<td>Follicle cells of ovaries</td>
<td>Estrogen secretion, follicle development</td>
</tr>
<tr>
<td></td>
<td>Nurse cells of testes</td>
<td>Sperm maturation</td>
</tr>
<tr>
<td>Luteinizing hormone (LH)</td>
<td>Follicle cells of ovaries</td>
<td>Ovulation, formation of corpus luteum, and progesterone secretion</td>
</tr>
<tr>
<td></td>
<td>Interstitial cells of testes</td>
<td>Testosterone secretion</td>
</tr>
<tr>
<td>Prolactin (PRL)</td>
<td>Mammary glands</td>
<td>Production of milk</td>
</tr>
<tr>
<td>Growth hormone (GH)</td>
<td>All cells</td>
<td>Growth, protein synthesis, lipid mobilization and catabolism</td>
</tr>
<tr>
<td>Melanocyte-stimulating hormone (MSH)</td>
<td>Melanocytes of skin</td>
<td>Increased melanin synthesis in epidermis</td>
</tr>
<tr>
<td><strong>POSTERIOR LOBE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antidiuretic hormone (ADH)</td>
<td>Kidneys</td>
<td>Reabsorption of water, elevation of blood volume and pressure</td>
</tr>
<tr>
<td>Oxytocin (OXT)</td>
<td>Uterus, mammary glands (females)</td>
<td>Labor contractions, milk ejection</td>
</tr>
<tr>
<td></td>
<td>Sperm duct and prostate gland (males)</td>
<td>Contractions of sperm duct and prostate gland</td>
</tr>
</tbody>
</table>
7. If a person were dehydrated, how would the amount of ADH released by the posterior lobe of the pituitary gland change?

8. A blood sample contains elevated levels of somatomedins. Which pituitary hormone would you also expect to be elevated?

9. What effect would elevated circulating levels of cortisol, a hormone from the adrenal cortex, have on the pituitary secretion of ACTH?
The Thyroid Gland (10-4)

- Found anterior to trachea and inferior to thyroid cartilage
- Has two lobes connected by narrow *isthmus*
- Contains many spherical *thyroid follicles*
  - Defined by simple cuboidal epithelium
  - Filled with viscous colloid with many proteins and thyroid hormone molecules
The Thyroid Follicles (10-4)

- Follicular cells make thyroid hormones that are then stored in colloid
- TSH causes release of thyroid hormones
  - Majority are transported by plasma proteins
  - Derived from amino acid tyrosine, and iodine
- **Thyroxine** \( (T_4) \) tetraiodothyronine has four atoms of iodine
  - **Triiodothyronine** \( (T_3) \) has three iodine and is more potent
The Effects of Thyroid Hormones (10-4)

- Activate nearly every cell in body
- Increase rate of ATP production in mitochondria
  - Activate genes coding for enzyme synthesis
  - Enzymes increase rate of metabolism
- **Calorigenic effect** is when cell uses more energy, measured in calories, and heat is produced
The C Cells of the Thyroid Gland (10-4)

- Also called *parafollicular cells*, are found between follicles

- Produce **calcitonin** (CT)
  - Stimulated by increases in plasma Ca$^{2+}$
  - Inhibits osteoclasts in bone
  - Stimulates calcium excretion by kidneys
  - Essential for normal bone growth in children and last trimester of pregnancy
Figure 10-9 The Thyroid Gland.

b Histological details of the thyroid gland

- C cell
- Cuboidal epithelium of follicle
- Thyroid follicles

a Location and anatomy of the thyroid gland

- Hyoid bone
- Thyroid artery
- Internal jugular vein
- Thyroid cartilage
- Thyroid vein
- Right lobe of thyroid gland
- Left lobe of thyroid gland
- Isthmus of thyroid gland
- Common carotid artery
- Trachea
- Thyroid veins
- Outline of sternum

Thyroid hormones stored in colloid of follicle

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Calcium Imbalances (10-4)

• Hypercalcemia causes:
  • Decreased sodium permeability of excitable membranes
  • Results in less responsive muscles and nerves

• Hypocalcemia causes:
  • Increased sodium permeability
  • Highly excitable, spasmodic muscles and nerves
  • Parathyroid glands prevent hypocalcemia
10. Identify the hormones of the thyroid gland.

11. What signs and symptoms would you expect to see in an individual whose diet lacks iodine?

12. When a person's thyroid gland is removed, signs of decreased thyroid hormone concentration do not appear until about one week later. Why?
The Parathyroid Glands (10-5)

- Paired, small glands embedded in posterior surface of thyroid
- Chief cells produce parathyroid hormone (PTH)
  - Stimulated by decrease in plasma Ca\(^{2+}\)
  - Activates osteoclasts in bone
  - Reduces calcium excretion by kidney
  - Stimulates kidney to secrete calcitriol, which increases Ca\(^{2+}\) absorption in digestive tract
Figure 10-10 The Homeostatic Regulation of Calcium Ion Concentrations.

Rising calcium levels in blood

HOMEOSTASIS DISTURBED
Increased excretion of calcium by kidneys
Calcium deposition in bone

HOMEOSTASIS RESTORED
Blood calcium levels decline

Blood calcium levels increase

HOMEOSTASIS
Normal blood calcium levels (8.5–11 mg/dL)

Falling calcium levels in blood

HOMEOSTASIS DISTURBED
Increased reabsorption of calcium by kidneys
Calcium release from bone
Increased calcitriol production by kidneys causes Ca\(^{2+}\) absorption by digestive system

Increased calcitonin production by thyroid gland
Calcium deposition in bone

Increased calcitriol production by kidneys causes Ca\(^{2+}\) absorption by digestive system

Parathyroid glands secrete parathyroid hormone (PTH)

Increased calcitriol production by kidneys causes Ca\(^{2+}\) absorption by digestive system
Figure 10-11 The Parathyroid Glands.
### Table 10-2  Hormones of the Thyroid Gland and Parathyroid Glands

<table>
<thead>
<tr>
<th>Gland/Cells</th>
<th>Hormone(s)</th>
<th>Targets</th>
<th>Hormonal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>THYROID</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follicular epithelium</td>
<td>Thyroxine ($T_4$), triiodothyronine ($T_3$)</td>
<td>Most cells</td>
<td>Increased energy utilization, oxygen consumption, growth, and development</td>
</tr>
<tr>
<td><strong>C cells</strong></td>
<td>Calcitonin (CT)</td>
<td>Bone, kidneys</td>
<td>Decreased calcium concentrations in body fluids (see Figure 10-10)</td>
</tr>
<tr>
<td><strong>PARATHYROIDs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chief cells</td>
<td>Parathyroid hormone (PTH)</td>
<td>Bone, kidneys</td>
<td>Increased calcium concentrations in body fluids (see Figure 10-10)</td>
</tr>
</tbody>
</table>
13. Identify the hormone secreted by the parathyroid glands.

14. Removal of the parathyroid glands would result in decreased blood concentration of what important mineral?
The Adrenal Gland (10-6)

- Also called the *suprarenal gland*
  - Yellow, pyramid-shaped
  - Sits on superior border of each kidney
  - Two portions
    1. Adrenal cortex
      - Outer part
    2. Adrenal medulla
      - Inner part
The Adrenal Cortex (10-6)

- Contains high levels of cholesterol and fatty acids
- Produces more than 24 steroid hormones called **corticosteroids**
  - Are essential for metabolic functions
  - Transported in plasma bound to proteins
  - Three zones of cortex produce three types
    1. Mineralocorticoids
    2. Glucocorticoids
    3. Androgens
Figure 10-12 The Adrenal Gland.

A superficial view of the left kidney and adrenal gland

An adrenal gland in section

The major regions of an adrenal gland
Mineralocorticoids (10-6)

- Also called MCs
  - Produced by outer zone
  - Affect electrolyte balance in body fluids
- **Aldosterone** – major MC
  - Secreted in response to low plasma $\text{Na}^+$, low BP, high plasma $\text{K}^+$, or presence of *angiotensin II*
  - Triggers reabsorption of sodium ions in kidney, sweat glands, salivary glands, and pancreas
  - Secondarily triggers water reabsorption through osmosis
Glucocorticoids (10-6)

• Also called GCs
  • Produced mostly by middle zone
  • Affect glucose metabolism

• Most important are **cortisol, corticosterone, and cortisone**
  • Secreted in response to ACTH
  • Increase rates of glycolysis and glycogenesis, resulting in increase in blood glucose levels
  • Also act as anti-inflammatory
The Androgens (10-6)

- Produced by inner zone in both males and females
- Some converted to estrogens in plasma
- In normal amounts do not affect sexual characteristics
- Function remains unclear
The Adrenal Medulla (10-6)

- Highly vascular, containing cells similar to sympathetic ganglia
- Innervated by preganglionic sympathetic fibers
- **Epinephrine** (E, or *adrenaline*) is 80 percent
- **Norepinephrine** (NE, or *noradrenaline*) is 20 percent
  - Triggers metabolic changes to increase availability of energy molecules
  - Supports and prolongs overall sympathetic response
## Table 10-3 The Adrenal Hormones

<table>
<thead>
<tr>
<th>Region/Hormone</th>
<th>Target</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADRENAL CORTEX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineralocorticoids, primarily aldosterone</td>
<td>Kidneys</td>
<td>Increase reabsorption of sodium ions and water by the kidneys; accelerate urinary loss of potassium ions</td>
</tr>
<tr>
<td>Glucocorticoids: cortisol (hydrocortisone), corticosterone, cortisone</td>
<td>Most cells</td>
<td>Release of amino acids from skeletal muscles and lipids from adipose tissues; promotes liver formation of glucose and glycogen; promotes peripheral use of lipids; anti-inflammatory effects</td>
</tr>
<tr>
<td>Androgens</td>
<td></td>
<td>Uncertain significance under normal conditions</td>
</tr>
<tr>
<td><strong>ADRENAL MEDULLA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epinephrine (E, adrenaline), norepinephrine (NE, noradrenaline)</td>
<td>Most cells</td>
<td>Increase cardiac activity, blood pressure, glycogen breakdown, and blood glucose levels; release of lipids by adipose tissue (see Table 8-5, p. 293)</td>
</tr>
</tbody>
</table>
15. Identify the two regions of the adrenal gland, and list the hormones secreted by each.

16. What effect would elevated cortisol levels have on blood glucose levels?
The Pineal Gland (10-7)

- Located on posterior portion of roof of third ventricle
- Contains neurons, glial cells, and secretory cells that produce melatonin
  - Rate of secretion affected by light and day–night cycles
  - May influence timing of sexual maturation
  - May protect CNS with antioxidant activity
  - Plays role in maintaining circadian rhythms (day–night cycles)
17. Increased amounts of light would inhibit the production of which hormone by which structure?

18. List three possible functions of melatonin.
The Endocrine Pancreas (10-8)

- **Pancreas** lies between stomach and proximal small intestine
- Contains both exocrine and endocrine cells
- Endocrine cells located in pancreatic islets
  - Also called *islets of Langerhans*, contain:
    - **Alpha cells** that secrete hormone glucagon
    - **Beta cells** that secrete hormone insulin
Figure 10-13  The Endocrine Pancreas.

- **Common bile duct**
- **Pancreatic duct**
- **Body of pancreas**
- **Lobule**
- **Tail**
- **Pancreatic acini** (clusters of exocrine cells)
- **Pancreatic islet** (islet of Langerhans)
- **Capillary**

**a** Location and gross anatomy of the pancreas

**b** A pancreatic islet surrounded by exocrine cells

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Pancreatic Regulation of Blood Glucose (10-8)

- Increases in blood glucose levels (BGL) activate beta cells to release more insulin
  - Stimulates glucose uptake by cells that have insulin receptors, all cells EXCEPT:
    - Neurons and red blood cells, epithelial cells of kidney tubules, epithelial cells of intestinal lining
  - Increases rates of protein synthesis and fat storage
  - Result is lower BGL
Pancreatic Regulation of Blood Glucose (10-8)

- Decreases in blood glucose levels activate alpha cells to release more glucagon
  - Mobilizes energy reserves
    - Glycogen in liver and muscles broken down to glucose
    - Adipose tissue releases fatty acids
    - Proteins broken down to convert to glucose in the liver
    - Result is higher BGL
Pancreatic Regulation of Blood Glucose (10-8)

- Secretion of hormones is independent of direct neural stimulus
- Indirectly affected by ANS activity and any hormone that also influences BGL
  - For example, cortisol and thyroid hormones
Diabetes Mellitus (10-8)

- Either hyposecretion of insulin or decreased sensitivity of insulin receptors

- Symptoms
  - Hyperglycemia
  - Glycosuria
  - Polyuria
Figure 10-14  The Regulation of Blood Glucose Concentrations.

- **Increased rate of glucose transport into target cells**
- **Increased rate of glucose utilization and ATP generation**
- **Increased conversion of glucose to glycogen (in liver, skeletal muscle)**
- **Increased amino acid absorption and protein synthesis**
- **Increased triglyceride synthesis in adipose tissue**

**HOMEOSTASIS DISTURBED**
- Rising blood glucose levels

**HOMEOSTASIS RESTORED**
- Blood glucose levels decrease

**HOMEOSTASIS DISTURBED**
- Falling blood glucose levels

**HOMEOSTASIS RESTORED**
- Blood glucose levels increase

- Beta cells secrete insulin

- Alpha cells secrete glucagon

- Normal blood glucose levels (70–110 mg/dL)
- Increased breakdown of glycogen to glucose (in liver, skeletal muscle)
- Increased breakdown of fat to fatty acids (in adipose tissue)
- Increased synthesis and release of glucose (by the liver)
19. Identify two important types of cells in the pancreatic islets and the hormones produced by each.

20. Which pancreatic hormone causes skeletal muscle and liver cells to convert glucose to glycogen?

21. What effect would increased levels of glucagon have on the amount of glycogen stored in the liver?
The Intestines (10-9)

- Secrete local hormones that coordinate digestive activities
- Major control over rate of digestive processes
- Can be influenced by ANS
The Kidneys (10-9)

- **Calcitriol**
  - Stimulated by PTH, derived from vitamin D$_3$, increases absorption of calcium and phosphate ions from gut

- **Erythropoietin**
  - Stimulated by kidney hypoxia, causes RBC production

- **Renin**
  - An enzyme that triggers hormonal chain reaction to increase BP, blood volume
The Heart (10-9)

- Endocrine cells in right atrium of heart
- Respond to increased blood volume entering chamber
- Excessive stretch causes them to release *atrial natriuretic peptide* (ANP)
  - Promotes loss of sodium, and therefore water
  - Inhibits renin release
  - Results in decrease in BP and blood volume
The Thymus (10-9)

- Located deep to sternum in *mediastinum*
- Very active in early childhood, atrophies in adults
- Secretes **thymosins**
  - Aid in development and maintenance of immune defenses
The Gonads: The Testes (10-9)

- In males, **interstitial cells** produce androgens
- Most important is **testosterone**
  - Promotes sperm production
  - Maintains secretory glands of reproductive tract
  - Determines secondary sex characteristics
  - Stimulates protein synthesis
  - Sperm production effect balanced by **inhibin**
The Gonads: The Ovaries (10-9)

- In females, the ova are surrounded by **follicles**
- FSH triggers follicular cells to produce:
  - **Estrogens**
    - Support maturation of ova and growth of uterine lining
  - **Inhibin**
    - Provides negative feedback to FSH
The Gonads: The Ovaries (10-9)

- Once follicle releases ovum (ovulation) the corpus luteum is formed from follicular cells
- Releases progesterone
  - Accelerates fertilized egg movement through uterine tube
  - Prepares uterus for arrival of developing embryo
- All gonadal hormones regulated by hormones of the anterior pituitary
### Table 10-4  Hormones of the Reproductive System

<table>
<thead>
<tr>
<th>Structure/Cells</th>
<th>Hormone</th>
<th>Primary Target</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TESTES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interstitial cells</td>
<td>Androgens</td>
<td>Most cells</td>
<td>Support functional maturation of sperm, protein synthesis in skeletal muscles, male secondary sex characteristics, and associated behaviors</td>
</tr>
<tr>
<td>Nurse cells</td>
<td>Inhibin</td>
<td>Anterior lobe of pituitary gland</td>
<td>Inhibit secretion of FSH</td>
</tr>
<tr>
<td><strong>OVARIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Follicular cells</td>
<td>Estrogens</td>
<td>Most cells</td>
<td>Support follicle maturation, female secondary sex characteristics, and associated behaviors</td>
</tr>
<tr>
<td></td>
<td>Inhibin</td>
<td>Anterior lobe of pituitary gland</td>
<td>Inhibits secretion of FSH</td>
</tr>
<tr>
<td>Corpus luteum</td>
<td>Progestins</td>
<td>Uterus, mammary glands</td>
<td>Prepare uterus for implantation; prepare mammary glands for secretory functions</td>
</tr>
</tbody>
</table>

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Adipose Tissue (10-9)

- Produces **leptin**
  - Provides negative feedback control of appetite
  - Binds to neurons in hypothalamus to trigger satiation (fullness) and suppression of appetite
  - Must be present for normal GnRH and gonadotropin synthesis
  - Low body fat can result in late puberty and cessation of menstrual cycles
  - Increase in body fat can increase fertility
Checkpoin (10-9)

22. Identify the two hormones secreted by the kidneys, and describe their functions.

23. Describe the action of renin.

24. Identify a hormone released by adipose tissue.
Hormonal Interactions (10-10)

- ECF contains hormones that may have the same target, resulting in four possibilities

1. **Antagonistic effects**
   - Opposing responses

2. **Synergistic effects**
   - Net result of two is greater than the sum of their individual effects

3. **Permissive effects**
   - Need for one hormone to be present for another to work

4. **Integrative effects**
   - Coordinate diverse activities
Hormones and Growth (10-10)

- Six key hormones required for normal growth

1. GH
   - Undersecretion causes dwarfism
   - Oversecretion causes gigantism

2. Thyroid hormones
   - Required for normal nervous system development

3. Insulin
   - Required for energy supply to growing cells
4. **PTH**
   - Promotes calcium availability for normal bone growth

5. **Calcitriol**, same as PTH
   - Lack of PTH and calcitriol can result in rickets

6. **Reproductive hormones**
   - Can affect activity of osteoblasts and influence secondary sex characteristic development
Hormones and Stress (10-10)

- Stress is triggered by:
  - Physical injury or disease
  - Emotional responses: anxiety or depression
  - Environmental conditions: extreme cold or heat
  - Metabolic conditions: acute starvation

- Stress triggers:
  - The general adaptation syndrome (GAS)
  - Also called the stress response
Alarm Phase ("Fight or Flight")

The alarm phase is an immediate response to stress, or crisis. The dominant hormone is epinephrine, and its secretion is part of a generalized sympathetic activation.

- Increases mental alertness
- Increases energy use by all cells
- Mobilizes glycogen and lipid reserves
- Changes circulation
- Reduces digestive activity and urine production
- Increases sweat gland secretion
- Increases heart rate and respiratory rate
Resistance Phase

The resistance phase begins if a stress lasts longer than a few hours. Glucocorticoids (GCs) are the dominant hormones of the resistance phase. GCs and other hormones act to shift tissue metabolism away from glucose, thus increasing its availability to neural tissue.

- **Mobilizes remaining energy reserves**: Lipids are released by adipose tissue; amino acids are released by skeletal muscle.
- **Conserves glucose**: Peripheral tissues (except neural) break down lipids to obtain energy.
- **Elevates blood glucose concentrations**: Liver synthesizes glucose from other carbohydrates, amino acids, and lipids.
- **Maintains blood volume**: Conservation of salts and water, loss of $K^+$ and $H^+$. 

**Long-Term Metabolic Adjustments**

- Mobilizes remaining energy reserves: Lipids are released by adipose tissue; amino acids are released by skeletal muscle.
- Conserves glucose: Peripheral tissues (except neural) break down lipids to obtain energy.
- Elevates blood glucose concentrations: Liver synthesizes glucose from other carbohydrates, amino acids, and lipids.
- Maintains blood volume: Conservation of salts and water, loss of $K^+$ and $H^+$.
Exhaustion Phase

The body’s lipid reserves are sufficient to maintain the resistance phase for weeks or even months. But when the resistance phase ends, homeostatic regulation breaks down and the exhaustion phase begins. Without immediate corrective actions, the ensuing failure of one or more organ systems will prove fatal.

Collapse of Vital Systems

- Exhaustion of lipid reserves
- Cumulative structural or functional damage to vital organs
- Inability to produce glucocorticoids
- Failure of electrolyte balance
Hormones and Behavior (10-10)

• Hypothalamus is key hormone regulator and monitor

• Behavior is also affected by hormonal abnormalities
  • Precocious puberty can occur when sex hormones are released at an earlier than normal age
  • CNS intellectual functions like learning, memory, and emotions can be altered in the adult due to hormone imbalances
Hormones and Aging (10-10)

- Usually most hormones remain the same throughout adulthood
- Exceptions are the reproductive hormones
- Changes to target organ receptors more likely to occur through reduced sensitivity
25. What type of hormonal interaction occurs when insulin lowers blood glucose levels while glucagon elevates blood glucose levels?

26. The lack of which hormones would inhibit skeletal formation and development?

27. What are the dominant hormones of the resistance phase of the general adaptation syndrome, and in what ways do they act?
Endocrine System Interaction with Other Systems (10-11)

- Endocrine system provides homeostatic regulation
- Adjusts metabolic rate of most tissue
- Regulates growth and development
The endocrine system provides long-term regulation and adjustments of homeostatic mechanisms that affect many body functions. For example, the endocrine system regulates fluid and electrolyte balance, cell and tissue metabolism, growth and development, and reproductive functions. It also works with the nervous system in responding to stressful stimuli through the general adaptation syndrome.

Gonads—ovaries in females and testes in males—are organs that produce gametes (sex cells). LH and FSH, hormones secreted by the anterior lobe of the pituitary gland, affect these organs. (The ovaries and testes are discussed further in Chapter 19.)
28. Discuss the general role of the endocrine system in the functioning of other body systems.

29. Discuss the functional relationship between the endocrine system and the muscular system.