10 The Endocrine System

PowerPoint® Lecture Outlines prepared by Alan Magid, Duke University

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Properties of the Endocrine System

1. Regulates longer term metabolic processes
2. Shares some features with nervous system
3. Releases **hormones** from endocrine cells
   - Hormones are **chemicals**
   - Hormones **alter metabolism** of many cells
   - Release regulated by **negative feedback**
   - Hormones act on **target cells**
An Overview of the Endocrine System

**Overview of the Endocrine System**

**HYPOTHALAMUS**
Production of ADH, oxytocin, and regulatory hormones

**PITUITARY GLAND**
- Anterior pituitary: ACTH, TSH, GH, PRL, FSH, LH, and MSH
- Posterior pituitary: Release of oxytocin and ADH

**THYROID GLAND**
- Thyroxine (T₄)
- Triiodothyronine (T₃)
- Calcitonin (CT)

**THYMUS**
(Undergoes atrophy during adulthood)
- Thymosins

**ADRENAL GLANDS**
Each adrenal gland is subdivided into:
- Adrenal medulla: Epinephrine (E)
- Norepinephrine (NE)
- Adrenal cortex: Cortisol, corticosterone, aldosterone, androgens

**PINEAL GLAND**
Melatonin

**PARATHYROID GLANDS**
(on posterior surface of thyroid gland)
- Parathyroid hormone (PTH)

**HEART**
- Atrial natriuretic peptide (ANP)
  (Chapter 12)

**KIDNEY**
- Renin
- Erythropoietin (EPO)
- Calcitriol
  (Chapters 11 and 18)

**ADIPOSE TISSUE**
- Leptin
- Resistin

**DIGESTIVE TRACT**
- Numerous hormones
  (detailed in Chapter 16)

**PANCREATIC ISLETS**
- Insulin, glucagon

**GONADS**
- Testes (male): Androgens (especially testosterone), inhibin
- Ovaries (female): Estrogens, progestins, inhibin

*Figure 10-1*
The Structure of Hormones

- Three chemical families
  1. Amino acid derivatives
     - E.g., *epinephrine*, thyroid hormones
  2. Peptides and proteins
     - Chains of amino acids
     - E.g., insulin, ADH
  3. 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, 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

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

NEURAL TISSUE
no binding, no hormonal effects

SKELETAL MUSCLE TISSUE
binding occurs, hormonal effects appear

Figure 10-2
Classes of Hormone Receptor

1. *Extracellular Receptors*
   - Located in cell membrane
   - Targeted by
     - Amino acid derivatives
     - Peptides
     - Eicosanoids
   - Operates through a second messenger such as cyclic-AMP
Membrane receptor
Hormone-receptor complex
First messengers (E, NE, peptide hormones, and eicosanoids)

G protein (inactive)  G protein (activated)

Activates adenylate cyclase
ATP  cAMP
Acts as second messenger

Activates kinase

Alterations in enzyme activity; opens ion channels

TARGET CELL RESPONSE
Membrane receptor

Hormone-receptor complex

First messengers (E, NE, peptide hormones, and eicosanoids)

G protein (inactive)

Cell membrane

Cytoplasm

Nuclear envelope

Nuclear pore

Nucleus

DNA
Membrane receptor

Hormone-receptor complex

First messengers (E, NE, peptide hormones, and eicosanoids)

G protein (inactive)

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Activates adenylate cyclase

Cell membrane

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Cytoplasm
ATP → cAMP → Activates kinase

Nuclear envelope
Nuclear pore

Nucleus
DNA

Cell membrane
Membrane receptor

Hormone-receptor complex

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cAMP

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Activates kinase

DNA

Nucleus

Nuclear pore

Nuclear envelope

Alterations in enzyme activity; opens ion channels

TARGET CELL RESPONSE

TARGET CELL RESPONSE

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Classes of Hormone Receptors

2. *Intracellular Receptors*
   - Located in cytoplasm or nucleus
   - Targeted by steroid and thyroid hormones
   - Operates through changes in gene expression (in other words, changes DNA)
   - Thyroid hormones also act on mitochondria
Overview of the Endocrine System

Mechanisms of Hormone Action

Figure 10-3(b)
Hormone Secretion and Distribution

- Hormones directly enter capillaries (endocrine = ductless)
- Distributed widely in the circulation
  - Most hormones travel free in solution
  - Steroid, thyroid hormones bind to blood proteins for transport
- Hormones are inactivated by
  - Removal by liver, kidney cells
  - Breakdown by extracellular enzymes
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

1. *Humoral* (fluid) stimuli
   - E.g., blood level of Ca\(^{2+}\) directly controls *parathyroid hormone* and *calcitonin* release

2. Hormonal stimuli
   - E.g., *thyroid stimulating hormone* triggers thyroid hormone release

3. Neural stimuli
   - E.g., *epinephrine* release from adrenal gland
Hypothalamus and Endocrine Control

• Three mechanisms of action

1. Hypothalamus secretes hormones as an endocrine organ
2. Hypothalamus secretes regulatory hormones to control pituitary gland endocrine cells
3. Directs neural control of adrenal medullae
Overview of the Endocrine System

Three Mechanisms of Hypothalamic Control over Endocrine Organs

1. Secretion of regulatory hormones to control activity of anterior pituitary gland
2. Production of ADH and oxytocin
3. Control of sympathetic output to adrenal medullae

Figure 10-4
The Pituitary Gland

Pituitary Gland

- 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

- Third ventricle
- Optic chiasm
- Infundibulum
- Anterior pituitary
- Sphenoid bone (sella turcica)
- Mamillary body
- Posterior pituitary

Anterior pituitary

- Secretes other pituitary hormones

Posterior pituitary

- Secretes MSH
- Releases ADH and oxytocin

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Figure 10-5
Anterior Pituitary Gland

- Controlled by *regulatory hormones* from hypothalamus
- Regulated by *negative feedback control*
The Pituitary Gland

The Hypophyseal Portal System and the Blood Supply to the Pituitary Gland

Figure 10-6
Anterior Pituitary Hormones

1. *Thyroid-Stimulating Hormone* (TSH)
   • Triggers thyroid hormone release

2. *Adrenocorticotropic Hormone* (ACTH)
   • Stimulates glucocorticoid release from adrenal gland

3. *Follicle-Stimulating Hormone* (FSH)
   • Stimulates estrogen secretion, egg production (females), sperm production (males)
4. Luteinizing Hormone (LH)
   • Triggers ovulation, progestin production (females), androgen production (males)

5. Prolactin (PRL)
   • Stimulates mammary gland development and milk secretion

6. Growth hormone (hGH)
   • Stimulates cell growth via somatomedins released from liver

7. Melanocyte Stimulating Hormone (MSH)
The Pituitary Gland

Negative Feedback Control of Endocrine Secretion

Figure 10-7(a)

<table>
<thead>
<tr>
<th>Releasing Hormone (RH)</th>
<th>Hormone 1 (from pituitary)</th>
<th>Endocrine Target Organ</th>
<th>Hormone 2 (from target organ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRH</td>
<td>TSH</td>
<td>Thyroid gland</td>
<td>Thyroid hormones</td>
</tr>
<tr>
<td>CRH</td>
<td>ACTH</td>
<td>Adrenal cortex</td>
<td>Gluco-corticoids</td>
</tr>
<tr>
<td>GnRH</td>
<td>FSH</td>
<td>Testes</td>
<td>Inhibin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ovaries</td>
<td>Inhibin Estrogens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Testes</td>
<td>Progestins Estrogens</td>
</tr>
</tbody>
</table>

(a) General pattern

KEY
- Stimulation
- Inhibition

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The Pituitary Gland

Negative Feedback Control of Endocrine Secretion

Figure 10-7(b)
The Pituitary Gland

Posterior Pituitary Gland

• Hormones:

1. Antidiuretic Hormone (ADH)
   • Reduces water loss in the urine
   • Increases thirst

2. Oxytocin
   • Stimulates uterine contraction, milk delivery
   • Stimulates prostate gland smooth muscle
The Pituitary Gland

Pituitary Hormones and Their Targets

Figure 10-8
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 Hormones

- Production requires adequate **iodine** in the diet

1. *thyroxine* \((T_4)\) and *triiodothyronine* \((T_3)\)
   - Increases **metabolism** and heat production
   - Required for normal development
The Thyroid Gland

Figure 10-9
2. **calcitonin**
   - Lowers blood Ca\(^{2+}\) levels
   - Inhibits osteoclasts of bone
   - Increases urinary calcium loss
   - Triggered by high blood Ca\(^{2+}\) level
The Thyroid Gland

Goiter:
The Parathyroid Glands

- Four glands embedded on thyroid posterior
- produce *parathyroid hormone* (*PTH*):
  - Low blood Ca\(^{2+}\) triggers secretion
  - PTH speeds bone breakdown by osteoclasts, increases dietary absorption; slows loss in kidney
  - PTH raises blood Ca\(^{2+}\)
Thyroid gland produces calcitonin

Increased excretion of calcium in kidneys

Calcium deposition in bone (inhibition of osteoclasts)

Uncertain significance in a healthy nonpregnant adult

Blood calcium levels decline

HOMEOSTASIS DISTURBED
Rising calcium levels in blood

HOMEOSTASIS
Normal calcium levels (8.5-11 mg/dl)

HOMEOSTASIS RESTORED

HOMEOSTASIS DISTURBED
Falling calcium levels in blood

Blood calcium levels increase

Parathyroid glands secrete parathyroid hormone (PTH)

Release of stored calcium from bone (stimulation of osteoclasts, inhibition of osteoblasts)

Enhanced reabsorption of calcium in kidneys

Stimulation of calcitriol production at kidneys; enhanced Ca^{2+}, PO_4^{3-} absorption by digestive tract

Figure 10-10
HOMEOSTASIS
DISTURBED

Rising calcium levels in blood

Normal calcium levels
(8.5-11 mg/dl)
Thyroid gland produces calcitonin

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Rising calcium levels in blood

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HOMEOSTASIS

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HOMEOSTASIS RESTORED.

Figure 10-10
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Normal calcium levels
(8.5-11 mg/dl)

Falling calcium levels in blood
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Normal calcium levels (8.5-11 mg/dl)

Falling calcium levels in blood

Parathyroid glands secrete parathyroid hormone (PTH)
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Parathyroid glands secrete parathyroid hormone (PTH)

Release of stored calcium from bone (stimulation of osteoclasts, inhibition of osteoblasts)
**HOMEOSTASIS**

Normal calcium levels (8.5-11 mg/dl)

---

**Falling calcium levels in blood**

- Release of stored calcium from bone (stimulation of osteoclasts, inhibition of osteoblasts)
- Enhanced reabsorption of calcium in kidneys

**Parathyroid glands secrete parathyroid hormone (PTH)**
HOMEOSTASIS
Normal calcium levels (8.5-11 mg/dl)

HOMEOSTASIS DISTURBED
Falling calcium levels in blood

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Enhanced reabsorption of calcium in kidneys

Stimulation of calcitriol production at kidneys;
enhanced $\text{Ca}^{2+}$, $\text{PO}_4^{3-}$ absorption by digestive tract

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HOMEOSTASIS DISTURBED

Falling calcium levels in blood

HOMEOSTASIS DISTURBED
The Parathyroid Glands

(a) Posterior view of the thyroid gland and parathyroid glands

(b) Thyroid and parathyroid tissues
# The Parathyroid Glands

<table>
<thead>
<tr>
<th>TABLE 10-2</th>
<th>Hormones of the Thyroid Gland and Parathyroid Glands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GLAND/CHELS</strong></td>
<td><strong>HORMONE(S)</strong></td>
</tr>
<tr>
<td><strong>THYROID</strong></td>
<td></td>
</tr>
<tr>
<td>Follicular epithelium</td>
<td>Thyroxine (T₄), triiodothyronine (T₃)</td>
</tr>
<tr>
<td>C cells</td>
<td>Calcitonin (CT)</td>
</tr>
<tr>
<td><strong>PARATHYROID</strong></td>
<td></td>
</tr>
<tr>
<td>Chief cells</td>
<td>Parathyroid hormone (PTH)</td>
</tr>
</tbody>
</table>

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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
  1. Adrenal cortex (outer)
  2. Adrenal medulla (inner)
The Adrenal Glands

The Adrenal Gland

Left adrenal gland
Arteries
Left renal artery
Left renal vein
Abdominal aorta
Inferior vena cava

Figure 10-12(a)
The Adrenal Glands

The Adrenal Gland

Cortex

Medulla

Figure 10-12(b)
Adrenal Cortex

- Makes **steroid** hormones (**corticosteroids**)
  1. **Glucocorticoids** (e.g., cortisol)
     - Stimulated by ACTH
     - Affect glucose metabolism
  2. **Mineralocorticoids** (e.g., aldosterone)
     - Restricts loss of water, Na$^+$ in urine, sweat, digestive tract, saliva
  3. **Androgens** (male hormone)
The Adrenal Glands

The Adrenal Gland

Adrenal medulla
Androgens

Adrenal cortex

Glucocorticoids

Mineralocorticoids

Capsule

Figure 10-12(c)
Adrenal Medulla

- Produces two related hormones
  1. *Epinephrine* (adrenaline)
  2. *Norepinephrine* (noradrenaline)
- Increases heart rate and force, releases glucose, fatty acids into blood, opens airways
# The Adrenal Glands

## Table 10-3: The Adrenal Hormones

<table>
<thead>
<tr>
<th>Region</th>
<th>Hormone</th>
<th>Target</th>
<th>Effects</th>
</tr>
</thead>
</table>
| Adrenal cortex  | Mineralocorticoids, primarily aldosterone  
                 |               | Kidneys           | Increased reabsorption of sodium ions and water by the kidneys; accelerates urinary loss of potassium ions |
|                 | Glucocorticoids: cortisol (hydrocortisone), corticosterone, cortisone | Most cells    | Release of amino acids from skeletal muscles and lipids from adipose tissues; promotes liver formation of glycogen and glucose; promotes peripheral use of lipids; anti-inflammatory effects |
|                 | Androgens                              |               | Uncertain significance under normal conditions                 |
| Adrenal medulla | Epinephrine (E, adrenaline), norepinephrine (NE, noradrenaline) | Most cells    | Increased cardiac activity, blood pressure, glycogen breakdown, and blood glucose levels; release of lipids by adipose tissue (see Chapter 8) |
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

- Synthesizes melatonin
  - Protects neural tissue from free radicals
  - Establishes daily wake-sleep cycle
  - Melatonin levels are higher at night and lower during the day
- Sometimes called the “3rd eye”
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

Figure 10-13(a)
The Pancreas

The Endocrine Pancreas

Pancreatic islet (islet of Langerhans)

Pancreatic acini (exocrine cells)

Figure 10-13(b)
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
Beta cells secrete insulin, which leads to an increased rate of glucose transport into target cells. This results in an increased rate of glucose utilization and ATP generation. Consequently, blood glucose concentration declines.

**HOMEOSTASIS RESTORED**

Normal glucose levels (70-110 mg/dl)

**HOMEOSTASIS DISTURBED**

Rising blood glucose levels

**HOMEOSTASIS DISTURBED**

Declining blood glucose levels

**HOMEOSTASIS RESTORED**

**HOMEOSTASIS RESTORED**

Alpha cells secrete glucagon, leading to increased breakdown of glycojen to glucose (liver, skeletal muscle) and increased breakdown of fats to fatty acids (adipose tissue). Increased synthesis and release of glucose (liver) also contribute to increased amino acid absorption and protein synthesis.

Increased breakdown of glycogen to glucose (liver, skeletal muscle)

Increased breakdown of fats to fatty acids (adipose tissue)

Increased synthesis and release of glucose (liver)

Blood glucose concentration rises.
HOMEOSTASIS
DISTURBED

Rising blood glucose levels

HOMEOSTASIS
Normal glucose levels (70-110 mg/dl)
Beta cells secrete insulin.

HOMEOSTASIS DISTURBED

Rising blood glucose levels

HOMEOSTASIS
Normal glucose levels (70-110 mg/dl)
Beta cells secrete insulin, which increases the rate of glucose transport into target cells.

HOMEOSTASIS

DISTURBED

Rising blood glucose levels

NORMAL GLUCOSE LEVELS (70-110 mg/dl)
Beta cells secrete insulin.

- Increased rate of glucose transport into target cell
- Increased rate of glucose utilization and ATP generation

HOMEOSTASIS DISTURBED

Rising blood glucose levels

HOMEOSTASIS
Normal glucose levels (70-110 mg/dl)
Beta cells secrete insulin.

Increased rate of glucose transport into target cell.

Increased rate of glucose utilization and ATP generation.

Increased conversion of glucose to glycogen (liver, skeletal muscle).

HOMEOSTASIS DISTURBED

Rising blood glucose levels.

HOMEOSTASIS

Normal glucose levels (70-110 mg/dl).
Beta cells secrete insulin.

- Increased rate of glucose transport into target cell
- Increased rate of glucose utilization and ATP generation
- Increased conversion of glucose to glycogen (liver, skeletal muscle)
- Increased amino acid absorption and protein synthesis

**HOMEOSTASIS**

**DISTURBED**

*Rising blood glucose levels*

**HOMEOSTASIS**

Normal glucose levels (70-110 mg/dl)
Beta cells secrete insulin.

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

Blood glucose concentration declines.

**HOMEOSTASIS DISTURBED**

*Rising blood glucose levels*

**HOMEOSTASIS**

Normal glucose levels (70-110 mg/dl)

Figure 10-14
Beta cells secrete insulin.

Increased rate of glucose transport into target cell.

Increased rate of glucose utilization and ATP generation.

Increased conversion of glucose to glycogen (liver, skeletal muscle).

Increased amino acid absorption and protein synthesis.

Increased fat synthesis (adipose tissue).

Blood glucose concentration declines.

**HOMEOSTASIS DISTURBED**

*Rising blood glucose levels*

**HOMEOSTASIS**

Normal glucose levels (70-110 mg/dl)

**HOMEOSTASIS RESTORED**
HOMEOSTASIS
Disturbed
Declining blood glucose levels

HOMEOSTASIS
Normal glucose levels
(70-110 mg/dl)
HOMEOSTASIS
Normal glucose levels (70-110 mg/dl)

DISTURBED
Declining blood glucose levels

Alpha cells secrete glucagon
**Normal glucose levels** (70-110 mg/dl)

**HOMEOSTASIS DISTURBED**

*Declining blood glucose levels*

**Increased breakdown of glycogen to glucose** (liver, skeletal muscle)

*Alpha cells secrete glucagon*
HOMEOSTASIS
Normal glucose levels (70-110 mg/dl)

HOMEOSTASIS DISTURBED
Declining blood glucose levels

- Increased breakdown of glycogen to glucose (liver, skeletal muscle)
- Increased breakdown of fats to fatty acids (adipose tissue)
- Alpha cells secrete glucagon
HOMEOSTASIS

Normal glucose levels (70-110 mg/dl)

HOMEOSTASIS DISTURBED
Declining blood glucose levels

Increased breakdown of glycogen to glucose (liver, skeletal muscle)
Increased breakdown of fats to fatty acids (adipose tissue)
Increased synthesis and release of glucose (liver)

Alpha cells secrete glucagon

Blood glucose concentration rises
Normal glucose levels (70-110 mg/dl)

HOMEOSTASIS RESTORED

Declining blood glucose levels

HOMEOSTASIS DISTURBED

Increased breakdown of glycogen to glucose (liver, skeletal muscle)

Increased breakdown of fats to fatty acids (adipose tissue)

Increased synthesis and release of glucose (liver)

Alpha cells secrete glucagon

Blood glucose concentration rises
Figure 10-14

HOMEOSTASIS

Normal glucose levels (70-110 mg/dl)

HOMEOSTASIS RESTORED

HOMEOSTASIS DISTURBED
Rising blood glucose levels

HOMEOSTASIS DISTURBED
Declining blood glucose levels

Beta cells secrete insulin

Increased rate of glucose transport into target cell

Increased rate of glucose utilization and ATP generation

Increased conversion of glucose to glycogen (liver, skeletal muscle)

Increased amino acid absorption and protein synthesis

Increased fat synthesis (adipose tissue)

Blood glucose concentration declines

Alpha cells secrete glucagon

Increased breakdown of glycogen to glucose (liver, skeletal muscle)

Increased breakdown of fats to fatty acids (adipose tissue)

Increased synthesis and release of glucose (liver)

Increased conversion of glucose to glycogen (liver, skeletal muscle)

Increased amino acid absorption and protein synthesis

Increased fat synthesis (adipose tissue)

Blood glucose concentration rises

Normal glucose levels (70-110 mg/dl)

HOMEOSTASIS RESTORED
Endocrine Tissues of Other Organs

- **Intestines**
  - Secretes hormones to control digestion
- **Kidneys**
  - Secretes three hormones
    1. *Calcitriol* — Stimulates calcium and phosphate absorption in intestine
    2. *Erythropoietin (EPO)* — Stimulates red blood cell production by bone marrow
    3. *Renin* — Enzyme that triggers release of *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
  - Helps produce T-cells
  - Most active prior to birth and up until puberty
  - After puberty is gradually replaced by fatty tissue

• **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 *testosterone*
- **Ovary** (female gonad)
  - *Follicle cells* secrete *estrogens*
  - *Corpus luteum* cells secrete *estrogens and progesterone*
- **Placenta** *(temporary endocrine gland)*
  - 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
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
  1. Alarm phase (sympathetic ANS response)
  2. Resistance phase (glucocorticoid response)
  3. Exhaustion phase (organ system failure)
Patterns of Hormonal Interaction

The General Adaptation Syndrome

ALARM PHASE (Fight or flight)
Immediate short-term response to crises

- Brain
- Sympathetic stimulation
- General sympathetic activation
- Epinephrine, Norepinephrine
- Adrenal medulla

1. Mobilization of glucose reserves
2. Changes in circulation
3. Increases in heart and respiratory rates
4. Increased energy use by all cells
Patterns of Hormonal Interaction

The General Adaptation Syndrome

**RESISTANCE PHASE**
Long-term metabolic adjustments

1. **Mobilization of remaining energy reserves:** Lipids are released by adipose tissue; amino acids are released by skeletal muscle
2. **Conservation of glucose:** Peripheral tissue (except neural) breaks down lipids to obtain energy
3. **Elevation of blood glucose concentrations:** Liver synthesizes glucose from other carbohydrates, amino acids, and lipids
4. **Conservation of salts and water, loss of K⁺ and H⁺**

**KEY**
- GH = Growth hormone
- GC = Glucocorticoids
- ACTH = Adrenocorticotrophic hormone
- MC = Mineralocorticoids (aldosterone)
- ADH = Antidiuretic hormone

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Patterns of Hormonal Interaction

The General Adaptation Syndrome

EXHAUSTION PHASE
Collapse of vital systems

Causes may include:
• Exhaustion of lipid reserves
• Inability to produce glucocorticoids
• Failure of electrolyte balance
• Cumulative structural or functional damage to vital organs

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Figure 10-15(c)
Hormones and Behavior

1. Sex hormones
   - Testosterone fosters aggressiveness
   - Estrogen fosters sexual receptivity

2. Thyroid hormones
   - Excess leads to nervousness, restlessness
   - Deficiency leads to sluggishness

3. 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 Endocrine System in Perspective

FIGURE 10-17
Functional Relationships Between the Endocrine System and Other Systems
The Integumentary System

- Protects superficial endocrine organs; epidermis synthesizes vitamin \( D_3 \)
- 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