Chapter 45
Hormones and the Endocrine System

Hormone (from the Greek horman, to excite)

• Overview: The Body’s Long-Distance Regulators

• Hormone definition:
  — a chemical signal secreted into the circulatory system and communicates regulatory messages within the body

• Hormones may reach all parts of the body
  — But only certain types of cells (target cells) are equipped to respond
Two systems act individually and together in regulating an animal’s physiology

Endocrine system
- Constituted by hormone-secreting cells and glands
- Secretes hormones that coordinate slower but longer-acting responses to stimuli
- “ductless”

Nervous system
- Conveys high-speed electrical signals along specialized cells called neurons
- Rapid messages control the movement of body parts
neurosecretory cells: release neurohormones into the blood

Homeostasis
Feedback
• negative
• positive
**Hormone composition**

Three major classes of molecules function as hormones in vertebrates
- Proteins and peptides (soluble)
- Amines derived from amino acids (soluble)
- Steroids (insoluble)

Signaling by any of these molecules involves three key events
- Reception
- Signal transduction
- Response

**Water-soluble hormones act on cell-surface receptors**

**Receptor**
- Embedded in the plasma membrane

**Signal transduction**
- Converts an extracellular chemical signal to an intracellular response

**Response**
- Cytoplasmic response
  - Nuclear response

eg: Glucagon (an 8-aa peptide)
Camouflage mechanism
Camouflage mechanism—melanosomes in melanocytes, controlled by melanocyte-stimulating hormones

**Intracellular Receptors for Lipid-Soluble Hormones**

- **Hormones:**
  - Mostly nonpolar (lipid–soluble) and diffusible

- **Receptor:**
  - Located in the nucleus or trapped in the cytoplasm

- **Signal transduction:**
  - Usually perform the entire task of transducing signals within a target cell.
The same hormone may have different effects on target cells that have

- Different receptors for the hormone
- Different proteins for carrying out the response

eg. Epinephrine (腎上腺素): fight–or–flight hormone

Epinephrine

- Responds to short-term stress
- Resulting in decreased blood flow to the digestive tract and increased delivery of glucose to major skeletal muscles.

Figure 45.4a–c
**Paracrine Signaling by Local Regulators**

Various types of chemical signals elicit responses in nearby target cells

- More quickly than hormones can

Examples:

- **Neurotransmitters**

- **Cytokines/ growth factors** : play a role in immune responses

- **Nitric oxide (NO)**: free radical, easy to breakdown (1998 Nobel)
  - secreted by endothelial cells
  - activates an enzyme that relaxes the neighboring smooth muscle cells → dilates the vessels and improves blood flow
  - *Viagra* (sildenafil citrate)

- **Prostaglandins** (PGs) (1982, Nobel Prize)

  **In the reproductive system**
  - First discovered in prostate–gland secretions
  - stimulate smooth muscles of the female’s uterus to contract
  - Secreted by *placenta* cells during childbirth
  - induce labor

  **In the immune system**
  - induce fever and inflammation; intensify the sensation of pain
  - *The anti-inflammatory drugs: aspirin and ibuprofen*
**In the circulation system**
- regulate the aggregation of platelets

**In the respiratory system**
Prostaglandin E
signals the muscle cells to relax

Prostaglandin F
signals the muscle cells to contract

---

**The major human endocrine glands**
### Major human endocrine glands and their hormones

#### Table 45.1 Major Human Endocrine Glands and Some of Their Hormones

<table>
<thead>
<tr>
<th>Gland</th>
<th>Hormone</th>
<th>Chemical Class</th>
<th>Representative Actions</th>
<th>Regulated By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothalamus</td>
<td>Hormones released from the posterior pituitary and hormones that regulate the anterior pituitary (see below)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pituitary gland</td>
<td>Growth hormone (GH)</td>
<td>Protein</td>
<td>stimulates growth of bones and soft tissues</td>
<td>GH and LH, ACTH</td>
</tr>
<tr>
<td></td>
<td>Antidiuretic hormone</td>
<td>Peptide</td>
<td>promotes retention of water by kidneys</td>
<td>Nervous system</td>
</tr>
<tr>
<td></td>
<td>Adrenocorticotropic</td>
<td>Peptide</td>
<td>stimulates release of adrenocorticotropic hormones</td>
<td>Nervous system</td>
</tr>
<tr>
<td></td>
<td>hormone (ACTH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior pituitary</td>
<td>Follicle-stimulating</td>
<td>Glycoprotein</td>
<td>stimulates production of sex hormones and accessory gland</td>
<td>Thyroid, adrenal</td>
</tr>
<tr>
<td></td>
<td>hormone (FSH)</td>
<td></td>
<td>tissues</td>
<td></td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>Thyroid stimulating</td>
<td>Glycoprotein</td>
<td>stimulates release of thyroid hormones</td>
<td>Thyroid, parathyroid</td>
</tr>
<tr>
<td></td>
<td>hormone (TSH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calcitonin (CT)</td>
<td>Peptide</td>
<td>lowers blood calcium level</td>
<td>Calcium in blood</td>
</tr>
<tr>
<td>Parathyroid glands</td>
<td>Parathyroid hormone (PT)</td>
<td>Peptide</td>
<td>raises blood calcium level</td>
<td>Calcium in blood</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Insulin</td>
<td>Protein</td>
<td>lowers blood glucose level</td>
<td>Glucose in blood</td>
</tr>
<tr>
<td></td>
<td>Glucagon</td>
<td>Protein</td>
<td>raises blood glucose level</td>
<td>Glucose in blood</td>
</tr>
<tr>
<td>Adrenal glands</td>
<td>Epinephrine and</td>
<td>Amines</td>
<td>stimulates release of adrenocorticotropic hormones</td>
<td>Nervous system</td>
</tr>
<tr>
<td></td>
<td>norepinephrine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adrenal cortex</td>
<td>Glucocorticoids</td>
<td>Steroid</td>
<td>stimulates release of glucocorticoids</td>
<td>ACTH</td>
</tr>
<tr>
<td></td>
<td>Mineralocorticoids</td>
<td>Steroid</td>
<td>stimulates release of hormones controlling sodium</td>
<td>Renin, aldosterone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>retention</td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>Androgens</td>
<td>Steroid</td>
<td>support spermatogenesis; promotes development and</td>
<td>FSH and LH, LH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>maintenance of male secondary sex characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estrogens</td>
<td>Steroid</td>
<td>stimulates uterine lining growth; promotes development and</td>
<td>FSH and LH, LH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>maintenance of female secondary sex characteristics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Progesterone</td>
<td>Steroid</td>
<td>promotes uterine lining growth</td>
<td>FSH and LH, LH</td>
</tr>
<tr>
<td>Pituicy gland</td>
<td>Melanocytes</td>
<td>Amines</td>
<td>involved in biological rhythms</td>
<td>Light/dark cycles</td>
</tr>
</tbody>
</table>
The pineal gland—Melatonin

- The pineal gland, located within the brain
  Contains **light-sensitive cells**
  Secretes melatonin
  
  ![Chemical structure of melatonin](http://en.wikipedia.org/wiki/Melatonin)

- The primary functions of melatonin (褪黑激素)
  - Affects skin pigmentation in many vertebrates
  - Appear to be related to biological rhythms associated with reproduction

- Release of melatonin
  - Is controlled by light/dark cycles
  - main target cells are in the part of the brain called the suprachiasmatic nucleus (SCN)
The hypothalamus, a region of the lower brain
- Contains different sets of neurosecretory cells

The pituitary gland: a lima bean–sized organ located at the base of the hypothalamus

The posterior pituitary (neurohypophysis):
- an extension of the hypothalamus
- stores and secretes two hormones from hypothalamus
**Posterior Pituitary Hormones**

The two hormones released from the posterior pituitary
Act directly on nonendocrine tissues

*Antidiuretic hormone (ADH) 抗利尿激素*
— acts on the kidneys, increasing water retention and thus decreasing urine volume.

*Oxytocin 催生素*
— acts on uterine muscles to contract during childbirth
— causes the mammary glands to eject milk during nursing

---

**The anterior pituitary**

A true-endocrine gland, controlled by the neurohormones from hypothalamus

Synthesize and secrete at least eight different hormones directly into the blood.
Tropic hormones:  

Hormones that regulate the function of endocrine organs

**Tropic Effects Only**  
FSH, follicle-stimulating hormone  
LH, luteinizing hormone  
TSH, thyroid-stimulating hormone  
ACTH, adrenocorticotropic hormone

**Nontropic Effects Only**  
Prolactin  
MSH, melanocyte-stimulating hormone  
Endorphin

**Nontropic and Tropic Effects**  
Growth hormone

---

**Anterior Pituitary Hormones**  
- Produces both tropic and nontropic hormones

**The four strictly tropic hormones are**

- Follicle-stimulating hormone (FSH)
- Luteinizing hormone (LH)
- Thyroid-stimulating hormone (TSH)
- Adrenocorticotropic hormone (ACTH)

**Gonadotropins:** stimulate the activities of the male and female gonads

**ACTH (促腎上腺皮質素)**  
Peptide; stimulates the production and secretion of steroid hormones by the adrenal cortex.
The nontropic hormones include:

- **Prolactin (PRL)**
  - Stimulates mammary gland growth and lactation in mammals
  - Regulates fat metabolism and reproduction in birds…

- **Melanocyte-stimulating hormone (MSH)**
  - Regulates the activity of pigment-containing cells in the skin of some fishes, amphibians, and reptiles.
  - Act on neurons in the brain, inhibiting hunger in mammals

- **β-endorphin**
  - Bind to brain receptors and inhibit the sensation of pain
  - “Runner’s high” effects

The hormones play both tropic and nontropic effects:

- **Growth hormone (GH)**

  Tropic action: signal the liver to release insulin–like growth factors (IGFs), which circulate stimulate bone/cartilage growth.

  Non-tropic action: exerts diverse metabolic effects that tend to raise blood glucose
Hyposecretion of GH in childhood

→ **Dwarfism**
~about 4 feet (1.2 m)

Hypersecretion of GH during childhood

→ **Gigantism**
as tall as 8 feet (2.4 m)

Excessive production of GH in adulthood

→ **Acromegaly**肢端肥大症
Nonpituitary hormones that regulate metabolism, homeostasis etc.

The thyroid gland
- Consists of two lobes located on the ventral surface of the trachea
- Produces two iodine-containing hormones, triiodothyronine (T3) and thyroxine (T4)
- T4 is converted to T3 by deiodinases

Secretion of thyroid hormones is regulated by hypothalamus and anterior pituitary hormones
- Two negative feedback loops

TSH–releasing hormone
thyroid–stimulating hormone

Hypothalamus

Anterior pituitary

Thyroid

T3 + T4

TRH

TSH

Figure 45.9
The thyroid hormones

Play crucial roles in stimulating metabolism and influencing development and maturation

Other vertebrate studies:
— the metamorphosis of a tadpole into a frog
— required for the normal functioning of bone-forming cells and the branching of nerve cells during embryonic development of the brain.

In mammalian development

— Thyroid hormones help maintain normal blood pressure, heart rate, muscle tone, digestion, and reproductive functions.

— Important in bioenergetics, generally increasing the rate of oxygen consumption and cellular metabolism

Hyperthyroidism

— lead to high body temperature, profuse sweating, weight loss, irritability, and high blood pressure.

— Graves' disease

Tissue behind the eyes can become swollen and fibrous

Fig 45.10

The tissue behind the eyes can become swollen and fibrous.
**Hypothyroidism**
Can produce symptoms such as weight gain, lethargy, and intolerance to cold in adults.

- **Goiter**
  A deficiency of iodine in the diet

  TSH enlarging the thyroid

---

**Cretinism**
Inherited condition of thyroid deficiency or lacked of thyroid hormones in childhoods

endemic cretinism in the Democratic Republic of Congo:
Four inhabitants aged 15-20 years:
a normal male and three females with severe longstanding hypothyroidism with dwarfism, retarded sexual development, puffy features, dry skin and hair and severe mental retardation. From Delange (229).
Calcitonin (抑鈣激素; from thyroid gland), a 32-aa peptide

Parathyroid glands
-four small structures embedded in the surface of the thyroid

Parathyroid Hormone; PTH (from parathyroid glands)
- Blood calcium homeostasis

Calcitonin and Parathyroid Hormone

**In bone**
- ↑Osteoclasts (蝕骨細胞)
- ↑Ca2+ reabsorption

**In kidney**
- ↑Conversion of vitamin D (indirect)

**In bone**
- ↓Osteoblasts (成骨細胞)
- ↓Ca2+ reabsorption (direct)

**In kidney**
- ↑Active vitamin D

**STIMULUS:**
- Rising blood Ca2+ level
- Falling blood Ca2+ level

**Homeostasis:**
- Blood Ca2+ level (about 10 mg/100 mL)

**Blood Ca2+ level rises to set point**
- Stimulation of Ca2+ deposition in bones
- Reduction of Ca2+ reabsorption in kidneys

**Blood Ca2+ level declines to set point**
- Stimulation of Ca2+ release from bones
- Stimulation of Ca2+ uptake in kidneys

**Fig 45.11**
• **Hormones in the pancreas**

Insulin

Glucagon (peptide, 11 aa)

Somatostatin (peptide, 14 aa)

islets of Langerhans

**Somatostatin (endocrine and paracrine functions)**

— first discovered in hypothalamic extracts

— identified as a hormone that inhibited secretion of growth hormone.

— a paracrine manner to inhibit the secretion of both glucagon and insulin.

— suppress pancreatic exocrine secretions.
Insulin and Glucagon
—antagonistic hormones that regulate the glucose concentration in the blood

• Promoting the cellular uptake of glucose (except brain cells)
• Slowing glycogen breakdown in the liver
• Promoting fat storage
• Inhibit the conversion to glucose

• Stimulating the conversion of glycogen to glucose in the liver
• Stimulating the breakdown of fat and protein into glucose

**Diabetes Mellitus**
- the best-known endocrine disorder
- Diabetes, from the Greek diabainein, to pass through, refers to this copious urination
- Mellitus, from the Greek meli, honey, refers to the presence of sugar in urine

- marked by high blood glucose.

Fat becomes the main substrate for cellular respiration ➔ threatening life by lowering blood pH.
**Diabetes Mellitus**

**Type I diabetes mellitus (insulin-dependent diabetes)**
- Is an autoimmune disorder in which the immune system destroys the beta cells of the pancreas
- Usually appears during childhood

**Type II diabetes mellitus (non-insulin-dependent diabetes)**
90% of people with diabetes have type II
- Reduced responsiveness of target cells due to some change in insulin receptors
- Deficiency of insulin
- Heredity; excess body weight and lack of exercise

---

**The adrenal glands**
- Are adjacent to the kidneys
- Are actually made up of two glands: the adrenal medulla and the adrenal cortex

**Adrenal Hormones: Response to Stress**
• Stress and the adrenal gland

Adrenal medulla secretes epinephrine and norepinephrine.

Adrenal cortex secretes mineralocorticoids and glucocorticoids.

Effects of epinephrine and norepinephrine:
1. Glycogen broken down to glucose; increased blood glucose
2. Increased blood pressure
3. Increased breathing rate
4. Increased metabolic rate
5. Change in blood flow patterns, leading to increased alertness and decreased digestive and kidney activity

Effects of mineralocorticoids:
1. Retention of sodium ions and water by kidneys
2. Increased blood volume and blood pressure

Effects of glucocorticoids:
1. Proteins and fats broken down and converted to glucose, leading to increased blood glucose
2. Immune system may be suppressed

(a) Short-term stress response
(b) Long-term stress response

Figure 45.13a,b

Hormones from the Adrenal Medulla

Epinephrine 腺上腺素
(adrenaline)

members of catecholamines 儿茶酚胺，
derived from tyrosine

Norepinephrine 正肾上腺素
(noradrenaline)
epinephrine and norepinephrine mediate fight–or–flight response

Main: give the body a rapid bioenergetic boost
— increase the rate of glycogen breakdown in the liver and skeletal muscles, promote glucose release
— stimulate the release of fatty acids from fat cells

Profound effects on cardiovascular/respiratory systems
— increase the heartbeat and dilate the bronchioles in the lungs (prescriptions for heart stimulant or asthma)
— cause blood vessels in smooth muscles to contract and vessels in skeletal muscles to relax
— shunting blood away from the skin, digestive organs, and kidneys

Corticosteroids (皮質類固醇) from the Adrenal Cortex

Glucocorticoids (腎上腺皮質酮), such as cortisol
• Augmenting glucagon from the pancreas
• Causing the breakdown of fat and muscle proteins
  → helping withstand long–term environmental challenge.
• Suppress certain components of the body’s immune system

Mineralocorticoids (礦物皮質酮), such as aldosterone
• Principally on salt and water balance
  → Act on kidneys to reabsorb sodium ions and water from filtrate, raising blood pressure and volume

Sex hormones, mainly male hormones (androgens)
Steroidogenesis

Glucocorticoids →

Mineralocorticoids →

Gonadal Sex Hormones

- The gonads—testes and ovaries
  - Produce most of the body's sex hormones: androgens, estrogens, and progestins

Major Pathways in Steroid Biosynthesis

Gonadal Sex Hormones

- The gonads—testes and ovaries
  - Produce most of the body's sex hormones: androgens, estrogens, and progestins
Steroidogenesis

Figure 46.13 The reproductive cycle of the human female

(a) Control by hypothalamus
Hypothalamus releases GnRH
Anterior pituitary releases FSH and LH
FSH and LH stimulate follicle to grow
Ovulation
Corpus luteum
Degenerating corpus luteum
FSH and LH surge trigger ovulation
Peak cause LH surge
Estrogen
Progesterone
Ovarian cycle
Growing follicle
Mature follicle
Degenerating follicle
Peak presence
Very low
Estrogen and progesterone secreted by corpus luteum
Estrogen and progesterone promote thickening of endometrium
Ovarian hormones in blood

(b) Pituitary gonadotropins in blood
LH
FSH
FSH and LH stimulate follicle to grow
Ovulation
Corpus luteum
Degenerating corpus luteum
FSH and LH surge trigger ovulation
Peak cause LH surge
Estrogen
Progesterone

(c) Ovarian cycle
Growing follicle
Mature follicle
Degenerating follicle
Peak presence
Very low
Estrogen and progesterone secreted by corpus luteum
Estrogen and progesterone promote thickening of endometrium
Ovarian hormones in blood

(d) Ovarian hormones in blood
Estrogen
Progesterone
Ovulation
Corpus luteum
Degenerating corpus luteum
FSH and LH surge trigger ovulation
Peak cause LH surge
Estrogen
Progesterone

(e) Urinary (menstrual) cycle
Endometrium
Menstrual flow phase
Proliferative phase
Secretory phase

Three phases

GnRH: gonadotropin-releasing hormone
Gonadotropin
Estrogens, the most important of which is estradiol

- Are responsible for the maintenance of the female reproductive system and the development of female secondary sex characteristics

Progestins, which include progesterone

- Are primarily involved in preparing and maintaining the uterus

The testes primarily synthesize androgens, the main one being testosterone

- Stimulate the 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 many health risks
    • testicular atrophy
    • baldness
    • masculinizing
    • breast shrinkage
    • acne
    • heart/bone/liver damage

Figure 45.14

• Invertebrate regulatory systems also involve endocrine and nervous system interactions

Three hormones play major roles in molting and metamorphosis

**Brain hormone**
• Is produced by neurosecretory cells
• Stimulates the release of ecdysone from the prothoracic glands

**Ecdysone**
• Promotes molting and the development of adult characteristics

**Juvenile hormone**
• Promotes the retention of larval characteristics
In insects

Molting and development are controlled by three main hormones

1. Neurosecretory cells in the brain produce brain hormone (BH), which is stored in the corpora cardiaca until release.

2. BH signals its main target organ, the prothoracic gland, to produce the hormone ecdysone.

3. Ecdysone secretion from the prothoracic gland is episodic, with each release stimulating a molt and metamorphosis.

4. Juvenile hormone (JH), secreted by the corpora allata, determines the result of the molt. At relatively high concentrations of JH, ecdysone-stimulated molting produces another larval stage. JH suppresses metamorphosis. But when levels of JH fall below a certain concentration, a pupa forms at the next ecdysone-induced molt. The adult insect emerges from the pupa.

Figure 45.15