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”

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<td>Low blood glucose</td>
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<td>Receptor protein</td>
<td>Pancreas secretes glucagon</td>
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<td>Liver</td>
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<td>Blood vessel</td>
<td>Glycogen breakdown, glucose release into blood</td>
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<td>Target effectors</td>
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**Nervous system**
- Conveys high-speed electrical signals along specialized cells called neurons
- Rapid messages control the movement of body parts
Endocrine cell secrete signal molecules (neurosecretory cells) and release neurohormones into the blood.

Pathway Example

- **Stimulus**: Low blood glucose
- **Receptor protein**: Pancreas secretes glucagon (↓)
- **Endocrine cell**: Blood vessel
- **Liver**: Target effectors
- **Response**: Glycogen breakdown, glucose release into blood

**Simple endocrine pathway**

**Homeostasis**

Feedback:
- negative
- positive

**neurosecretory cells**: release **neurohormones** into the blood

Pathway Example

- **Stimulus**: Suckling
- **Sensory neuron**: Hypothalamus/posterior pituitary
- **Neurosecretory cell**: Blood vessel
- **Posterior pituitary**: Secretes oxytocin (↓)
- **Blood vessel**: Target effectors
- **Smooth muscle in breast**: Response

**Simple neurohormone pathway**

Pathway Example

- **Stimulus**: Hypothalamic neurohormone released in response to neural and hormonal signals
- **Sensory neuron**: Hypothalamus
- **Neurosecretory cell**: Blood vessel
- **Anterior pituitary**: Secretes prolactin (↓)
- **Blood vessel**: Target effectors
- **Memmary glands**: Response

**Simple neuroendocrine pathway**
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
Intracellular Receptors for Lipid-Soluble Hormones

• Steroids (estrogens, progesterone), thyroid hormones, and the hormonal form of vitamin D

Hormones:
• mostly nonpolar (lipid–soluble) 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.

![Diagram of different receptors and cell responses](image)

(a) skin, Intestinal blood vessel
(b) Skeletal muscle blood vessel
(c) Liver cell

Glycogen deposits
Glycogen breaks down and glucose is released from cell

Different intercellular proteins → different cell responses

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

![Prostaglandins E and F](figure45_5.png)

Prostaglandin F
- signals the muscle cells to contract

*Figure 45.5 platelets (pink and purple) develop a sticky outer surface and adhere to each other*
• The major human endocrine glands

- Pineal
- Hypothalamus
- Pituitary
- Thyroid
- Parathyroids
- Thymus
- Adrenals
- Pancreas
- Ovary
- Testes

• Major human endocrine glands and their hormones

| Table 45.1 Major Human Endocrine Glands and Some of Their Hormones |
|-----------------------------|------------------|----------------|-----------------|------------------|
| Gland                       | Hormone          | Chemical Class | Representative Actions                                      | Regulated By      |
| Hypothalamus                | Hormones released from the posterior pituitary and hormones that regulate the anterior pituitary (see below). |
| Pituitary gland             | Oxytocin (催生素)  | Peptide        | Stimulates contraction of uterine and mammary gland cells   | Nervous system    |
| Posterior pituitary         | Antidiuretic hormone (ADH) (抗利尿激素) | Peptide | Promotes retention of water by kidneys | Water/salt balance |
| (releases neurohormones made in hypothalamus) | Growth hormone (GH) (催乳素) | Protein | Stimulates growth (especially bones) and metabolic functions | Hypothalamic hormones |
| Anterior pituitary          | Prolactin (PRL) (泌乳素) | Protein | Stimulates milk production and secretion | Hypothalamic hormones |
|                               | Follicle-stimulating hormone (FSH) (促卵泡激素) | Glycoprotein | Stimulates production of ova and sperm | Hypothalamic hormones |
|                               | Luteinizing hormone (LH) (促黄体激素) | Glycoprotein | Stimulates ovaries and tests | Hypothalamic hormones |
|                               | Thyroid-stimulating hormone (TSH) (促甲状腺激素) | Glycoprotein | Stimulates thyroid gland | Thyroxine in blood; hypothalamic hormones |
|                               | Adrenocorticotropic hormone (ACTH) (促肾上腺皮质激素) | Peptide | Stimulates adrenal cortex to secrete glucocorticoids | Glucocorticoids; hypothalamic hormones |
| Thyroid gland                | Triiodothyronine (T<sub>3</sub>) and thyroxine (T<sub>4</sub>) (三碘甲状腺原氨酸和甲状腺素) | Amines | Stimulates and maintains metabolic processes | TSH |
|                               | Calcitomin (抑钙素) | Peptide | Lowers blood calcium level | Calcium in blood |
| Parathyroid glands           | Parathyroid hormone (PTH) (甲状旁腺素) | Peptide | Raises blood calcium level | Calcium in blood |
- Major human endocrine glands and their hormones

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<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>
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<td>Adrenal glands</td>
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<td></td>
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<tr>
<td>Adrenal medulla</td>
<td>Epinephrine and</td>
<td>Amine</td>
<td>Raise blood glucose level; increase metabolic activities; constrict certain blood</td>
<td>Nervous system</td>
</tr>
<tr>
<td></td>
<td>norepinephrine</td>
<td></td>
<td>vessels</td>
<td></td>
</tr>
<tr>
<td>Adrenal cortex</td>
<td>Glucocorticoids</td>
<td>Steroid</td>
<td>Raise blood glucose level</td>
<td>ACTH</td>
</tr>
<tr>
<td></td>
<td>Mineralocorticoids</td>
<td>Steroid</td>
<td>Promote reabsorption of Na and excretion of K in kidneys</td>
<td>K in blood</td>
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<tr>
<td>Gonads</td>
<td></td>
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<td></td>
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<tr>
<td>Testes</td>
<td>Androgens</td>
<td>Steroid</td>
<td>Support sperm formation; promote development and maintenance of male secondary sex</td>
<td>FSH and LH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>characteristics</td>
<td></td>
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<tr>
<td>Ovaries</td>
<td>Estrogens</td>
<td>Steroid</td>
<td>Stimulate uterine lining growth; promote development and maintenance of female</td>
<td>FSH and LH</td>
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<td>Pineal gland</td>
<td>Melatonin</td>
<td>Amin</td>
<td>Involved in biological rhythms</td>
<td>Light/dark cycles</td>
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The pineal gland-Melatonin 褪黑激素
- The pineal gland, located within the brain
  - Contains light-sensitive cells
  - Secretes melatonin

<http://en.wikipedia.org/wiki>

trp w Tryptophan

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)

Relation Between the Hypothalamus and Pituitary Gland
• 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)**
- acts on the kidneys, increasing water retention and thus decreasing urine volume.

**Oxytocin**
- 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

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.

Anterior Pituitary Hormones

The nontropic hormones include

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

- **Melanocyte-stimulating hormone (MSH)** 黑色素細胞刺激素
  - 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** 腦內啡
  - Bind to brain receptors and inhibit the sensation of pain
  - “Runner's high” effects
Anterior Pituitary Hormones

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

Hyposcretion 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

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

http://www.answers.com/topic/thyroid-hormone
Secretion of thyroid hormones is regulated by hypothalamus and anterior pituitary hormones

- two negative feedback loops

Functions in mammals

- 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
**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

![Thyroid hormone production diagram](image)

**Cretinism** 矮呆病
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
↑Osteoblasts 成骨細胞
In kidney
↓Ca2+ reabsorption

In bone
↑Osteoclasts 蝕骨細胞 (direct)
In kidney
↑Ca2+ reabsorption (direct)
↑Conversion of vitamin D (indirect)
Hormones in the pancreas

- Insulin
- Glucagon (peptide, 11 aa)
- Somatostatin (peptide, 14 aa)

Islets of Langerhans

- Hormone-secreting cells make up only **1–2% of its weight**

**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.
- Suppresses pancreatic exocrine secretions.

- Tropic
- Endocrine
- Paracrine
- Non-tropic
**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 (≈6.5% of US population)**
- the best-known endocrine disorder

- Diabetes (diabainein): to pass through, refers to this copious urination
- Mellitus (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
— 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

Spinal cord (cross section)
Nerve signals
Nerve cell
Releasing hormone
Hypothalamus
Anterior pituitary
Blood vessel
ACTH
Adrenal gland
Kidney
Adrenal medulla
Adrenal cortex

(a) Short-term stress response
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

(b) Long-term stress response
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

Figure 45.13a,b

Hormones from the Adrenal Medulla (Short-term response)

Epinephrine (adrenaline)
members of catecholamines, derived from tyrosine

Norepinephrine (noradrenaline)

E ffects 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

E ffects of mineralocorticoids:
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Figure 45.13a,b

Hormones from the Adrenal Medulla (Short-term response)

Epinephrine 睫上腺素
(adrenaline)

members of catecholamines

Norepinephrine 正睫毛腺素
(noradrenaline)
epinephrine and norepinephrine mediate **Short-term** 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

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**Corticosteroids (皮質類固醇) from the Adrenal Cortex**

**Long-term response**

**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 (andro gens)
Steroidogenesis

Glucocorticoids →

Mineralocorticoids →