Unit IV

The Endocrine System
Neurotransmitter

Nerve impulse

(b) Endocrine system

Endocrine cells

Hormone in bloodstream

Target cells
Lipid Soluble Hormone Action
Water Soluble
Hormone Action

1. Binding of hormone (first messenger) to its receptors activates G proteins, which activate adenylate cyclase.
2. Activated adenylate cyclase converts ATP to cAMP.
3. cAMP serves as a second messenger to activate protein kinases.
4. Activated protein kinases phosphorylate other enzymes.
5. Millions of phosphorylated enzymes catalyze reactions that produce physiological responses.
6. Phosphodiesterase inactivates cAMP.
Fig. 17.19

Hormone → Receptor → G protein → Adenylate cyclase → cAMP + PPI

1. GTP → GDP + Pi
2. ATP → cAMP
3. PPI
4. Activated protein kinase
5. Activated enzymes
6. Enzyme substrates → Enzyme products → Various metabolic effects

ACTH, FSH, LH, PTH, TSH, Glucagon, Calcitonin, Catecholamines
Up-regulation

Hormone

Receptor

Low receptor density
Weak response

Increased receptor density
Increased sensitivity

Response

Stronger response

(a)
Down-regulation

(b)
Fig. 17.4a

Nuclei of hypothalamus
Paraventricular nucleus
Supraoptic nucleus
Optic chiasm
Adenohypophysis

Third ventricle of brain
Floor of hypothalamus
Median eminence
Hypothalamohypophyseal tract
Neurohypophysis

Pars tuberalis
Anterior lobe
Posterior lobe

Oxytocin
Antidiuretic hormone
Axons to primary capillaries
Primary capillaries
Superior hypophysyal artery

Gonadotropin-releasing hormone
Thyrotropin-releasing hormone
Corticotropin-releasing hormone
Prolactin-releasing hormone
Prolactin-inhibiting hormone
Growth hormone–releasing hormone
Somatostatin

Secondary capillaries

Follicle-stimulating hormone
Luteinizing hormone
Thyroid-stimulating hormone (thyrotropin)
Adrenocorticotropic hormone
Prolactin
Growth hormone
Fig. 17.7

- Larynx
- Thyroid gland
- Trachea
- Thymus
- Lung
- Heart
- Diaphragm
Pharynx (posterior view)

Thyroid gland

Parathyroid glands

Esophagus

Trachea
Fig. 17.12

- Follicle
- Egg (ovum)
- Granulosa cells (estrogen and progesterone source)
- Ovulation
- Corpus luteum
- Seminiferous tubule
- Sustentacular cell
- Future sperm cells
- Maturing sperm
- Interstitial cells (testosterone source)
<table>
<thead>
<tr>
<th>Nervous System</th>
<th>Endocrine System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicates by means of electrical impulses and neurotransmitters</td>
<td>Communicates by means of hormones</td>
</tr>
<tr>
<td>Releases neurotransmitters at synapses at specific target cells</td>
<td>Releases hormones into bloodstream for general distribution throughout body</td>
</tr>
<tr>
<td>Usually has relatively local, specific effects</td>
<td>Sometimes has very general, widespread effects</td>
</tr>
<tr>
<td>Reacts quickly to stimuli, usually within 1 to 10 msec</td>
<td>Reacts more slowly to stimuli, often taking seconds to days</td>
</tr>
<tr>
<td>Stops quickly when stimulus stops</td>
<td>May continue responding long after stimulus stops</td>
</tr>
<tr>
<td>Adapts relatively quickly to continual stimulation</td>
<td>Adapts relatively slowly; may continue responding for days to weeks of stimulation</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Name</td>
</tr>
<tr>
<td>--------------</td>
<td>------</td>
</tr>
<tr>
<td>ACTH</td>
<td>Adrenocorticotropic hormone (corticotropin)</td>
</tr>
<tr>
<td>ADH</td>
<td>Antidiuretic hormone (vasopressin)</td>
</tr>
<tr>
<td>ANP</td>
<td>Atrial natriuretic peptide</td>
</tr>
<tr>
<td>CRH</td>
<td>Corticotropin-releasing hormone</td>
</tr>
<tr>
<td>DHEA</td>
<td>Dehydroepiandrosterone</td>
</tr>
<tr>
<td>EPO</td>
<td>Erythropoietin</td>
</tr>
<tr>
<td>FSH</td>
<td>Follicle-stimulating hormone</td>
</tr>
<tr>
<td>GH</td>
<td>Growth hormone (somatotropin)</td>
</tr>
<tr>
<td>GHRH</td>
<td>Growth hormone–releasing hormone</td>
</tr>
<tr>
<td>GnRH</td>
<td>Gonadotropin-releasing hormone</td>
</tr>
<tr>
<td>IGFs</td>
<td>Insulin-like growth factors (somatomedins)</td>
</tr>
<tr>
<td>LH</td>
<td>Luteinizing hormone</td>
</tr>
<tr>
<td>NE</td>
<td>Norepinephrine</td>
</tr>
<tr>
<td>OT</td>
<td>Oxytocin</td>
</tr>
<tr>
<td>PIH</td>
<td>Prolactin-inhibiting hormone (dopamine)</td>
</tr>
<tr>
<td>PRH</td>
<td>Prolactin-releasing hormone</td>
</tr>
<tr>
<td>PRL</td>
<td>Prolactin</td>
</tr>
<tr>
<td>PTH</td>
<td>Parathyroid hormone (parathormone)</td>
</tr>
<tr>
<td>T₃</td>
<td>Triiodothyronine</td>
</tr>
<tr>
<td>T₄</td>
<td>Thyroxine (tetraiodothyronine)</td>
</tr>
<tr>
<td>TH</td>
<td>Thyroid hormone ($T_3$ and $T_4$)</td>
</tr>
<tr>
<td>TRH</td>
<td>Thyrotropin-releasing hormone</td>
</tr>
<tr>
<td>TSH</td>
<td>Thyroid-stimulating hormone</td>
</tr>
</tbody>
</table>
Table 17.3  Hypothalamic Releasing and Inhibiting Hormones that Regulate the Anterior Pituitary

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Principal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRH: Thyrotropin-releasing hormone</td>
<td>Promotes TSH and PRL secretion</td>
</tr>
<tr>
<td>CRH: Corticotropin-releasing hormone</td>
<td>Promotes ACTH secretion</td>
</tr>
<tr>
<td>GnRH: Gonadotropin-releasing hormone</td>
<td>Promotes FSH and LH secretion</td>
</tr>
<tr>
<td>PRH: Prolactin-releasing hormone</td>
<td>Promotes PRL secretion</td>
</tr>
<tr>
<td>PIH: Prolactin-inhibiting hormone</td>
<td>Inhibits PRL secretion</td>
</tr>
<tr>
<td>GHRH: Growth hormone–releasing hormone</td>
<td>Promotes GH secretion</td>
</tr>
<tr>
<td>Somatostatin</td>
<td>Inhibits GH and TSH secretion</td>
</tr>
<tr>
<td>Hormone</td>
<td>Target Organ</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td><strong>Anterior Pituitary</strong></td>
<td></td>
</tr>
<tr>
<td>FSH: Follicle-stimulating hormone</td>
<td>Ovaries, testes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>LH: Luteinizing hormone</td>
<td>Ovaries, testes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>TSH: Thyroid-stimulating hormone</td>
<td>Thyroid gland</td>
</tr>
<tr>
<td>ACTH: Adrenocorticotropic hormone</td>
<td>Adrenal cortex</td>
</tr>
<tr>
<td>PRL: Prolactin</td>
<td>Mammary glands, testes</td>
</tr>
<tr>
<td>GH: Growth hormone (somatotropin)</td>
<td>Liver</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Posterior Pituitary</strong></td>
<td></td>
</tr>
<tr>
<td>ADH: Antidiuretic hormone</td>
<td>Kidneys</td>
</tr>
<tr>
<td>OT: Oxytocin</td>
<td>Uterus, mammary glands</td>
</tr>
</tbody>
</table>
Table 17.5a

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Target</th>
<th>Principal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pineal Gland</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melatonin and serotonin</td>
<td>Brain</td>
<td>Influence mood; may regulate the timing of puberty</td>
</tr>
<tr>
<td><strong>Thyroid</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thymopoietin and thymosins</td>
<td>T-lymphocytes</td>
<td>Stimulate T lymphocytes</td>
</tr>
<tr>
<td><strong>Thyroid</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triiodothyronine (T₃) and thyroxine (T₄)</td>
<td>Most tissues</td>
<td>Elevate metabolic rate, O₂ consumption, and heat production; stimulate circulation and respiration; promote nervous system and skeletal development</td>
</tr>
<tr>
<td>Calcitonin</td>
<td>Bone</td>
<td>Promotes Ca²⁺ deposition and exorrhesis; reduces blood Ca²⁺ level</td>
</tr>
<tr>
<td><strong>Parathyroids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parathyroid hormone (PTH)</td>
<td>Bone, kidneys</td>
<td>Increases blood Ca²⁺ level by stimulating bone resorption and calcitriol synthesis and reducing urinary Ca²⁺ excretion</td>
</tr>
<tr>
<td><strong>Adrenal Medulla</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epinephrine, norepinephrine, dopamine</td>
<td>Most tissues</td>
<td>Complement effects of sympathetic nervous system</td>
</tr>
<tr>
<td><strong>Adrenal Cortex</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aldosterone</td>
<td>Kidney</td>
<td>Promotes Na⁺ retention and K⁺ excretion; maintains blood pressure and volume</td>
</tr>
<tr>
<td>Cortisol and corticosterone</td>
<td>Most tissues</td>
<td>Stimulate fat and protein catabolism, gluconeogenesis, stress resistance, and tissue repair; inhibit immune system</td>
</tr>
<tr>
<td>Androgen (DHEA) and estrogen</td>
<td>Bone, muscles, integument, many other tissues</td>
<td>Growth of pubic and axillary hair; bone growth, sex drive, male prenatal development</td>
</tr>
<tr>
<td><strong>Pancreatic Islets</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulin</td>
<td>Most tissues</td>
<td>Stimulates glucose and amino acid uptake; lowers blood glucose level; promotes glycogen, fat, and protein synthesis</td>
</tr>
<tr>
<td>Glucagon</td>
<td>Primarily liver</td>
<td>Stimulates gluconeogenesis, glycogen and fat breakdown, release of glucose and fatty acids into circulation</td>
</tr>
<tr>
<td><strong>Ovaries</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estradiol</td>
<td>Many tissues</td>
<td>Stimulates female reproductive development, regulates menstrual cycle and pregnancy, prepares mammary glands for lactation</td>
</tr>
<tr>
<td>Progesterone</td>
<td>Uterus, mammary glands</td>
<td>Regulates menstrual cycle and pregnancy, prepares mammary glands for lactation</td>
</tr>
<tr>
<td>Inhibin</td>
<td>Anterior pituitary</td>
<td>Inhibits FSH secretion</td>
</tr>
<tr>
<td><strong>Testes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testosterone</td>
<td>Many tissues</td>
<td>Stimulates reproductive development, skeletal growth, sperm production, and libido</td>
</tr>
<tr>
<td>Inhibin</td>
<td>Anterior pituitary</td>
<td>Inhibits FSH secretion</td>
</tr>
<tr>
<td><strong>Heart</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atrial natriuretic peptide</td>
<td>Kidney</td>
<td>Lowers blood volume and pressure by promoting Na⁺ and water loss</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Hormone</th>
<th>Target</th>
<th>Principal Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Skin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin D₃</td>
<td>—</td>
<td>First step in calcitriol synthesis (see kidneys)</td>
</tr>
<tr>
<td><strong>Liver</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcidiol</td>
<td>—</td>
<td>Second step in calcitriol synthesis (see kidneys)</td>
</tr>
<tr>
<td>IGF-I</td>
<td>Many tissues</td>
<td>Mediates action of growth hormone</td>
</tr>
<tr>
<td>Erythropoietin</td>
<td>Red bone marrow</td>
<td>Promotes red blood cell production</td>
</tr>
<tr>
<td>Angiotensinogen (a prohormone)</td>
<td>Blood vessels</td>
<td>Precursor of angiotensin II, a vasoconstrictor</td>
</tr>
<tr>
<td><strong>Kidneys</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcitriol</td>
<td>Small intestine, kidneys</td>
<td>Promotes bone deposition by increasing calcium and phosphate absorption in small intestine and reducing their urinary loss</td>
</tr>
<tr>
<td>Erythropoietin</td>
<td>Red bone marrow</td>
<td>Promotes red blood cell production</td>
</tr>
<tr>
<td><strong>Stomach and Small Intestine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enteric hormones</td>
<td>Stomach and intestines</td>
<td>Coordinate digestive motility and secretion</td>
</tr>
<tr>
<td><strong>Placenta</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estrogen, progesterone, and others</td>
<td>Many tissues of mother and fetus</td>
<td>Enhance effects of ovarian hormones on fetal development, maternal reproductive system, and preparation for lactation</td>
</tr>
</tbody>
</table>
Table 17.6

<table>
<thead>
<tr>
<th>Steroids and Steroid Derivatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldosterone</td>
</tr>
<tr>
<td>Calcitriol</td>
</tr>
<tr>
<td>Corticosterone</td>
</tr>
<tr>
<td>Cortisone</td>
</tr>
<tr>
<td>Estrogens</td>
</tr>
<tr>
<td>Progesterone</td>
</tr>
<tr>
<td>Testosterone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oligopeptides (3–10 amino acids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiotensin II</td>
</tr>
<tr>
<td>Anti-diuretic hormone</td>
</tr>
<tr>
<td>Gonadotropin-releasing hormone</td>
</tr>
<tr>
<td>oxytocin</td>
</tr>
<tr>
<td>Thyrotropin-releasing hormone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Polypeptides (14–199 amino acids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrenocorticotropic hormone</td>
</tr>
<tr>
<td>Afelin (natriuretic peptide)</td>
</tr>
<tr>
<td>Calcitonin</td>
</tr>
<tr>
<td>Corticotropin-releasing hormone</td>
</tr>
<tr>
<td>Glucagon</td>
</tr>
<tr>
<td>Growth hormone</td>
</tr>
<tr>
<td>Growth hormone–releasing hormone</td>
</tr>
<tr>
<td>insulin</td>
</tr>
<tr>
<td>Parathyroid hormone</td>
</tr>
<tr>
<td>Prolactin</td>
</tr>
<tr>
<td>Somatostatin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glycoproteins (92 amino acids in the α chain, 112–18 amino acids in the β chain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follicle-stimulating hormone</td>
</tr>
<tr>
<td>Human chorionic gonadotropin</td>
</tr>
<tr>
<td>Inhibin</td>
</tr>
<tr>
<td>Luteinizing hormone</td>
</tr>
<tr>
<td>Thyroid-stimulating hormone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Monoamines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dopamine</td>
</tr>
<tr>
<td>Epinephrine</td>
</tr>
<tr>
<td>Melatonin</td>
</tr>
<tr>
<td>Norepinephrine</td>
</tr>
<tr>
<td>Serotonin</td>
</tr>
<tr>
<td>Thyroxine (T₄)</td>
</tr>
<tr>
<td>Triiodothyronine (T₃)</td>
</tr>
</tbody>
</table>
### Table 17.7  Some of the Roles of Prostaglandins

**Inflammatory**
Promote fever and pain, two cardinal signs of inflammation

**Endocrine**
Mimic effects of TSH, ACTH, and other hormones; alter sensitivity of anterior pituitary to hypothalamic hormones; work with glucagon, catecholamines, and other hormones in regulation of fat mobilization

**Nervous**
Function as neuromodulators, altering the release or effects of neurotransmitters in the brain

**Reproductive**
Promote ovulation and formation of corpus luteum; induce labor contractions

**Gastrointestinal**
Inhibit gastric secretion

**Vascular**
Act as vasodilators and vasoconstrictors

**Respiratory**
Constrict or dilate bronchioles

**Renal**
Promote blood circulation through the kidney, increase water and electrolyte excretion
**Table 17.8 Some Disorders of the Endocrine System**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addison	extsuperscript{24} disease</td>
<td>Hypossecution of adrenal glucocorticoids and mineralocorticoids, causing hypoglycemia, hypotension, weight loss, weakness, loss of stress resistance, darkening or bronzing (metallic discoloration) of the skin, and potentially fatal dehydration and electrolyte imbalances</td>
</tr>
<tr>
<td>Congenital hypothyroidism</td>
<td>Thyroid hormone hypossecution present from birth, resulting in stunted physical development, thickened facial features, low body temperature, lethargy, and irreversible brain damage in infancy</td>
</tr>
<tr>
<td>Diabetes insipidus</td>
<td>Chronic polyuria due to ADH hypossecution. Can result from tumors, skull fractures, or infections that destroy hypothalamic tissue or the hypothalmo-hypophyseal tract</td>
</tr>
<tr>
<td>Hyperinsulinism</td>
<td>Insulin excess caused by islet hypersecretion or injection of excess insulin, causing hypoglycemia, weakness, hunger, and sometimes <em>insulin shock</em>, which is characterized by disorientation, convulsions, or unconsciousness</td>
</tr>
<tr>
<td>Myxedema</td>
<td>A syndrome occurring in severe or prolonged adult hypothyroidism, characterized by low metabolic rate, sluggishness and sleepiness, weight gain, constipation, dry skin and hair, abnormal sensitivity to cold, hypertension, and tissue swelling</td>
</tr>
<tr>
<td>Pheochromocytoma</td>
<td>A tumor of the adrenal medulla that secretes excess epinephrine and norepinephrine. Causes hypertension, elevated metabolic rate, nervousness, indigestion, hyperglycemia, and glycosuria</td>
</tr>
<tr>
<td>Toxic goiter (Graves disease)</td>
<td>Thyroid hypertrophy and hypersecretion, occurring when autoantibodies mimic the effect of TSH and overstimulate the thyroid. Results in elevated metabolic rate and heart rate, nervousness, sleeplessness, weight loss, abnormal heat sensitivity and sweating, and bulging of the eyes (exophthalmos) resulting from eyelid retraction and edema of the orbital tissues</td>
</tr>
</tbody>
</table>

### Disorders described elsewhere

- Acromegaly p. 667
- Adrenogenital syndrome p. 668
- Androgen-insensitivity syndrome p. 1021
- Cushing syndrome p. 668
- Endemic goiter p. 667
- Gigantism p. 667
- Hyperparathyroidism p. 668
- Hypoparathyroidism p. 667
- Pituitary dwarfism p. 667

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\textsuperscript{24}Adolph Kussmaul (1822–1902), German physician

\textsuperscript{24}Thomas Addison (1793–1860), English physician