THE ENDOCRINE SYSTEM
How Steroid Hormones Work
Figure 37.4

1. Steroid hormone (S) passes through plasma membrane.
2. Inside target cell, steroid hormone bonds to a specific receptor protein.
3. Receptor-steroid hormone complex enters the nucleus and binds to DNA, causing transcription of genes.
4. Protein synthesis is induced.
5. Protein is produced.
6. Protein alters cell activity.

How Peptide Hormones Work
Figure 37.5
Second Messengers
Figure 37.6

Endocrine Glands

Pineal gland
Hypothalamus
Pituitary
Anterior lobe
Posterior lobe
Thyroid
Parathyroids (behind thyroid)
Thymus
Adrenal cortex
Adrenal glands
Adrenal medulla
Pancreas
Ovaries (in females)
Testes (in males)

Only the major glands; there are many more

The Human Neuroendocrine System
Figure 37.7
<table>
<thead>
<tr>
<th>Principal Endocrine Glands and their Hormones</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Endocrine Gland and Hormone</th>
<th>Target Tissue</th>
<th>Principal Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antidiuretic hormone (ADH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxytocin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth hormone (GH)</td>
<td>Thyroid gland</td>
<td></td>
</tr>
<tr>
<td>Thyroid-stimulating hormone (TSH)</td>
<td>Sex organs</td>
<td>Stimulates ovulation (females); stimulates secretion of testosterone (males).</td>
</tr>
<tr>
<td>Gonadotropic hormones</td>
<td>Adrenal cortex</td>
<td>Stimulates ovarian follicle (females) and sperm production (males).</td>
</tr>
<tr>
<td>Luteinizing hormone (LH)</td>
<td>Mammary glands</td>
<td>Stimulates secretion of adrenal cortical hormones.</td>
</tr>
<tr>
<td>Follicle-stimulating hormone (FSH)</td>
<td>Melanin-producing cells</td>
<td>Stimulates milk production. Controls pigmentation in some animals.</td>
</tr>
<tr>
<td>Adrenocorticotropic hormone (ACTH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prolactin (PRL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melanocyte-stimulating hormone (MSH)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Thyroid gland</td>
<td>General</td>
<td>Stimulates metabolic rate; essential to normal growth and development.</td>
</tr>
<tr>
<td>Thyroid hormone (thyroxine)</td>
<td>Bone</td>
<td>Lowers blood calcium levels by inhibiting loss of calcium from bone.</td>
</tr>
<tr>
<td>Calcitonin</td>
<td></td>
<td>Increases blood calcium levels by stimulating bone breakdown; stimulates calcium reabsorption from in kidneys; activates vitamin D.</td>
</tr>
<tr>
<td>4. Parathyroid glands</td>
<td>General</td>
<td>Stimulates ovulation (females); stimulates secretion of testosterone (males).</td>
</tr>
<tr>
<td>Parathyroid hormone (PTH)</td>
<td>Bone, kidneys, digestive tract</td>
<td>Stimulates ovarian follicle (females) and sperm production.</td>
</tr>
<tr>
<td>5. Adrenal medulla</td>
<td>Muscle, cardiac muscle, blood vessels</td>
<td>Initiate stress response; increase heart rate, blood pressure, metabolic rate, dilate blood vessels, mobilize fat stores; raise blood sugar levels.</td>
</tr>
<tr>
<td>Epinephrine and norepinephrine</td>
<td></td>
<td>Maintains proper balance of sodium and potassium ions in blood.</td>
</tr>
<tr>
<td>6. Adrenal cortex</td>
<td>Kidney tubules</td>
<td></td>
</tr>
<tr>
<td>Aldosterone</td>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Cortisol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Pancreas (islets of Langerhans)</td>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Insulin</td>
<td>Liver, fat tissue</td>
<td>Lowers blood glucose levels; increases storage of glycogen.</td>
</tr>
<tr>
<td>Glucagon</td>
<td></td>
<td>Raises blood glucose levels; stimulates breakdown of glycogen in liver.</td>
</tr>
<tr>
<td>Estrogens</td>
<td></td>
<td>Completes preparation of uterus for pregnancy. Stimulates development.</td>
</tr>
<tr>
<td>Progesterone</td>
<td>Uterus</td>
<td></td>
</tr>
<tr>
<td>9. Testis</td>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Testosterone</td>
<td>Male reproductive structures</td>
<td>Stimulates development of secondary sexual characteristics and growth spurt at puberty.</td>
</tr>
<tr>
<td>10. Pineal gland</td>
<td>Sex organs (?), pigment cells</td>
<td>Stimulates development of sex organs; stimulates production of sperm.</td>
</tr>
<tr>
<td>Melatonin</td>
<td></td>
<td>Function not well understood; influences pigmentation in some animals; may control biorhythms in some animals; may help control onset of puberty in humans.</td>
</tr>
<tr>
<td>11. Thymus</td>
<td>White blood cells</td>
<td>Stimulates maturation and production of white blood cells.</td>
</tr>
<tr>
<td>Thymosin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The pituitary gland is composed of two separate lobes: the posterior lobe and the anterior lobe.

(a) The cells of the hypothalamus synthesize antidiuretic hormone (ADH) and oxytocin, which travel from the hypothalamus to the pituitary along specialized nerve cells. The hormones remain in the pituitary gland and are released into the blood when they are needed. ADH acts on the kidneys and helps regulate body water. Oxytocin initiates strong uterine contractions during labour.

(b) Hormones released by nerve cells of the hypothalamus regulate hormones secreted by the anterior pituitary.
The Master Gland

Figure 3

- Hypothalamus
- Anterior pituitary
- Thyroid-stimulating hormone (TSH)
- Thyroid
- Adrenocorticotropic hormone (ACTH)
- Adrenal cortex
- Growth hormone (GH)
- Gonadotropin-releasing hormone (GnRH)
- Gonadotropin-releasing hormone (GnRH)
- Gonadotropin-stimulating hormone (FSH)
- Follicle-stimulating hormone (FSH)
- Luteinizing hormone (LH)
- Luteinizing hormone (LH)
- Antidiuretic hormone (ADH)
- Posterior pituitary
- Kidney tubules
- Oxytocin
- Prostaglandin (PG)
- Muscles of uterus
- Mammary glands
- Bone
- Testis
- Ovary

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### Table 26.3 Hormones Released From the Mammalian Pituitary Gland

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Hormone</th>
<th>Secretion Site</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Mostly glandular tissue</td>
<td>Corticotropin</td>
<td>ACTH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thyrrotropin</td>
<td>TSH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Follicle-stimulating hormone</td>
<td>FSH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Luteinizing hormone</td>
<td>LH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prolactin</td>
<td>PRL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Somatotropin (also called growth hormone)</td>
<td>STH</td>
</tr>
<tr>
<td>Intermediate*</td>
<td>Mostly glandular tissue</td>
<td>Melanocyte-stimulating hormone</td>
<td>MSH</td>
</tr>
</tbody>
</table>

*Present in most vertebrates (not adult humans).

### Figure 26.5 Functional links between the hypothalamus and the anterior lobe of the pituitary.

1. Cell bodies of hypothalamic neurons secrete releasing or inhibiting hormones.
2. Secretions picked up by first capillary bed in base of hypothalamus.
3. Secretions carried by portal vessels to second capillary bed in anterior pituitary.
4. Releasing hormones leave capillaries, act on hormone-secreting pituitary cells.
5. Hormone secretions leave anterior pituitary through venules to lead general circulation.

### Figure 26.6 Secretions of the anterior lobe of the pituitary and some of their targets.
ANTIDIURETIC HORMONE

INCREASED Concentration of PLASMA SALT due to
LACK of Dietary WATER or to
LOSS of BODY WATER from
Sweat Glands (in sweat)
Lungs (in expired air)
Gut (in faeces)
or to
EXCESS DIETARY SALT
results in
INCREASED OSMOTIC PRESSURE
of BLOOD

[Diminished Concentration of Plasma Salt due to
e.g. Excess Intake of Water
Dilution of Blood Stream
Diminished Osmotic Pressure
Fall in Activity of the Osmoreceptors
Fall in Output of ADH
Diminished Reabsorption of Water
Increased Output of Dilute Urine
Restores OSMOTIC PRESSURE RELATIONSHIPS to normal]

FLUID EQUILIBRUM

(With hormone also has vasoconstrictor effects – increased Blood Pressure)
Secretion of Hormone, OXYTOCIN, seems to depend on AFFERENT (sensory) nerve impulses to HYPOTHALAMUS.

Nerve cells of the SUPRA-OPTIC NUCLEUS, send impulses along axons of SUPRAOPTICO-HYPOPHYSEAL TRACT to POSTERIOR PITUITARY to discharge OXYTOCIC HORMONE into BLOOD STREAM for PRIMARY ACTION.

Stimulates MYOEPITHELIAL CELLS in ducts to contract.

Rapid expression of preformed MILK from secreting alveoli to RESERVOIRS (GALACTAGOGUE action— or “Let-down” of milk).

Reinforces contractions of uterine smooth muscle during and after childbirth and leads eventually to INVOLUTION of the UTERUS (i.e., return to approximately pre-pregnant size).

The function of Oxytocin in the male is unknown.
UNDERACTIVITY of POSTERIOR PITUITARY

Damage, by INJURY or DISEASE, to

- HYPOTHALAMUS
- SUPRAOPTICO-HYPOPHYSIAL TRACT
- POSTERIOR PITUITARY causes

Absence from Blood Stream of ANTIDIURETIC HORMONE (ADH)

DIMINISHED REABSORPTION of WATER from

[OBLIGATORY REABSORPTION of PROXIMAL (1st) CONVOLUTED TUBULE]

FACULTATIVE REABSORPTION of DISTAL (2nd) CONVOLUTED TUBULE and COLLECTING DUCT does not occur (Cells lining collecting duct remain impermeable to water)

Increased ELIMINATION of WATER

URINARY VOLUME rises

DIABETES INSIPIDUS characterized by EXCESSIVE THIRST and EXCESSIVE PRODUCTION of DILUTE URINE

Normal GLOMERULAR FILTRATE—of over 100 litres/day

about 70 to 80 litres of glomerular filtrate water are reabsorbed outwith influence of ADH.

about 20 to 30 litres per day

normally under ADH control.

up to 20 or 30 litres of PALE DILUTE URINE excreted/day (SPECIFIC GRAVITY 1.001 to 1.002) instead of normal 1-1½ litres straw coloured more concentrated fluid (S.G. 1.020 - 1.032)

Small amounts of Posterior Pituitary extract absorbed from under the tongue or given by subcutaneous injection reduce elimination of water to normal.
OVERACTIVITY of PITUITARY EOSINOPHIL CELLS

Functional overactivity (or tumour) chiefly of the EOSINOPHIL cells of the Anterior Pituitary leads to GIANTISM in the CHILD: ACROMEGALY in the ADULT.

Overproduction of GROWTH Hormone

Overgrowth of all Body Tissues

General Circulation

Onset before bony epiphyses have closed at puberty

Onset after puberty

Increases NITROGEN retention, influences Protein, Carbohydrate and Fat metabolism of ALL CELLS of the body.

Long bones grow in length (height 7-9 feet)

Overgrowth of MUSCLES

Bones thicken especially of FACE, JAW, NOSE, HANDS and FEET

Overgrowth of SOFT TISSUES and INTERNAL ORGANS (e.g. Heart, Spleen, Stomach, etc.)

Coarse thick SKIN

[These patients frequently show a raised Basal Metabolic rate; a high Blood Sugar level and the presence of Sugar in the urine. Other features of this condition are due often to pressure of tumour on surrounding brain tissue or sometimes to overproduction of other Anterior Pituitary Hormones.]

NORMAL CHILD
AGE 13

AGE 13

Destruction of the overactive tissue—usually by Radium therapy—prevents progression of the condition.
UNDERACTIVITY of ANTERIOR PITUITARY

Deficiency or absence of EOSINOPHIL cells

Underproduction of GROWTH Hormone (Somatotrophin)

LORAIN DWARF
Delayed Skeletal Growth and Retarded Sexual Development but alert, intelligent, well proportioned child.

NORMAL CHILD
AGE 13

Destructive disease of part of Anterior Pituitary (usually with damage to Posterior Pituitary and/or Hypothalamus)

Underproduction of GROWTH and other ENDOCRINE-TROPHIC Hormones

FRÖHLICH'S DWARF
Stunting of Growth, Obesity (Large appetite for sugar); Arrested Sexual Development; Lethargic; Somnolent; Mentally Subnormal.

Atrophy of other Endocrine glands

Signs of deficiency of their hormones.

NORMAL CHILD
AGE 13

A similar condition occurs in ADULT without dwarfing but with suppression of sex functions and regression of secondary sex characteristics.

Extracts of GROWTH and GONADOTROPHIC hormones aid in restoring patient to normal.

Extracts of human GROWTH hormone restore growth and development pattern to normal.
OVERACTIVITY of PITUITARY BASOPHIL CELLS

Overactivity (often due to Tumour) of the Basophil cells of the Anterior Pituitary gives

Overproduction especially of

ADRENOCORTICOTROPHIC HORMONE

(ACTH or Corticotrophin)

Overstimulation, Hypertrophy and Overactivity of

SUPRARENAL CORTEX

Excess Corticoids

"Glucocorticoids"

"Mineralocorticoids" (except Aldosterone)

Androgens

Weakness
Obesity
Hirsutism

High Blood Sugar
Sugar in Urine

This condition is usually indistinguishable clinically from that seen in primary overactivity or tumour of the Suprarenal Cortex itself. The syndrome is here shown in the adult woman.

Overproduction of THYROTROPHIN ——> Overactivity of THYROID gland.
**PANHYPOPITUITARISM**

**Complete Atrophy** (or insufficiency) of all secreting cells of Anterior Pituitary in Adult — **SIMMOND’S DISEASE** —

**Failure to produce any hormones**

**Appearance of Premature Senility**

- **Lack of Growth Hormone**
  - Grave upset in tissue metabolism
  - **Hair** grey, sparse:
  - Loss of body hair.
  - **Skin** dry, sallow, wrinkled.
  - **Body** emaciated
    - (great loss of weight)
  - **Bones** frail

- **Lack of Gonadotrophins**
  - **Sex Organs** atrophy.
  - Menstruation ceases.
  - Reproductive cycle stops.
  - Secondary sex characteristics gradually regress.

- **Lack of Endocrine-Trophic Hormones**
  - **All Endocrines** atrophy and show depressed secretion of their hormones
  - Basal metabolism depressed
  - Body temperature depressed.
  - Heart rate low.
  - Blood pressure low.
  - Blood sugar low.
  - Electrolytic upset.

- Extracts of Anterior Pituitary may relieve the condition but rarely succeed in completely restoring the patient to normal.
Figure 37.12 The interaction of PTH and calcitonin to regulate calcium (Ca\(^{2+}\)) levels in the blood.

PTH acts to remove calcium from bone and deposit it in the blood. Calcitonin acts to remove calcium from the blood and deposit it in bone.

Figure 37.13 How hormones control water and salt levels in the blood.

Control of water (H\(_2\)O) and salt (Na\(^{+}\)) balance within the kidney is centered in the hypothalamus. The posterior pituitary produces antidiuretic hormone (ADH), which renders the kidney's collecting ducts freely permeable to water. As a result, water leaves the ducts and flows into the blood, increasing water retention. When water retention is too high, blood pressure rises. Pressure-sensitive receptors in the hypothalamus detect this and cause ADH production to shut down. If the level of salts in the blood falls, the adrenal cortex initiates production of the hormone aldosterone, which stimulates salt reabsorption by the kidney ducts.

1. ADH is released from anterior pituitary.
2. ADH causes kidney tubules to release water into blood.
3. High water pressure shuts down ADH.
4. High water pressure dilutes salts in blood; aldosterone is released.
5. Aldosterone causes kidney ducts to reabsorb sodium and other salts.
### Table 1  Pituitary Hormones

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Target</th>
<th>Primary function</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>stimulates release of thyroxine from thyroid, thyroxine regulates cell metabolism</td>
</tr>
<tr>
<td>adrenocorticotropic hormone (ACTH)</td>
<td>adrenal cortex</td>
<td>stimulates release of hormones involved in stress responses</td>
</tr>
<tr>
<td>somatotropin (STH), or growth hormone (GH)</td>
<td>most cells</td>
<td>promotes growth</td>
</tr>
<tr>
<td>follicle-stimulating hormone (FSH)</td>
<td>ovaries, testes</td>
<td>in females, stimulates follicle development in ovaries, in males, promotes the development of sperm cells in testes</td>
</tr>
<tr>
<td>luteinizing hormone (LH)</td>
<td>ovaries, testes</td>
<td>in females, stimulates ovulation and formation of the corpus luteum, in males, stimulates the production of the sex hormone testosterone</td>
</tr>
<tr>
<td>prolactin (PRL)</td>
<td>mammary glands</td>
<td>stimulates and maintains milk production in lactating females</td>
</tr>
<tr>
<td><strong>Posterior lobe</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>oxytocin</td>
<td>uterus, mammary glands</td>
<td>initiates strong contractions, triggers milk release in lactating females</td>
</tr>
<tr>
<td>antidiuretic hormone (ADH)</td>
<td>kidneys</td>
<td>increases water reabsorption by kidneys</td>
</tr>
</tbody>
</table>

### Hormones That Affect Metabolism

<table>
<thead>
<tr>
<th>Gland</th>
<th>Hormone</th>
<th>Effect on metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>thyroid</td>
<td>thyroxine (T4) and triiodothyronine (T3)</td>
<td>regulates the rate at which glucose is oxidized within body cells</td>
</tr>
<tr>
<td>thyroid</td>
<td>calcitonin</td>
<td>lowers calcium levels in the blood</td>
</tr>
<tr>
<td>parathyroid glands</td>
<td>parathyroid hormone (PTH)</td>
<td>raises calcium levels in the blood</td>
</tr>
<tr>
<td>anterior pituitary</td>
<td>growth hormone (GH), or somatotropin</td>
<td>promotes protein synthesis by increasing the uptake of amino acids by cells, causes a switch in cellular fuels from glucose to fatty acids</td>
</tr>
</tbody>
</table>
UNDERACTIVITY of THYROID

If the THYROID shows atrophy of its secretory cells or is inadequately stimulated by the Anterior Pituitary:-

FALL (or absence) of THYROID HORMONES in blood

LESS (or no) THYROID HORMONES enter blood to depress activity of ANTERIOR PITUITARY

In the ADULT
MYXOEDEMA

SLOWING UP OF ALL BODILY PROCESSES

In the CHILD — congenital absence of the gland
CRETIN

DWARFING

FAILURE of
SKELETAL GROWTH and DEVELOPMENT
SEXUAL
MENTAL

All "milestones" of babyhood are delayed.

THYROID EXTRACT (taken by mouth) restores individuals to normal.
OVERACTIVITY of THYROID

If an enlarged THYROID shows increased activity of its secretory cells:

- Great FALL in blood THYROID HORMONES
  - promotes greater production of TSH by ANTERIOR PITUITARY
  - stimulates greater production and release of TSH by ANTERIOR PITUITARY
  - THYROID GLAND takes up more IODINE

- Great RISE in blood THYROID HORMONES
  - depresses production of TSH by ANTERIOR PITUITARY

EXCESS THYROID HORMONES are distributed by blood stream to the Tissues of the Body.
- SPEED up OXIDATIONS in the cells, i.e. rate at which all cells use ENERGY.
- The Basal Metabolic Rate is raised.
- As a by-product of this increased cellular activity more heat is produced → rise in Body Temperature (person feels WARM).
  - Profuse Sweating.
  - Energy stores of body (i.e. GLYCOGEN and FAT) are depleted.
  - Appetite increases but weight falls.
  - Movements of digestive tract are increased → Diarrhoea.
  - Heart and Respiratory Rates rise.
  - Blood Pressure is raised.
  - Muscular tremor and nervousness are marked.
  - Person becomes excitable and apprehensive.

EXOPHTHALMOS (protrusion of eyeballs) may be due to an excess of some Pituitary Hormone. It is not due to an excess of Thyroid Hormones.

Surgical removal of part of the overactive gland reduces the Thyroid activity.
UNDERACTIVITY of PARATHYROIDS

Atrophy or removal of Parathyroid tissue causes a fall in BLOOD CALCIUM level and increased excitability of Neuromuscular tissue. This leads to severe convulsive disorder – TETANY.

PARATHYROID GLANDS

Inadequate Production of PTH

KIDNEY

Diminished tubular reabsorption of Ca and decreased phosphate excretion

GUT

Diminished absorption of dietary Ca

BONE

Diminished solubility of Ca and P

PARATHYROID GLANDS

Usual Manifestations:
- TWITCHINGS,
- NERVOUSNESS,
- OCCASIONAL SPASMS OF FACIAL AND LIMB MUSCLES.

If concentration of Ca in blood falls below 6mg/100ml plasma.

[Note the inverse relationship between plasma calcium and inorganic phosphate]

Symptoms are relieved by injection of Calcium or of Extract of Parathyroid.
OVERACTIVITY of PARATHYROID GLANDS

Overactivity of the Parathyroids (due often to tumour) leads to rise in BLOOD CALCIUM level and eventually to OSTEITIS FIBROSA CYSTICA.

The increased level of blood calcium eventually leads to excessive loss of CALCIUM in URINE and also of WATER since the salts are excreted in solution.

Excision of the overactive Parathyroid tissue abolishes syndrome.
**Summary**

**Hormones That Affect Blood Sugar**

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Location of hormone production</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>insulin</td>
<td>islets of Langerhans (pancreas)</td>
<td>• increases permeability of cells to glucose; increases glucose uptake</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• allows for the conversion of glucose to glycogen</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• brings about a decrease in blood sugar</td>
</tr>
<tr>
<td>glucagon</td>
<td>islets of Langerhans (pancreas)</td>
<td>• promotes the conversion of glycogen to glucose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• brings about an increase in blood sugar</td>
</tr>
<tr>
<td>epinephrine and norepinephrine</td>
<td>adrenal medulla</td>
<td>• promotes the conversion of glycogen to glucose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• brings about an increase in blood sugar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• brings about an increase in heart rate, and cell metabolism</td>
</tr>
<tr>
<td>cortisol (a type of glucocorticoid)</td>
<td>adrenal cortex</td>
<td>• promotes the conversion of amino acids to glucose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• promotes the breakdown of fats to fatty acids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• decreases glucose uptake by the muscles (not by the brain)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• brings about an increase in blood sugar in response to stress</td>
</tr>
</tbody>
</table>

**Figure 5**

Stress responses
The pancreas contains two types of cells: one type produces digestive enzymes; the other type produces hormones. The hormone-producing cells are located in structures called the islets of Langerhans, named after their discoverer, German scientist Paul Langerhans. More than 2000 tiny islets, each containing thousands of cells, are scattered throughout the pancreas. The islets contain beta and alpha cells that are responsible for the production of two hormones: insulin and glucagon.

Insulin is produced in the beta cells of the islets of Langerhans and is released when the blood sugar level increases. After a meal, the blood sugar level rises and an appropriate amount of insulin is released (Figure 1). The insulin causes cells of the muscles, the liver, and other organs to become permeable to glucose. In the liver, the glucose is converted into glycogen, the primary storage form for glucose. In this way, insulin enables the blood sugar level to return to normal. As discussed in Chapter 7, insulin helps maintain homeostasis.
follicle-stimulating hormone (FSH) in females, a gonadotropin that promotes the development of the follicles in the ovary

luteinizing hormone (LH) in females, a gonadotropin that promotes ovulation and the formation of the corpus luteum

**Figure 1**
Feedback loop showing the regulation of ovarian hormones

**Figure 2**
Negative feedback regulatory system for FSH and LH hormones

gonadotropic hormones
hormones produced by the pituitary gland that regulate the functions of the testes in males and the ovaries in females

follicle-stimulating hormone (FSH) in males, hormone that increases sperm production

luteinizing hormone (LH) in males, hormone that regulates the production of testosterone

gonadotropin-releasing hormone (GnRH) chemical messenger from the hypothalamus that stimulates secretions of FSH and LH from the pituitary
<table>
<thead>
<tr>
<th>Drug</th>
<th>Advantage</th>
<th>Side effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anabolic steroids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Stanozolol, Androstenediol, Nandrolone</td>
<td>• increases muscle mass and strength</td>
<td>• decreased growth, kidney problems, hair loss, oily skin, acne, shrinking testes, infertility, and cancer</td>
</tr>
<tr>
<td><strong>Peptide hormones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• growth hormone</td>
<td>• decreases fat</td>
<td>• diabetes, abnormalities of bones, liver, heart, and kidneys, and liver disease</td>
</tr>
<tr>
<td></td>
<td>• improves muscle mass</td>
<td>• high blood pressure</td>
</tr>
<tr>
<td>• erythropoietin (EPO)</td>
<td>• increases red blood cells that carry greater oxygen</td>
<td>• thickens the blood increasing chances of stroke</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• heart problems</td>
</tr>
<tr>
<td><strong>Beta blockers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Atenolol, Bisoprolol, Nandolol</td>
<td>• slows heart rate</td>
<td>• reduces cardiac response time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• makes skin more sensitive to sun</td>
</tr>
<tr>
<td><strong>Stimulants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• amphetamine</td>
<td>• increases endurance</td>
<td>• irregular heart beat, nervousness, difficulty sleeping</td>
</tr>
<tr>
<td></td>
<td>• relief of fatigue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• improves reaction time</td>
<td></td>
</tr>
<tr>
<td>• caffeine</td>
<td>• increases alertness</td>
<td>• increases blood pressure</td>
</tr>
<tr>
<td>• pseudoephedrine</td>
<td>• increases alertness</td>
<td>• narrows blood vessels and increases blood pressure</td>
</tr>
<tr>
<td><strong>Masking agents</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Bromantan</td>
<td>• makes steroid difficult to detect</td>
<td>• unknown</td>
</tr>
<tr>
<td>• Probenecid</td>
<td>• stops excretion of steroids for a few hours</td>
<td>• headache, tissue swelling, nausea</td>
</tr>
</tbody>
</table>
ALDOSTERONE and ANTIDIURETIC HORMONE (ADH) and the MAINTENANCE of BLOOD VOLUME

CIRCULATION
- A reduction (↓) in BLOOD VOLUME (as after hemorrhage) leads to temporary ↓ CARDIAC OUTPUT ↓ B.P.
- ANGIOTENSINOGEN (part of α globulin)
- RENIN (protease-splitting enzyme)
- ANGIOTENSIN (powerful vaso-constrictor) ↑ B.P.
- ↑ ALDOSTERONE
  - ↑ Na⁺
  - ↓ O.P.
  - ↑ ADH
  - ↑ H₂O
  - (this together with ↑ Na⁺)
  - ↓ BLOOD VOLUME (i.e. restores to normal)

TISSUE FLUIDS
- For reduction in total volume of EXTRACELLULAR FLUID (such as may result from loss of ISOTONIC SECRETIONS from GUT)

KIDNEY
- PULSE PRESSURE in AFFERENT ARTERIOLE (i.e. less stretch applied to walls)
- JUXTAGLOMERULAR APPARATUS releases RENIN
- ENDOCRINES
  - SUPRArenal CORTEX
    - Zona Glomerulosa
      - secretes ALDOSTERONE
  - HYPOTHALAMUS
    - OSMORECEPTORS secretes..... and POSTERIOR PITUITARY releases ↑ ADH
  - DISTAL and COLLECTING TUBULES rendered permeable to water
    - H₂O reabsorption ↑

Aldosterone and ADH co-operate in other ways to maintain salt and water balance e.g. where osmotic pressure relationships (and not primarily volumes) are disturbed (see pp 144, 145).
Inhibitory neurotransmitters (see chapter 34)

Releasing hormones

"True" hormones

Second messengers

Excitatory neurotransmitters (see chapter 34)

GABA

Acetylcholine

Endorphins

Neuropeptides

Pituitary hormones

Adrenaline

Insulin

Pancreas

Liver

Atrial peptides

Heart

Digestive hormones

Stomach

Muscle

cAMP

IP₃