Introduction

• Toxic chemicals that interfere with the endocrine system are aptly named *endocrine disruptors*.

• Endocrine disruptors include
  • atrazine, an ingredient in weed killers and a contaminant found in farm water runoff that makes its way to ground and surface reservoirs, and
  • bisphenol A (BPA), used in many plastics that line bottles, canned goods, and other manufactured drinking water and food containers.
Chapter 26: Big Ideas

The Nature of Chemical Regulation

The Vertebrate Endocrine System

Hormones and Homeostasis
THE NATURE OF CHEMICAL REGULATION
26.1 Chemical and electrical signals coordinate body functions

• Organ systems must communicate with one another
  • to maintain homeostasis and
  • to carry out other coordinated functions.

• Organ systems use chemical and electrical signals that travel through the body by way of two major organ systems:
  1. the endocrine system and
  2. the nervous system.
26.1 Chemical and electrical signals coordinate body functions

• The **endocrine system** is a group of interacting glands and tissues throughout the animal body that produce and secrete chemicals to initiate and maintain body functions and activities.
26.1 Chemical and electrical signals coordinate body functions

- In the endocrine system, chemical signals called **hormones**
  - are made and secreted mainly by organs called **endocrine glands**,
  - are released into the bloodstream by endocrine cells,
  - are carried to all locations in the body, and
  - affect only **target cells** that have receptors for that specific hormone.
Figure 26.1a

Signal travels everywhere via the bloodstream.

Response: Limited to cells that have the receptor for the signal.
26.1 Chemical and electrical signals coordinate body functions

• The nervous system also communicates, regulates, and uses electrical signals via nerve cells called neurons.
Figure 26.1b

Signal travels along axon to a specific location

Response: Limited to cells that connect by specialized junctions to an axon that transmits an impulse
26.1 Chemical and electrical signals coordinate body functions:

- Comparing the endocrine and nervous systems:
  - The nervous system reacts faster.
  - The responses of the endocrine system last longer.
26.2 Hormones affect target cells using two main signaling mechanisms

- Hormone signaling involves three stages:
  1. *Reception* of the signal occurs when a hormone binds to a specific receptor protein on or in the target cell.
  2. *Signal transduction* converts the signal from one form to another.
  3. *Response* is a change in the cell’s behavior.
26.2 Hormones affect target cells using two main signaling mechanisms

- Based on chemical properties, hormones can be classified into two groups.
  1. The water-soluble hormones include proteins, short polypeptides, and some modified versions of single amino acids. Most hormones produced by the endocrine glands are water-soluble.
  2. The lipid-soluble hormones include the steroid hormones, small molecules made from cholesterol.
Animation: Water-Soluble Hormone
26.2 Hormones affect target cells using two main signaling mechanisms

• Water-soluble hormones cannot pass through the phospholipid bilayer of the plasma membrane, but they can bring about cellular changes without entering their target cells.
Figure 26.2a-1

Interactions of hormones with target cells:

1. Water-soluble hormone
2. Receptor protein
3. Interstitial fluid
4. Target cell
5. Plasma membrane
6. Nucleus
Figure 26.2a-2

1. Water-soluble hormone
2. Signal transduction pathway

Interstitial fluid
Receptor protein
Plasma membrane
Target cell
Relay molecules
Nucleus
Figure 26.2a-3

Water-soluble hormone

1. Receptor protein

Interstitial fluid

Target cell

2. Signal transduction pathway

Plasma membrane

Relay molecules

3. Cellular responses

Cytoplasmic response or Gene regulation

Nucleus
26.2 Hormones affect target cells using two main signaling mechanisms

- Lipid-soluble hormones, such as steroid hormones,
  - pass through the phospholipid bilayer and
  - bind to receptors inside the cell.
Animation: Lipid-Soluble Hormone
Figure 26.2b-1

Steroid hormone → Interstitial fluid

Target cell

Nucleus
Figure 26.2b-2

Steroid hormone
Interstitial fluid

1

Target cell

2

Receptor protein

Nucleus
Figure 26.2b-3

Steroid hormone

Interstitial fluid

Target cell

Receptor protein

Nucleus

Hormone-receptor complex

DNA
Figure 26.2b-4

Steroid hormone

1. Interstitial fluid

Target cell

2. Receptor protein

Nucleus

3. Hormone-receptor complex

DNA

4. mRNA

Transcription

mRNA

New protein

Cellular response:
activation of a gene and
synthesis of new protein

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26.3 SCIENTIFIC THINKING: A widely used weed killer demasculinizes male frogs

- Almost all of us are routinely exposed to chemicals called endocrine disruptors, such as atrazine, found in weed-killers, and BPA in food and beverage containers, which specifically mimic the lipid-soluble hormone estrogen.

- Scientists use controlled studies to test whether a chemical causes specific biological effects.
26.3 SCIENTIFIC THINKING: A widely used weed killer demasculinizes male frogs

- Scientists exposed developing male frogs to very low levels of atrazine for three years.
  - An equal number of control and atrazine-exposed adult males of similar weights were placed into a pool with females.
  - A mating contest was set up, in which control males and atrazine-exposed males competed for females.
  - The scientists recorded each male frog’s ability to successfully grasp a female with his front legs during a mating behavior called amplexus.
Data from T. B. Hayes et al., Atrazine induces complete feminization and chemical castration in male African clawed frogs (*Xenopus laevis*), *Proceedings of the National Academy of Sciences* 107: 10 (2007).
Data from T. B. Hayes et al., Atrazine induces complete feminization and chemical castration in male African clawed frogs (Xenopus laevis), *Proceedings of the National Academy of Sciences* 107: 10 (2007).
26.3 SCIENTIFIC THINKING: A widely used weed killer demasculinizes male frogs

• Atrazine’s demasculinizing effect on male frogs was demonstrated by
  • reduced mating behaviors,
  • testosterone deficiencies, and
  • some sex reversals.
THE VERTEBRATE ENDOCRINE SYSTEM
26.4 The vertebrate endocrine system consists of more than a dozen major glands

- Some endocrine glands (such as the thyroid) primarily secrete hormones into the blood.
- Other glands (such as the pancreas) have endocrine and nonendocrine functions.
- Other organs (such as the stomach and heart) are primarily nonendocrine but have some cells that secrete hormones.
26.4 The vertebrate endocrine system consists of more than a dozen major glands

- The following figure shows
  - the locations of the major endocrine glands and
  - the main hormones they produce.
Figure 26.4

**Pineal gland**
(Melatonin helps regulate biological rhythms.)

**Thyroid gland**
(Thyroid hormone affects metabolic processes; calcitonin lowers blood calcium.)

**Parathyroid glands**
(Parathyroid hormone raises blood calcium.)

**Hypothalamus**
(Multiple hormones control the pituitary gland.)

**Pituitary gland**

*Anterior pituitary*
(Multiple hormones affect other endocrine glands and cells.)

*Posterior pituitary*
(Oxytocin stimulates mammary gland cells and contraction of uterus; antidiuretic hormone promotes retention of water by kidneys.)

**Testes (in males)**
(Androgens support sperm formation and promote development of male secondary sex characteristics.)

**Adrenal glands (atop kidneys)**

*Adrenal medulla*
(Epinephrine and norepinephrine raise blood glucose, increase metabolic activities, and constrict some blood vessels.)

*Adrenal cortex*
(Glucocorticoids raise blood glucose; mineralocorticoids promote reabsorption of Na\(^+\) and excretion of K\(^+\) in kidneys.)

**Ovaries (in females)**
(Estrogens stimulate uterine lining growth and promote development of female secondary sex characteristics; progestins promote uterine lining growth.)

**Pancreas**
(Insulin lowers blood glucose; glucagon raises blood glucose.)
What stimulates an endocrine gland to produce a hormone?

We can categorize stimuli into three major types.

1. For some endocrine glands, a change in levels of certain ions and nutrients is the stimulus.
2. Other endocrine glands, such as the adrenal glands, are stimulated directly by the nervous system.
3. Hormones can also stimulate endocrine glands.
26.4 The vertebrate endocrine system consists of more than a dozen major glands

- The hormones produced by endocrine glands have a wide range of effects, including
  - regulating ion and nutrient levels, water balance, and metabolism,
  - controlling reproduction, growth, and development, and
  - initiating responses to stress and the environment.
- For a particular example of hormonal effects, let’s take a brief look at the pineal gland.
26.4 The vertebrate endocrine system consists of more than a dozen major glands

- The **pineal gland**
  - is pea-sized,
  - is located near the center of the brain, and
  - synthesizes and secretes melatonin, a hormone that links environmental light conditions with biological rhythms.
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- The **hypothalamus**
  - is the main control center of the endocrine system,
  - receives input from nerves about the internal conditions of the body and the external environment,
  - responds by sending out appropriate nervous or endocrine signals, and
  - directly controls the pituitary gland, which in turn secretes hormones that influence numerous body functions.
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- The **pituitary gland** consists of two parts:
  - an anterior lobe and
  - a posterior lobe.
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

• In the **posterior pituitary**, a set of neurosecretory cells extends from the hypothalamus into the posterior pituitary, connecting them structurally and functionally.

• The hormones oxytocin and antidiuretic hormone
  • are produced by these neurosecretory cells and
  • are stored in the posterior pituitary.
Figure 26.5b

Hypothalamus

Posterior pituitary

Blood vessel

Anterior pituitary

Neurosecretory cell

Oxytocin and ADH

Oxytocin

Uterine muscles
Mammary glands

ADH

Kidney tubules
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- Neurosecretory cells in the anterior pituitary secrete two kinds of hormones into short blood vessels that connect to the anterior pituitary.

1. **Releasing hormones** stimulate the anterior pituitary to secrete one or more specific hormones.

2. **Inhibiting hormones** induce the anterior pituitary to stop secreting one or more specific hormones.
Figure 26.5c

Thyroid

Neurosecretory cell of hypothalamus

Blood vessel

Releasing hormones from hypothalamus

Endocrine cells of the anterior pituitary

Pituitary hormones

- TSH
- ACTH
- FSH and LH
- Prolactin (PRL)
- Growth hormone (CH)

Thyroid

Adrenal cortex

Testes or ovaries

Mammary glands (in mammals)

Entire body

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26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- Many of the protein hormones secreted from the anterior pituitary stimulate other endocrine glands to produce their hormones. These include
  - thyroid-stimulating hormone (TSH), which regulates hormone production by the thyroid gland,
  - adrenocorticotropic hormone (ACTH), which stimulates the adrenal cortex, which in turn releases hormones that affect water balance and metabolism,
  - follicle-stimulating hormone (FSH) and luteinizing hormone (LH), which stimulate the testes and ovaries to produce reproductive hormones,
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- **prolactin** (PRL), which in mammals, directly stimulates the mammary glands to produce milk, and
- **growth hormone** (GH), which promotes protein synthesis and the use of body fat for energy metabolism.
Figure 26.5d
26.5 The hypothalamus, which is closely tied to the pituitary, connects the nervous and endocrine systems

- Feedback control of the hypothalamus and pituitary serves as a useful example of a hormone cascade pathway directed by the hypothalamus.
  - The hypothalamus secretes a releasing hormone known as TRH (TSH-releasing hormone).
  - In turn, TRH stimulates the anterior pituitary to produce thyroid-stimulating hormone (TSH).
  - Under the influence of TSH, the thyroid grows and secretes thyroid hormone into the blood.
Figure 26.5e

Hypothalamus

TRH

Anterior pituitary

TSH

Thyroid

Thyroid hormone

Inhibition
HORMONES AND HOMEOSTASIS
26.6 The thyroid regulates development and metabolism

- The **thyroid gland** is located in the neck, just under the larynx (voice box).
- The thyroid gland produces two similar hormones, **thyroxine** ($T_4$) and **triiodothyronine** ($T_3$).
- These hormones regulate many aspects of
  - metabolism,
  - reproduction, and
  - development.
26.6 The thyroid regulates development and metabolism

• Thyroid imbalance can cause disease.
  • Hyperthyroidism
    • results from too much $T_4$ and $T_3$ in the blood,
    • leads to high blood pressure, loss of weight, overheating, and irritability, and
    • produces Graves’ disease.
  • Hypothyroidism
    • results from too little $T_4$ and $T_3$ in the blood and
    • leads to low blood pressure, being overweight, and often feeling cold and lethargic.
26.6 The thyroid regulates development and metabolism

- Iodine deficiency can produce a goiter, an enlargement of the thyroid. In this condition,
  - the thyroid gland cannot synthesize adequate amounts of $T_4$ and $T_3$, and
  - the thyroid gland enlarges.
Figure 26.6b

Hypothalamus

TRH

Anterior pituitary

TSH

Thyroid

Thyroid grows to form goiter

No inhibition

No inhibition

No iodine

Insufficient $T_4$ and $T_3$ produced
26.7 The gonads secrete sex hormones

- The **gonads**, or sex glands (ovaries in the female and testes in the male),
  - secrete sex hormones and
  - produce gametes (ova and sperm).

- Steroid sex hormones
  - affect growth,
  - affect development, and
  - regulate reproductive cycles and sexual behavior.
26.7 The gonads secrete sex hormones

• The synthesis of sex hormones by the gonads is regulated by the
  • hypothalamus and
  • pituitary.
Figure 26.7a

Hypothalamus

Releasing hormone

Anterior pituitary

FSH and LH

Gonads

Sex hormones
The gonads secrete sex hormones

The gonads of mammals produce three major categories of sex hormones.

1. **Estrogens** maintain the female reproductive system and promote the development of female characteristics.

2. **Progestins**, such as progesterone, prepare and maintain the uterus to support a developing embryo.

3. **Androgens**, such as **testosterone**, stimulate the development and maintenance of the male reproductive system.
26.7 The gonads secrete sex hormones

- Imbalance of sex hormones can complicate the development of sexual characteristics.
- Androgen insensitivity syndrome is an X-linked recessive trait that results when testosterone enters the target cell but cannot bind to its nuclear receptor because the nuclear receptor is defective.
Figure 26.7b

Key

- Female
- Male
- Individual with androgen insensitivity syndrome
26.7 The gonads secrete sex hormones

- The process of sex determination is driven by androgens in a very similar manner in all vertebrates, suggesting that androgens had this role early in evolution.

- Testosterone causes
  - the aggressive male behavior in elephant seals and
  - the development of manes in male lions.
The pancreas is a gland with dual functions. It secretes digestive enzymes into the small intestines. It secretes two protein hormones, insulin and glucagon, directly into the blood.
• Insulin and glucagon are said to be **antagonistic hormones** because the effects of one oppose the effects of the other.
• The balance in secretion of insulin and glucagon maintains a homeostatic “set point” of glucose in the blood.
• Two negative feedback systems manage the amount of glucose circulating in the blood.
REGULATION OF BLOOD GLUCOSE

Effects of antagonistic hormones

Blood glucose level (mg/100 mL)

Glucose level “set point”

Time

7:00 AM  2:00 PM
REGULATION OF BLOOD GLUCOSE

Insulin release
Beta cells of the pancreas release insulin into the blood

Effect of antagonistic hormones
Insulin stimulates nearly all cells to take up glucose
Liver and muscle cells use glucose to form glycogen stores

Blood glucose level decreases, and the stimulus for beta cells diminishes

Effects of antagonistic hormones
Insulin production lowers glucose level.

7:00 AM
Stimulus
Carbohydrate-rich breakfast

Glucose level at “set point”

Blood glucose level (mg/100 mL)

0 45 90 135 180

Time

7:00 AM 2:00 PM

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Figure 26.8-0-3

REGULATION OF BLOOD GLUCOSE

Effects of antagonistic hormones

Blood glucose level (mg/100 mL)

- Insulin production lowers glucose level.
- Glucose level at "set point".
- Glucagon production raises glucose level.

7:00 AM
Stimulus: Carbohydrate-rich breakfast

Blood glucose level increases, and the stimulus for beta cells diminishes.

2:00 PM
Stimulus: Lunch skipped

Blood glucose level decreases, and the stimulus for alpha cells diminishes.

Insulin release
- Beta cells of the pancreas release insulin into the blood.
- Insulin stimulates nearly all cells to take up glucose.
- Liver and muscle cells use glucose to form glycogen stores.

Glucagon release
- Alpha cells of the pancreas release glucagon into the blood.
- Liver cells break down glycogen stores and return glucose to the blood.

Liver cells
Glycogen
Liver cell
Skeletal muscle cell

Glucose
Insulin
Glycogen
Glucagon

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Beta cells of the pancreas release insulin into the blood when the blood glucose level rises. Insulin stimulation nearly all cells to take up glucose. Liver and muscle cells use glucose to form glycogen stores. Glucose level at “set point” and the stimulus for beta cells diminishes.
Glucose Declining blood glucose level stimulates the pancreas Alpha cells of the pancreas release glucagon into the blood Liver cells break down glycogen stores and return glucose to the blood

Blood glucose level increases, and the stimulus for alpha cells diminishes

Stimulus Lunch skipped Glucose level at "set point"
26.9 CONNECTION: Diabetes is a common endocrine disorder

• **Diabetes mellitus** is a serious hormonal disorder caused by the body’s inability to produce and/or use insulin, thereby decreasing the absorption of glucose from the blood and resulting in elevated blood glucose levels, or **hyperglycemia**.

• Diabetes is quickly becoming a major public health crisis.
26.9 CONNECTION: Diabetes is a common endocrine disorder

- Muscle or fat cells normally respond to insulin by taking up glucose from the blood, thus lowering blood glucose levels.
- In this process, the binding of insulin to the insulin receptor initiates internal cell signals that result in glucose transporters being shuttled from vesicles to the plasma membrane, and glucose enters the target cell via facilitated diffusion.
Normal glucose and insulin levels:

1. Insulin receptors
2. Facilitated diffusion of glucose
3. Glucose transporter

Type I diabetes: insulin is absent

Elevated glucose level:

Type II diabetes: insulin signaling is defective

Lack of insulin

“Insulin-resistant” cell

Defective signaling
Figure 26.9-1

Capillary, Insulin, Blood, Glucose

Insulin receptors

Vesicle containing glucose transporters

Facilitated diffusion of glucose

Glucose transporter

Normal glucose and insulin levels
Figure 26.9-2

Elevated glucose level

Lack of insulin

Type I diabetes:
insulin is absent
Type II diabetes: insulin signaling is defective
26.9 CONNECTION: Diabetes is a common endocrine disorder

• There are three types of diabetes mellitus.
  1. Type 1 (insulin-dependent) is an autoimmune disease caused by the destruction of insulin-producing cells.
• Patients can be treated with injections, several times daily, of human insulin, which is produced by genetically engineered bacteria.
26.9 CONNECTION: Diabetes is a common endocrine disorder

2. Type 2 (non-insulin-dependent)
   • is caused by a reduced response to insulin,
   • is associated with being overweight and underactive, and
   • is the cause of more than 90% of diabetes.
26.9 CONNECTION: Diabetes is a common endocrine disorder

3. Gestational diabetes
   • can affect any pregnant woman and
   • can lead to dangerously large babies, which can complicate delivery.
26.10 The adrenal glands mobilize responses to stress

• The endocrine system includes two adrenal glands sitting on top of each kidney.
• Each adrenal gland is made of two glands fused together:
  1. a central portion called the adrenal medulla and
  2. an outer portion called the adrenal cortex.
• Both glands secrete hormones that enable the body to respond to stress.
26.10 The adrenal glands mobilize responses to stress

- Nerve signals from the hypothalamus stimulate the adrenal medulla to secrete
  - epinephrine (adrenaline) and
  - norepinephrine (noradrenaline).
- These hormones quickly trigger the “fight-or-flight” responses, which are short-term responses to stress.
**Short-term stress response**

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

**Long-term stress response**

**Mineralocorticoids**
1. Retention of sodium ions and water by kidneys
2. Increased blood volume and blood pressure

**Glucocorticoids**
1. Proteins and fats broken down and converted to glucose, leading to increased blood glucose
2. Immune system may be suppressed
Figure 26.10-2

Stress signals cross section of spinal cord

1. Nerve cell
2. Adrenal medulla
3. ACTH
4. Anterior pituitary
5. Blood vessel

- Stress
- Hypothalamus
- Releasing hormone
- Mineralocorticoids
- Glucocorticoids

Short-term stress response
Long-term stress response
### Short-term stress response

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
26.10 The adrenal glands mobilize responses to stress

- **Adrenocorticotropic hormone (ACTH)** from the pituitary causes the adrenal cortex to secrete **corticosteroids**, which include
  - **glucocorticoids**, which function mainly in mobilizing cellular fuel, thus reinforcing the effects of glucagon, and
  - **mineralocorticoids**, which act mainly on salt and water balance.
- Both help maintain homeostasis when the body experiences long-term stress.
<table>
<thead>
<tr>
<th>Long-term stress response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mineralocorticoids</strong></td>
</tr>
<tr>
<td>1. Retention of sodium ions and water by kidneys</td>
</tr>
<tr>
<td>2. Increased blood volume and blood pressure</td>
</tr>
</tbody>
</table>
26.11 EVOLUTION CONNECTION: A single hormone can perform a variety of functions in different animals

- The hormone prolactin (PRL)
  - is produced and secreted by the anterior pituitary under the direction of the hypothalamus and
  - in humans, stimulates mammary glands to grow and produce milk during late pregnancy.
    - Suckling by a newborn stimulates further release of PRL.
    - High PRL during nursing inhibits ovulation.
26.11 EVOLUTION CONNECTION: A single hormone can perform a variety of functions in different animals

- PRL has many roles unrelated to childbirth, suggesting that PRL is an ancient hormone diversified through evolution.
  - In some nonhuman mammals, PRL stimulates nest building.
  - In birds, PRL regulates fat metabolism and reproduction.
  - In amphibians, PRL stimulates movement to water.
  - In fish that migrate between salt and fresh water, PRL helps regulate salt and water balance in the gills and kidneys.
26.12 CONNECTION: Hormones can promote social behaviors

- Recently, scientists studied whether it is a hormone that induces the human-dog relationship.
- The hormone oxytocin plays a part in
  - uterine contractions,
  - mammary milk ejection, and
  - promotes mating and maternal bonds.
- Levels of the hormone rise
  - when human mothers gaze into the eyes of their babies and
  - when dog owners received long gazes from their dogs.
You should now be able to

1. Define endocrine disruptors and give two common examples.

2. Compare the mechanisms and functions of the endocrine and nervous systems.

3. Distinguish between the two major classes of vertebrate hormones.

4. Describe experiments demonstrating atrazine’s demasculinizing effect on male frogs.

5. Describe the different types and functions of vertebrate endocrine organs.

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You should now be able to

6. Describe the specific structure, location, and function of the pineal gland.

7. Describe the interrelationships between the hypothalamus and pituitary glands.

8. Describe the functions of the thyroid gland.

9. Describe the three major types of sex hormones and their functions.

10. Explain how insulin and glucagon manage blood glucose levels.
You should now be able to

11. Describe the causes and symptoms of type 1 diabetes, type 2 diabetes, and gestational diabetes.

12. Compare the functions of the adrenal gland hormones.

13. Describe the diverse functions of prolactin in vertebrate groups and its evolutionary significance.

14. Explain how hormones can promote social behaviors.
**Gene regulation**

**Water-soluble hormone**
- **Receptor protein in plasma membrane**
- **Signal transduction pathway**
- **Cytoplasmic response**
- **Gene regulation**

**Lipid-soluble hormone**
- **Receptor protein in cytoplasm**
- **Hormone receptor complex**
- **Gene regulation**
Brain

Hypothalamus:
• Master control center of the endocrine system

Anterior pituitary:
• Composed of endocrine tissue
• Controlled by hypothalamus
• Produces and secretes its own hormones

Posterior pituitary:
• Composed of nervous tissue
• Stores and secretes hormones made by hypothalamus
Figure 26.UN04

Insulin Causes Glucose in blood

Pancreas Releases Glucagon Causes Glucose in blood

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Internal communication and regulation

vertebrate systems responsible are

endocrine system

signals used are

(b)

are secreted into the bloodstream and bind with

(c)

located either on target cell surfaces

are produced by

(e)

such as

(f)

under the control of the hypothalamus

(g)

producing hormones involved in “fight or flight” response
Figure 26.UN06

Blood glucose (mg/100 mL)

Hours after glucose ingestion

Diabetic

Healthy