10.1 Hormones: Chemical Regulators

Puberty brings about many changes in the human body. Both males and females experience a growth spurt during puberty, and the secondary sex characteristics begin to develop. Males experience the growth of body and facial hair, a deepening of the voice, and the development of the genitals. Females experience the growth of body hair, the onset of their menstrual cycle, and the development of breasts and broader hips.

All of these developments of puberty are timed and controlled by hormones: chemicals produced by cells in one part of the body that regulate the processes of cells in another part of the body. Hormones act as chemical messengers, enabling one part of the body to give instructions to another part. Other chemicals, called local regulators, are like hormones but act on nearby cells, rather than cells some distance away. Some cells even self-regulate, producing chemicals to stimulate their own cellular processes.

Hormones are secreted by the cells, tissues, and organs that compose the endocrine system. The endocrine system, like the nervous system, regulates and coordinates the functions of organs throughout the body. In this way, the endocrine system contributes to the control of growth, development, reproduction, behaviour, energy metabolism, and water balance. The nervous and endocrine systems are structurally, chemically, and functionally related, but they control organ and tissue functions in different ways. The nervous system sends fast electrical signals along the nerves. The speed of these nerve impulses enables an organism to interact rapidly with its external environment. The endocrine system uses hormones, with slower, longer-acting responses, to control organ and tissue functions. Of course, the endocrine system itself has to be controlled, so that hormones are released when needed. Because the nervous system can regulate the release of most hormones, it ultimately controls the actions of the endocrine system.

Endocrine glands are ductless secretory organs that secrete their hormones directly into the blood or extracellular fluid. (In contrast, exocrine glands, such as the sweat and salivary glands, release their secretions into ducts that lead outside the body or into the body cavities.) The hormones are then circulated throughout the body in the blood and other body fluids. As a result, most body cells are constantly exposed to a wide variety of hormones. Only target cells, however, will respond to a specific hormone because only they have receptor proteins that recognize and bind to that type of hormone (**Figure 1**). Hormones are cleared from the body at a steady rate by enzymatic breakdown in their target cells, in the blood, or in organs such as the liver or kidneys. The breakdown products are reused or excreted.

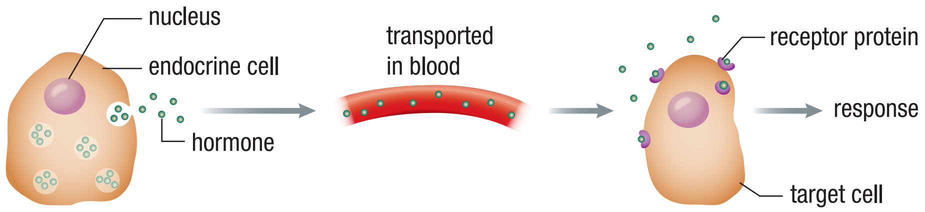


Figure 1 Hormones are produced by the cells of the endocrine glands and released into the bloodstream, where most of the body cells are exposed to them. Only the target cells with the appropriate receptor proteins respond to a hormone.

In this section, you will consider the nature of hormones, the way they work, and their importance in the normal functioning of the body and the maintenance of homeostasis.

Types of Hormones

There are more than 60 known hormones and local regulators in humans. Many are identical or very similar in structure and function to the hormones in other animals, although many animals have hormones not found in humans. Hormones are identified by their chemical structure. There are two main types: protein hormones, which are water soluble, and steroid hormones, which are lipid soluble. Most hormones fall into one of these two types.

Protein hormones consist of amino acid chains, ranging in length from as few as 3 amino acids to more than 200. They are released into the blood or extracellular fluid by the cells in the endocrine glands where they are produced. Protein hormones are usually hydrophilic: they have an affinity for water and diffuse well through the blood and intercellular fluids. One group of protein hormones, the growth factors, regulates the division and differentiation of many types of cells in the body.

protein hormone a hormone composed of chains of amino acids that is water soluble; usually acts on cell membrane receptors

Steroid hormones are derived from cholesterol and are not very soluble in blood. However, they can pass easily through the lipid bilayer of cellular membranes. Steroid hormones can combine with hydrophilic carrier proteins to form water-soluble complexes, which allow them to diffuse easily into blood and other fluids. When a steroid hormone contacts a cell, it is released from its carrier protein. It passes through the plasma membrane of the target cell and then binds to internal receptors in the nucleus or cytosol. Steroid hormones include aldosterone, cortisol, and the sex hormones. Some steroid hormones have very similar structures but produce very different effects. For example, testosterone and estradiol, two major sex hormones that are responsible for the development of male and female characteristics, respectively, differ only in the presence or absence of a single methyl group.

steroid hormone a hormone composed of cholesterol that is not very water soluble; usually passes through the cell membrane and acts on receptors inside the cell

Hormone Mechanisms

Many hormones are secreted in an inactive or less active form called prohormones. Prohormones are converted by the target cells or by enzymes in the blood or other tissues to the active form. Protein hormones are commonly synthesized as prohormones, which are then converted to the active form in the source cell. In some cases, further conversion occurs once the hormone has been secreted. For example, angiotensin is a hormone that regulates blood pressure in humans. It is secreted by the liver as angiotensinogen. An enzyme cleaves an inactive form of angiotensin from angiotensinogen. When this inactive form is converted to the active hormone by the angiotensin-converting enzyme (ACE), there is an increase in blood pressure. ACE inhibitors are often prescribed to control high blood pressure.

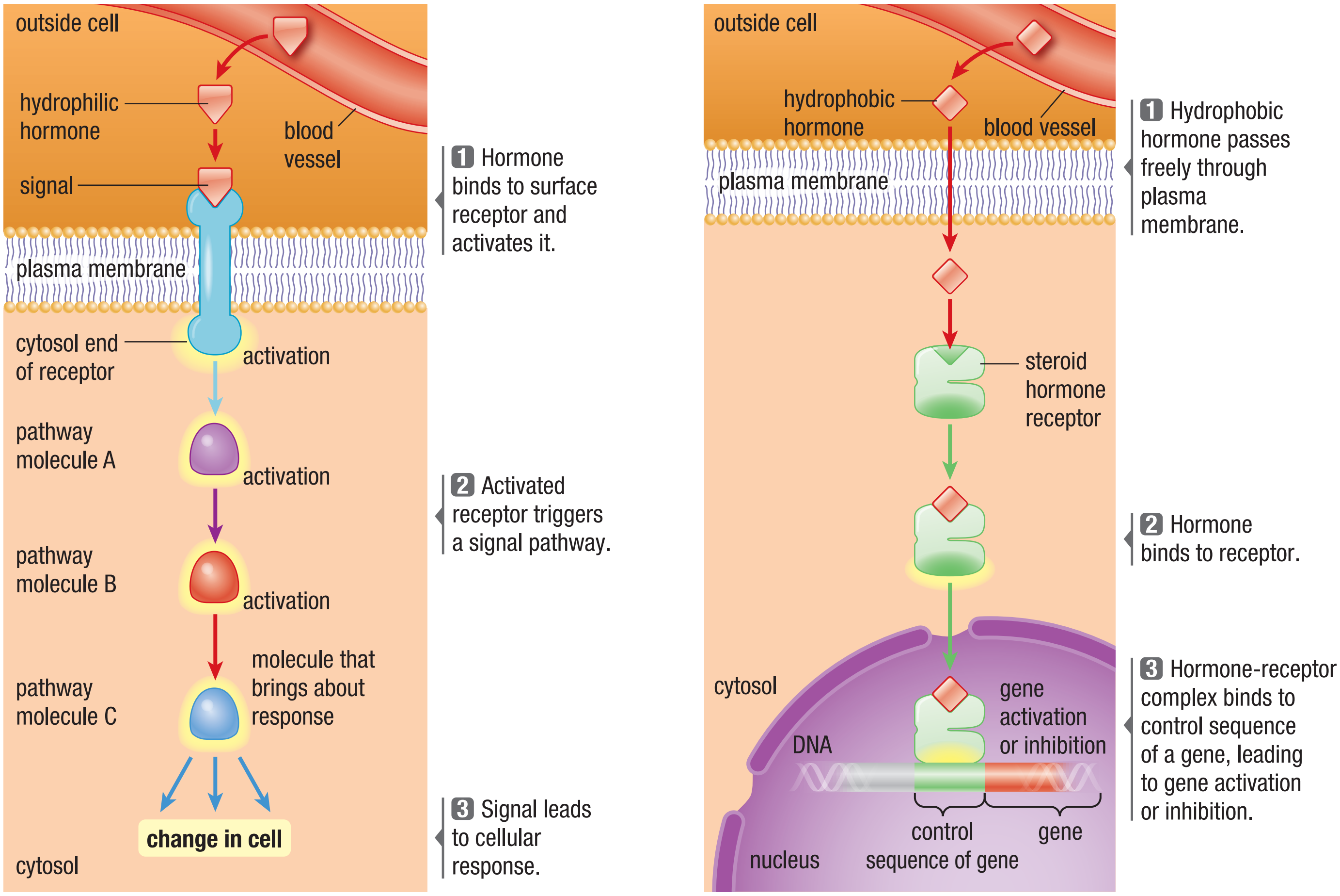
Hormones are usually secreted in relatively small amounts, but a process of amplification magnifies their effects. Once a receptor cell activates a few proteins, these proteins activate other proteins, each of which activates other proteins, and so on. This chain reaction amplifies the effect of the small amount of hormone initially received.

Pathways for Water-Soluble Hormones

Hormones use two main mechanisms to control cellular activities. The first mechanism governs water-soluble protein hormones, which cannot easily cross membranes (**Figure 2(a)**, next page). Protein hormones bind to receptor molecules in the cell membrane, causing the receptor molecule to change shape. This activates a signal, which passes into the cell. The signal causes further changes inside the cell, such as the release of enzymes that add phosphate groups to certain proteins, activating or deactivating them. The signal initiated by the hormone may act in the cytosol only, or it may affect the nucleus of the cell, as with many protein hormones such as growth factors.

An example of the surface receptor mechanism is the protein hormone **glucagon**. When glucagon binds to surface receptors on liver cells, it triggers a series of reactions. These reactions lead to the addition of phosphate groups, which activate the enzyme that governs the breakdown of stored glycogen into glucose.

glucagon a hormone produced by alpha cells in the pancreas that raises the blood glucose level by promoting the breakdown of glycogen in the liver



(a) water-soluble hormones

(b) lipid-soluble hormones

Figure 2 Reaction pathways are (a) in the plasma membrane for water-soluble hormones, and (b) inside the cell for lipid-soluble hormones.

Pathways for Lipid-Soluble Hormones

The second main mechanism involves hormones binding to receptors inside a cell (**Figure 2(b)**). This mechanism is used by most steroid hormones. Steroid hormones are lipid based and therefore lipid soluble, and they pass easily through the plasma membrane. Steroid hormones attach to receptors in the cytosol or nucleus of a cell. The hormone-receptor complex then binds to a control sequence on a specific gene, turning the gene's action on or off. Activation and deactivation of the gene changes the amount of protein that it synthesizes, which changes the cellular activity.

The internal receptor hormone mechanism can be illustrated by the steroid hormone aldosterone. If blood pressure falls below normal levels, aldosterone is secreted by the adrenal glands. The aldosterone travels through cell membranes and attaches to specific receptors found only in certain cells, including cells in the kidneys, sweat glands, and colon. When aldosterone is attached to a receptor, the receptor acts as a transcription factor for a specific gene, leading to the synthesis of proteins that increase sodium reabsorption. The increase in sodium in the blood then increases water retention and thus blood pressure.

Comparison of Water-Soluble and Lipid-Soluble Mechanisms

The two mechanisms used by hormones are not mutually exclusive. A single target cell may have receptors for several hormones and respond differently to each hormone. For example, the liver cells of vertebrates have receptors for the pancreatic hormones insulin and glucagon. Insulin increases the uptake of glucose and its conversion to glycogen, which decreases the blood glucose level. Glucagon stimulates the breakdown of glycogen into glucose, which increases the blood glucose level.

Conversely, particular hormones can interact with different types of receptors in or on a range of target cells. Different responses are then triggered in each target cell because the receptors trigger different signal pathways. As well, the response to a hormone may differ among species. For example, melatonin, a protein hormone derived from tryptophan, is important in regulating daily and annual cycles in most animals. However, it also plays a role in regulating the salt glands of marine birds.

In summary, the mechanisms by which hormones work have four major features:

1. Only the cells that contain surface or internal receptors for the hormones respond to the hormones.
2. Once bound to their receptors, hormones produce a response by turning cellular processes on or off. They do this by altering the proteins that are functioning in or produced by the cell.
3. Hormones are effective in very small concentrations because of the amplification that occurs in both the surface and internal receptor mechanisms.
4. The response to a hormone differs among target organs and among species.

Hormones as Part of Feedback Mechanisms

The secretion of most hormones is regulated by negative feedback mechanisms. In a negative feedback mechanism, a chemical that is affected at the end of the action pathway of a hormone controls the further action of the hormone by inhibiting an earlier chemical reaction. A response in a feedback loop may be the production of a substance or a decrease in the production of a substance. For example, a brain structure called the hypothalamus releases thyroid-releasing hormone (TRH), which initiates a pair of hormone releases by the pituitary and thyroid glands (**Figure 3**). As the concentration of the thyroid hormone in the blood increases, it inhibits an earlier step in the pathway, the secretion of thyroid-stimulating hormone (TSH) by the pituitary gland.

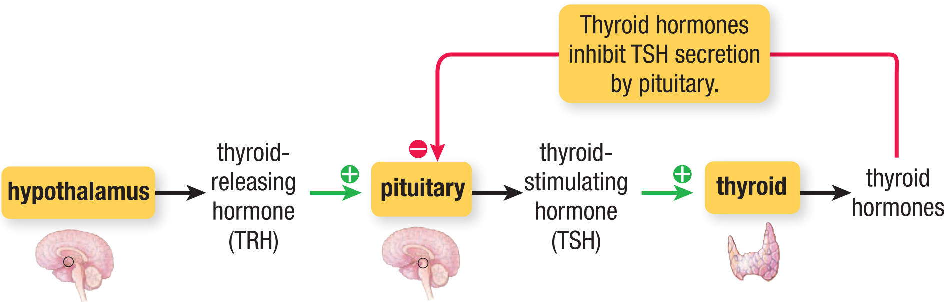


Figure 3 A simple negative feedback loop regulates the secretion of hormones.

Regulation of Body Processes by Hormones

Some glands produce multiple hormones, and many body processes are affected by more than one hormone at a time. The blood concentrations of glucose, fatty acids, and ions (such as Ca^{2+}, K^{+}, and Na^{+}) are regulated by the coordinated activities of several hormones, which are secreted by different glands. Similarly, body processes such as oxidative metabolism, digestion, growth, sexual development, and reactions to stress are all controlled by multiple hormones.

In many of these systems, negative feedback loops adjust the level of secretion of hormones that act in opposing ways. This creates a balance in their effects that maintains homeostasis in the body. Consider the regulation of fuel molecules, such as glucose, fatty acids, and amino acids, in the blood. In Canada, many people eat three meals a day. Between meals, five separate hormone systems, involving the digestive tract, pancreas, nervous system, and pituitary and adrenal glands, all act together in a coordinated fashion to keep the body's fuel levels in balance.

10.1 Review

Summary

- Most hormones are chemicals secreted by the cells of the endocrine system that control the activities of cells elsewhere in the body.
- Only target cells that have the correct receptor proteins respond to the presence of a specific hormone. Once a receptor protein is bound to a hormone, it signals other proteins inside the cell to turn certain cellular processes on or off.
- Most hormones are either protein hormones or steroid hormones. Protein hormones are water soluble and tend to bind to cell membrane receptors. Steroid hormones are lipids and not as water soluble, but they pass easily through the plasma membrane and tend to attach to receptors inside the cell.
- Hormones can function at low concentrations because their effects can be amplified.
- Many hormones are controlled by negative feedback mechanisms in which the increasing concentration of a chemical turns off further production of a hormone.
- The glands of the endocrine system and their hormones work together to control other body systems and maintain homeostasis.

Questions

1. What is a hormone? K/U
2. Name and describe the two most common types of hormones, classified according to their molecular structure. K/U
3. What are the two main mechanisms that hormones use to produce their effects in target cells? K/U
4. If a particular hormone, such as the hormone that stimulates the development of facial hair, is released throughout the bloodstream, why does it not affect all the cells in the same way? K/U T/I
5. Use a graphic organizer to compare and contrast the endocrine system's methods of controlling and regulating processes in the body with the nervous system's methods. K/U C
6. Testosterone is a hormone derived from cholesterol. Explain how you would expect testosterone to perform its intended action in a cell. T/I
7. Research a hormone whose path was not explained in this section, such as cholecystokinin (CCK), insulin, progesterone, or estrogen. Create a flow chart to explain its pathway. T/I C
8. Osteoporosis is a loss of bone tissue usually associated with aging. Research the hormone calcitonin and its use as a therapy and preventive agent for osteoporosis. Summarize your findings in a report. You are free to choose the format for your report. For example, you could choose to do a written report, an oral presentation, or a slide show. T/I C A
9. Why does the imbalance of a particular hormone affect the entire body and cause so many different symptoms? K/U
10. Steroid hormones bind to receptors inside cells. Why can steroid hormones diffuse into a cell while protein hormones cannot? K/U
11. Use a t-chart to contrast the ways in which steroid and protein hormones
    (a) interact with cell membranes
    (b) get messages into cells
    (c) cause chemical reactions
    (d) make products K/U C
12. How are the target cell's activities changed if a gland produces too much of a particular hormone? Support your answer with an example. K/U

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