CHAPTER 25

COMMUNICATION II:

THE ENDOCRINE SYSTEM AND CHEMICAL MESSENGERS

Outline

Concepts

1. Chemical messengers are involved in communication, in maintaining homeostasis in an animal's body, and in the body's response to various stimuli. One type of chemical messenger is a hormone. Only those cells that have specific receptors for a hormone can respond to that hormone.
2. Hormones work with nerves to communicate, coordinate, and integrate activities within the body of an animal.
3. Almost every invertebrate produces hormones. However, the physiology of invertebrate hormones is often quite different from that of vertebrate hormones.
4. The major endocrine glands of vertebrates include the hypothalamus, pituitary, thyroid, parathyroids, adrenals, pineal, thymus, pancreas, and gonads. Various other tissues, however, such as the kidneys, heart, digestive system, and placenta also secrete hormones.

Chapter 24 discussed ways that the nervous and sensory systems work together to rapidly communicate information and maintain homeostasis in an animal's body. In addition, many animals have a second, slower form of communication and coordination—the endocrine system with its chemical messengers.

Some scientists suggest that chemical messengers may initially have evolved in single-celled organisms to coordinate feeding or reproduction. As multicellularity evolved, more complex organs also evolved to govern the many individual coordination tasks, but control centers relied on the same kinds of messengers that were present in the simpler organisms. Some of the messengers worked fairly slowly but had long-lasting effects on distant cells; these became the modern hormones. Others worked more quickly but influenced only adjacent cells for short periods; these became the neurotransmitters and local chemical messengers. Clearly, chemical messengers have an ancient origin and must have been conserved for hundreds of millions of years.

Evolutionarily, new messengers are uncommon. Instead, "old" messengers are adapted to new purposes. For example, some ancient protein hormones are in species ranging from bacteria to humans.

One key to the survival of any group of animals is proper timing of activity so that growth, maturation, and reproduction coincide with the times of year when climate and food supply favor survival. It seems likely that the chemical messengers

This chapter contains evolutionary concepts, which are set off in this font.

regulating growth and reproduction were among the first to appear. These messengers were probably secretions of neurons. Later, specific hormones developed to play important regulatory roles in molting, growth, metamorphosis, and reproduction in various invertebrates. Chemical messengers and their associated secretory structures became even more complex with the appearance of vertebrates.

CHEMICAL MESSENGERS

The development of most animals commences with fertilization and the subsequent division of the zygote. Further development then depends on continued cell proliferation, growth, and differentiation. The integration of these events, as well as the communication and coordination of physiological processes, such as metabolism, respiration, excretion, movement, and reproduction, depend on chemical messengers—molecules that specialized cells synthesize and secrete. Chemical messengers can be categorized as follows:

1. **Local chemical messengers.** Many cells secrete chemicals that alter physiological conditions in the immediate vicinity (figure 25.1*a*). Most of these chemicals act on adjacent cells and do not accumulate in the blood. Vertebrate examples include some of the chemicals called lumones that the gut produces and that help regulate digestion. In a wound, mast cells secrete a substance called histamine that participates in the inflammatory response.
2. **Neurotransmitters.** As presented in chapter 24, neurons secrete chemicals called neurotransmitters (e.g., nitric oxide and acetylcholine) that act on immediately adjacent target cells (figure 25.1*b*). These chemical messengers reach high concentrations in the synaptic cleft, act quickly, and are actively degraded and recycled.
3. **Neuropeptides.** Some specialized neurons (called neurosecretory cells) secrete neuropeptides **(neurohormones).** The blood or other body fluids transport neuropeptides to nonadjacent target cells, where neuropeptides exert their effects (figure 25.1*c*). In mammals, for example, certain nerve cells in the hypothalamus release a neuropeptide that causes the pituitary gland to release the hormone oxytocin, which induces powerful uterine contractions during the delivery of offspring.
4. **Hormones.** Endocrine glands or cells secrete hormones that the bloodstream transports to nonadjacent target cells (figure 25.1*d*). Many examples are given in the rest of this chapter.
5. **Pheromones.** Pheromones are chemical messengers released to the exterior of one animal that affect the behavior of another individual of the same species (figure 25.1*e*; *see also table 15.2*).

Overall, scientists now recognize that the nervous and endocrine systems work together as an all-encompassing communicative and integrative network called the **neuroendocrine system.** In this system, feedback systems regulate chemical messengers in their short- and long-term coordination of animal body function to maintain homeostasis.

HORMONES AND THEIR FEEDBACK SYSTEMS

A **hormone** (Gr. *hormaein,* to set in motion or to spur on) is a specialized chemical messenger that an endocrine gland or tissue produces and secretes. The study of endocrine glands and their hormones is called **endocrinology.** Hormones circulate through body fluids and affect the metabolic activity of a target cell or tissue in a specific way. By definition, a **target cell** has receptors to which chemical messengers either selectively bind or on which they have an effect. Only rarely does a hormone operate independently. More typically, one hormone influences, depends on, and balances another hormone in a controlled feedback network.

BIOCHEMISTRY OF HORMONES

Most hormones are proteins (polypeptides), derivatives of amino acids (amines), or steroids. A few are fatty acid derivatives. For example, most invertebrate neurosecretory cells produce polypeptides called neuropeptides. Hormones that the vertebrate pancreas secretes are proteins; those that the thyroid gland secretes are amines. The ovaries, testes, and cortex of the adrenal glands secrete steroids.

Hormones are effective in extremely small amounts. Only a few molecules of a hormone may be enough to produce a dramatic response in a target cell. In the target cell, hormones help control biochemical reactions in three ways: (1) a hormone can increase the rate at which other substances enter or leave the cell; (2) it can stimulate a target cell to synthesize enzymes, proteins, or other substances; or (3) it can prompt a target cell to activate or suppress existing cellular enzymes. As is the case for enzymes, hormones are not changed by the reaction they regulate.

FEEDBACK CONTROL SYSTEM OF HORMONE SECRETION

Although hormones are always present in some amount in endocrine cells or glands, they are not secreted continuously. Instead, the glands secrete the amount of hormone that the animal needs to maintain homeostasis. A feedback control system monitors changes in the animal or in the external environment and sends information to a central control unit (such as the central nervous system), which makes adjustments. A feedback system that produces a response that counteracts the initiating stimulus is called a negative feedback system. In contrast, a positive feedback system reinforces the initial stimulus. Positive feedback systems are relatively rare in animals because they usually lead to instability or pathological states.

Negative feedback systems monitor the amount of hormone secreted, altering the amount of cellular activity as needed to

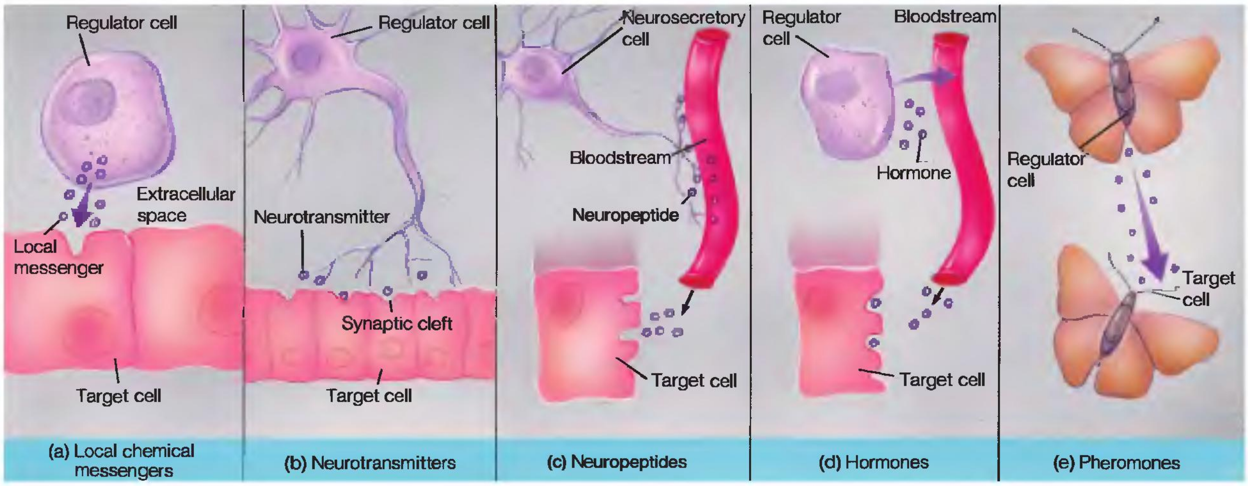

FIGURE 25.1

Chemical Messengers: Targets and Transport. *(a)* Short-distance local messengers act on an adjacent cell. *(b)* Individual nerve cells secrete neurotransmitters that cross the synaptic cleft to act on target cells. *(c)* Individual nerve cells can also secrete neuropeptides (neurohormones) that travel some distance in the bloodstream to reach a target cell. *(d)* Regulatory cells, usually in an endocrine gland, secrete hormones, which enter the bloodstream and travel to target cells. *(e)* Regulatory cells in exocrine glands secrete pheromones. They leave the body and stimulate target cells in another animal.

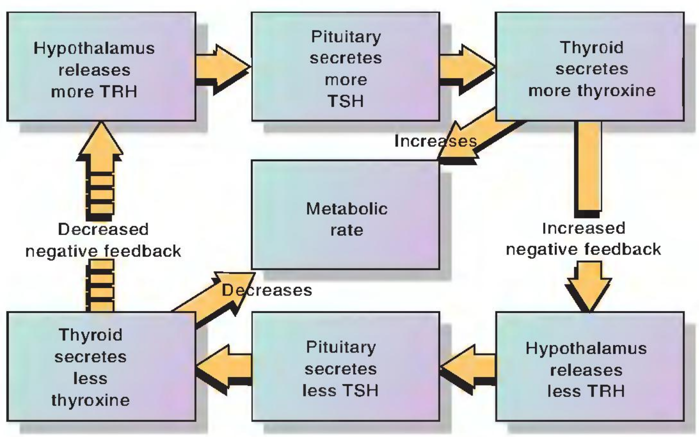

FIGURE 25.2

Hormonal Feedback. Negative feedback system that helps control metabolic rate in a vertebrate such as a dog. (TRH = thyrotropin-releasing hormone; TSH = thyroid-stimulating hormone.)

maintain homeostasis. For example, suppose that the rate of chemical activity (metabolic rate) in the body cells of a dog slows (figure 25.2). The hypothalamus responds to this slow rate by releasing more thyrotropin-releasing hormone (TRH), which causes the pituitary gland to secrete more thyrotropin, or thyroid-stimulating hormone (TSH). This hormone, in turn, causes the thyroid gland to secrete a hormone called thyroxine. Thyroxine increases the metabolic rate, restoring homeostasis. Conversely, if the metabolic rate speeds up, the hypothalamus releases less TRH, the pituitary secretes less TSH, the thyroid secretes less thyroxine, and the metabolic rate decreases once again, restoring homeostasis.

MECHANISMS OF HORMONE ACTION

Hormones modify the biochemical activity of a target cell or tissue. Two basic mechanisms are involved. The first, the fixed-membrane-receptor mechanism, applies to hormones that are proteins or amines. Because they are water-soluble and cannot diffuse across the plasma membrane, these hormones initiate their response by means of specialized receptors on the plasma membrane of the target cell. The second, the mobile-receptor mechanism, applies to steroid hormones. These hormones are lipid-soluble