28 PLANTS AND ANIMALS—COMMON CHALLENGES

Too Hot To Handle

When was the last time the word **homeostasis** slipped into one of your conversations? Years ago? Or maybe never? So why should it? Homeostasis is a state in which the body's internal environment is being kept within a range that its cells can tolerate. In humans, that happens when activities of trillions of living cells of many organ systems are being integrated. To understand "homeostasis," you have to know the details of how complex, multicelled organisms are put together and how their parts function.

Sometimes terrible things can happen to the body in the absence of that understanding. In the summer of 2001 Korey Stringer, a football player for the Minnesota Vikings, collapsed after morning practice (Figure 28.1). On that day, his team had been working out in full uniform on a field where temperatures were in the high 90s. High humidity put the heat index above 100°F.

Stringer's internal body temperature had soared to 108.8°F, and his blood pressure was too low even to record. He was rushed to the hospital, where doctors immersed him in an icewater bath, then wrapped him in cold, wet towels. It was too late.

Stringer's blood clotting mechanism shut down and he started to bleed internally. His kidneys faltered and he was placed on dialysis. He stopped breathing on his own and was attached to a respirator. However, his heart gave out. Less than twenty-four hours after football practice had started, Stringer was pronounced dead. He was twenty-seven years old.

All organisms function best within a limited range of internal operating conditions. For humans, "best" is when the body's internal temperature remains between about 97°F and 100°F. Past 104°F, metabolism is in an uproar, and blood is transporting a great deal of metabolic heat. Controls over blood transport divert heat from the brain and other internal organs to the skin. Then skin transfers heat to the outside environment—as long as it is not too hot outside. Profuse sweating can dissipate more heat, but not on hot, humid days.

These normal cooling mechanisms fail above 105°F. The body cannot sweat as much, and its temperature starts to climb rapidly. The heart beats faster and the individual becomes confused or faints. These are signs of *heat stroke*. The high internal temperature that causes it can affect the enzymes and other proteins that keep us alive. When heat stroke is not countered fast enough, brain damage or death is the expected outcome.

We use this sobering example as our passport to the world of anatomy and physiology. *Anatomy* is the study

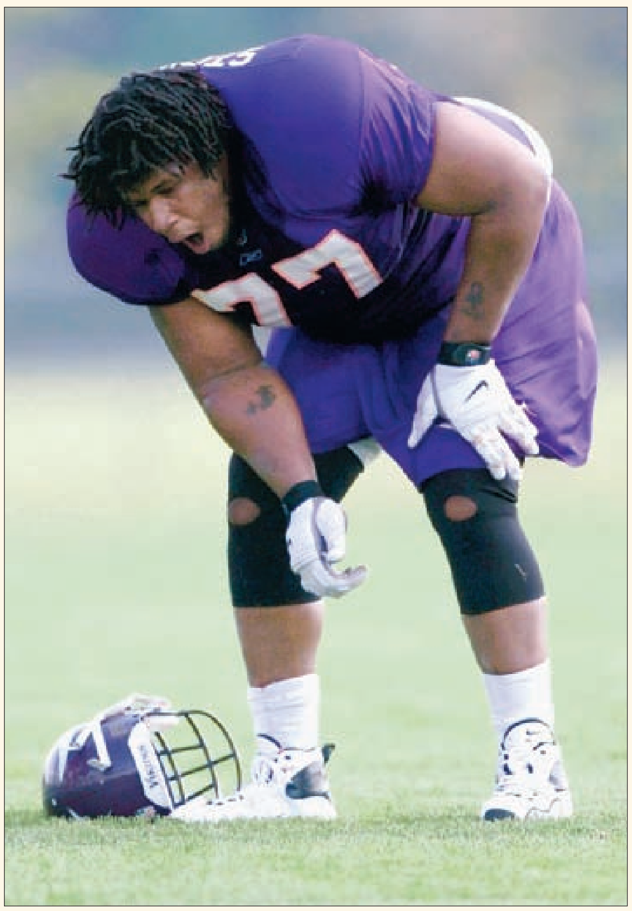

Figure 28.1 Temperature control mechanisms that have worked for millions of years. Water helps dissipate excess body heat when it can move out through pores of glands at the skin surface (*facing page*). Also, blood circulating through the body reaches fine blood capillaries in skin. When the skin's tissues are not as warm as the blood circulating past, heat is transferred into them, then into the air—if the air is cooler still. In Korey Stringer's case, cooling could not happen fast enough.

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IMPACTS, ISSUES

of body form—that is, its morphology. *Physiology* is the study of patterns and processes by which an individual survives and reproduces in the environment. It deals with how the body's parts are put to use and how metabolism and behaviors are adjusted when conditions change. It also deals with how, and to what extent, physiological processes can be controlled.

On a personal level, this information can help you monitor what is going on in your own body. More broadly, it also can help you identify commonalities among animals and plants. Regardless of the species, *the structure of any given body part almost always has something to do with a present or past function.* Most aspects of form and function are long-standing adaptations that evolved as responses to environmental challenges.

That said, nothing in the evolutionary history of the human species suggests that the organ systems making up our body are fine-tuned to handle intense football practice on hot, humid days.

How Would You Vote?

Heat sickness can affect a person's ability to think clearly. Should a coach who does not stop team practice or a game when the heat index soars be held responsible if a player dies from heat stroke? See BiologyNow for details, then vote online.

Key Concepts

MANY LEVELS OF STRUCTURE AND FUNCTION

Anatomy is the study of body form at successive levels of structural organization, from molecules on up through organ systems. Physiology is the study of how the body functions in response to the environment. The structure of most body parts correlates with current or past functions, and it emerges during stages of growth and development. Section 28.1

SIMILARITIES BETWEEN ANIMALS AND PLANTS

Animals and plants are alike in their requirements for gas exchange, internal transport, maintaining the volume and composition of their internal environment, and cell-to-cell communication. They show variations in their response to resources and threats. Section 28.2

HOMEOSTASIS

Extracellular fluid bathes all living cells in the multicelled body. Cells, tissues, organs, and organ systems contribute to maintaining this internal environment within a range that individual cells can tolerate. This concept yields insight into the functions and interactions of body parts.

Homeostasis is the name for stable operating conditions in the internal environment. Negative and positive feedback mechanisms are among the controls that work to maintain these conditions. Sections 28.3, 28.4

CELL COMMUNICATION IN MULTICELLED BODIES

Cells of tissues and organs communicate with one another by secreting hormones and other signaling molecules into extracellular fluid, and by selectively responding to signals from other cells. Section 28.5

Links to Earlier Concepts

Look back on the road map through the levels of biological organization in Section 1.1. You are about to see how new properties of life emerge through interactions among the tissues, organs, and organ systems of plants and animals.

You will draw on your understanding of the constraints on multicelled body plans—the surface-to-volume ratio (4.1, 25.1), diffusion and demands for gas exchange (5.3), and internal transport (5.4, 23.2, 25.2). You will find examples of how signaling molecules help control growth, development, day-to-day activities, and reproduction (5.2, 22.12). You also will consider specific cases of evolutionary adaptation (8.9).

28.1 Levels of Structural Organization

LINKS TO SECTIONS 1.1, 4.9, 23.2, 25.1

We introduce important concepts in this chapter. They have broad application across the next two units of the book. Become familiar with them; they can deepen your sense of how plants and animals function under environmental conditions, both favorable and stressful.

FROM CELLS TO MULTICELLED ORGANISMS

Most plants and animals have cells, tissues, organs, and organ systems that split up the task of survival. A separate cell lineage gives rise to body parts that will function in reproduction. Said another way, the plant or animal body shows a division of labor.

A **tissue** is a community of cells and intercellular substances that are interacting in one or more tasks. For example, wood and bone are tissues that function in structural support. Each **organ** is a structural unit of at least two tissues, organized in certain proportions and patterns, that carries out one or more common tasks. A leaf adapted for photosynthesis and an eye responsive to light in the surroundings are examples. An **organ system** has two or more organs interacting physically, chemically, or both in the performance of one or more tasks. The organs of photosynthesis and reproduction of a flowering plant are like this (Figure 28.2). So is an animal's digestive system, which takes in food, breaks it up into bits of nutrients, absorbs the bits, and expels the unabsorbed leftovers.

GROWTH VERSUS DEVELOPMENT

A plant or animal becomes structurally organized as it grows and develops. For any multicelled species, **growth** refers to an increase in the number, size, and volume of cells. **Development** is a series of stages in which specialized tissues, organs, and organ systems form. That is why we measure growth in *quantitative* terms and development in *qualitative* terms.

STRUCTURAL ORGANIZATION HAS A HISTORY

The structural organization of each tissue, organ, and organ system has an evolutionary history. Remember how plants invaded land? Section 23.2 already gave you an idea of how their structure relates to function. The pioneers encountered an abundance of sunlight and carbon dioxide for photosynthesis, which meant more oxygen for aerobic respiration and a foundation for increases in size. However, in leaving the aquatic cradle, they faced a new challenge—how to keep from drying out in air.

Think about that challenge when micrographs show the internal structure of plant roots, stems, and leaves (Figure 28.2). Pipelines conduct streams of water from soil to leaves. Stomata, the small gaps across a leaf's epidermis, open and close in ways that conserve water (Section 30.4). Collectively, lignin-reinforced cell walls support the upright growth of stems. Remember that same challenge when you come across examples of

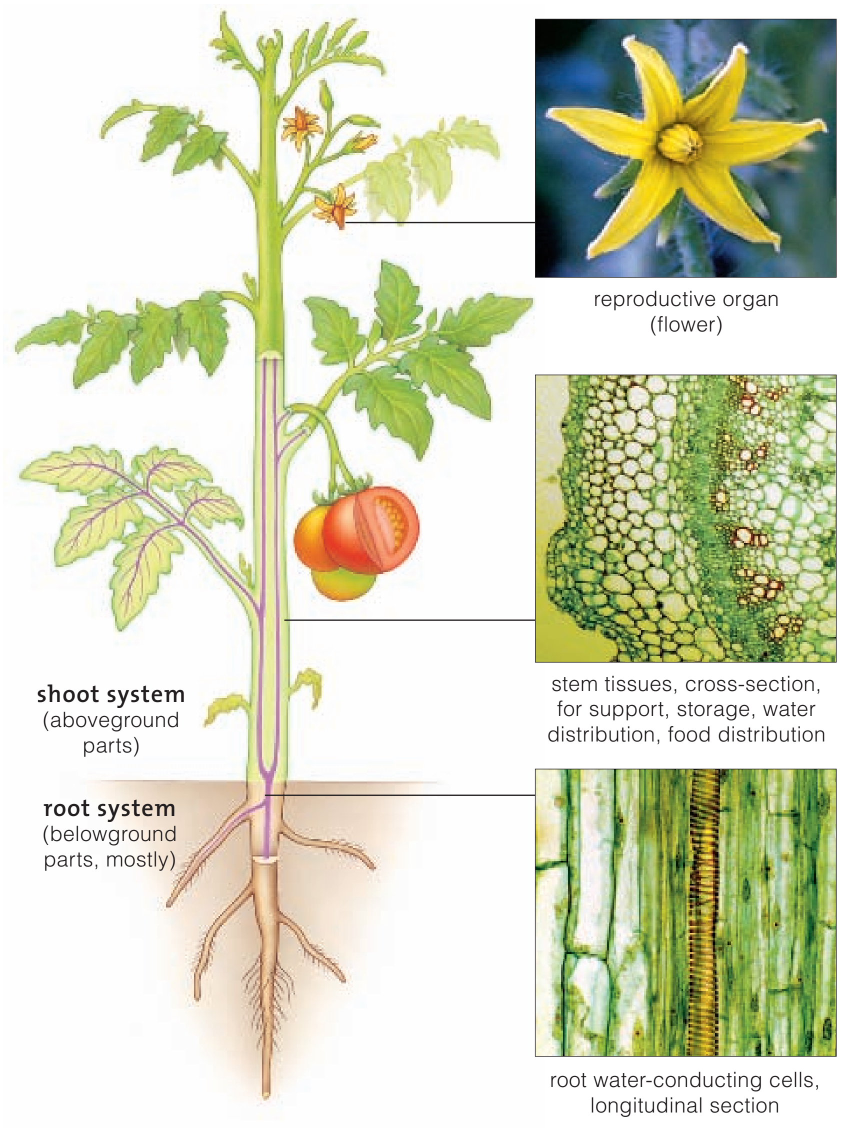


Figure 28.2 ***Animated!*** Morphology of a tomato plant (*Solanum lycopersicon*). Different cell types make up vascular tissues that conduct water, dissolved mineral ions, and organic compounds. These tissues thread through others that make up most of the plant body. Another tissue covers all surfaces exposed to the surroundings.

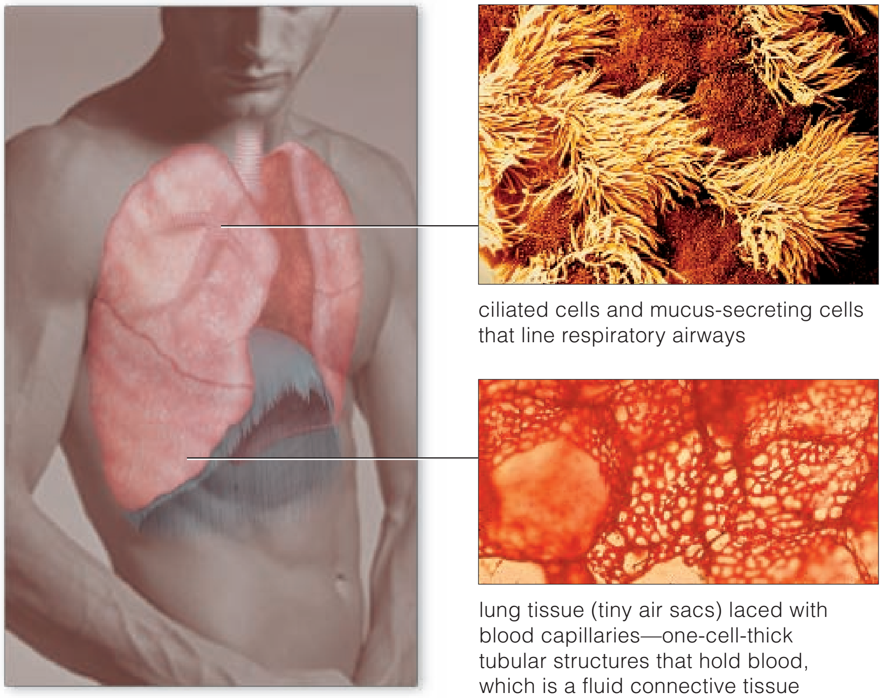


Figure 28.3 Some of the structures that function in human respiration. Their cells carry out specialized tasks. Airways to a pair of organs called lungs are lined with ciliated cells that whisk away bacteria and other airborne particles that might cause infections. Inside the lungs are tubes (blood capillaries), a fluid connective tissue we call blood, and thin air sacs (epithelial tissue). All of these components indirectly or directly facilitate the flow of oxygen into the internal environment and the flow of carbon dioxide out of it.

organs (lungs), part of an organ system (the respiratory tract) of a whole organism

ciliated cells and mucus-secreting cells that line respiratory airways

lung tissue (tiny air sacs) laced with blood capillaries—one-cell-thick tubular structures that hold blood, which is a fluid connective tissue

root systems. Any patch of soil with plenty of water and dissolved mineral ions stimulates root growth in its direction; hence the branching roots.

Similarly, respiratory systems of land animals are adaptations to life in air. Gases only move into and out of their body by diffusing across a moist surface. This is not a problem for aquatic organisms, but moist surfaces dry out in air. The animals on dry land have moist sacs for gas exchange *inside* their body (Figure 28.3), which brings us to the internal environment.

THE BODY'S INTERNAL ENVIRONMENT

Plant and animal cells must be bathed in a fluid that delivers nutrients and carries away metabolic wastes. In this they are no different from free-living single cells. But each plant or animal has thousands to many trillions of living cells. All must draw nutrients from the fluid bathing them and release wastes into it.

Body fluid *not* inside cells—extracellular fluid—is an **internal environment**. Changes in its composition and volume affect cell activities. The type and number of ions are vital; they must be kept at concentrations compatible with metabolism. It makes no difference whether the plant or animal is simple or complex. *It requires a stable fluid environment for all of its living cells*. This concept is central to understanding how plants and animals work.

START THINKING "HOMEOSTASIS"

The next two units describe how a plant or an animal carries out these basic functions: The body works to maintain favorable conditions for all of its living cells. It acquires water, nutrients, and other raw materials, distributes them, and disposes of wastes. It passively and actively defends itself against attack. It has the capacity to reproduce. Parts of it nourish and protect gametes, and, in most species, the embryonic stages of the next generation.

Each living cell engages in metabolic activities that will favor its own survival. Collectively, however, the activities of cells in tissues, organs, and organ systems sustain the body as a whole. Their interactions keep the operating conditions of the internal environment within tolerable limits—*the state we call homeostasis*.

The structural organization of plants and animals emerges during stages of growth and development.

Cells, tissues, and organs require a favorable internal environment, and they collectively maintain it. All body fluids not contained in cells make up that environment.

Acquiring materials and distributing them to cells, getting rid of wastes, protecting cells and tissues, reproducing, and often nurturing offspring are basic body functions.

28.2 Recurring Challenges to Survival

LINKS TO SECTIONS 4.1, 5.3, 5.4

Plants and animals have such diverse body plans that we sometimes forget how much they have in common.

GAS EXCHANGE IN LARGE BODIES

How often do you think of similarities between, say, Tina Turner and a tulip (Figure 28.4)? Connections are there. Cells in both would die if oxygen and carbon dioxide stopped diffusing across their body surface. Tina, a heterotroph, supplies her aerobically respiring cells with oxygen and disposes of the carbon dioxide products. The plant, an autotroph, exchanges oxygen for carbon dioxide, but it keeps some for its own cells, which also engage in aerobic respiration.

All multicelled species respond, structurally and functionally, to this same challenge. *They must quickly move gaseous molecules to and from individual cells.*

Remember **diffusion**? When they are concentrated in one place, ions or molecules of any substance tend to move to a place where they are not as concentrated. Animals and plants keep gases diffusing in directions most suitable for metabolism and cell survival. How? That question will lead you to stomata at leaf surfaces (Chapter 30) and to the circulatory and respiratory systems of animals (Chapters 38 and 40).

INTERNAL TRANSPORT IN LARGE BODIES

Metabolic reactions happen fast. If reactants take too long to diffuse through the body or to and from the surface, systems shut down. This is one reason cells and multicelled species have the sizes and shapes that they do. As they grow, their volume increases in three dimensions—in length, width, and depth—but their surface area increases in two dimensions only. That is the essence of the **surface-to-volume ratio** (Section 4.1). If the body were to develop into a densely solid mass, it would not have enough surface area for fast, efficient exchanges with the environment.

When a body or some body part is thin, as it is for the flatworm and lily pads in Figure 28.5, substances easily diffuse between individual cells and the outer environment. In massive bodies, individual cells that are far from an exchange point with the environment depend on systems of rapid internal transport.

Most plants and animals have vascular tissues, or systems of tubes through which substances move to and from all living cells. In land plants, xylem moves soil water and mineral ions. Phloem moves sucrose to cells from leaves. Each leaf vein has long strands of xylem and phloem (Figure 28.5*c*).

In big animals, the vascular tissues extend from a surface facing the environment to living cells inside. Each time Tina belts out a song, she is moving oxygen into her lungs and carbon dioxide out of them. Blood vessels thread through lung tissue where the gases are exchanged. Large vessels transport oxygen and branch into small capillaries in all tissues—where interstitial fluid and cells exchange gases (Figure 28.5*d*).

In both plants and animals, the vascular system also transports diverse substances, such as nutrients, water, and hormones. In animals, it moves infection-fighting white blood cells and chemical weapons about. As you will see, phloem distributes defensive chemicals that are produced in response to infection or wounds.

MAINTAINING THE WATER–SOLUTE BALANCE

Plants and animals continually gain and lose water and solutes, and produce metabolic wastes. Given all the inputs and outputs, how does the volume and composition of their internal environment stay within a tolerable range? Plants and animals differ hugely in this respect. Yet we still can find common responses by zooming down to the level of molecular motions.

Substances tend to follow concentration gradients when moving into and out of the body or from one body compartment into another. At such interfaces, the individual cells of sheetlike tissues passively and actively transport substances. **Active transport**, recall, pumps substances against the direction in which their concentration gradient would take them (Section 5.4).

Active transport mechanisms in roots help control which solutes can move into the plant. In leaves, they help control water loss and gas exchange by closing

Figure 28.4 What do these organisms have in common besides their good looks?

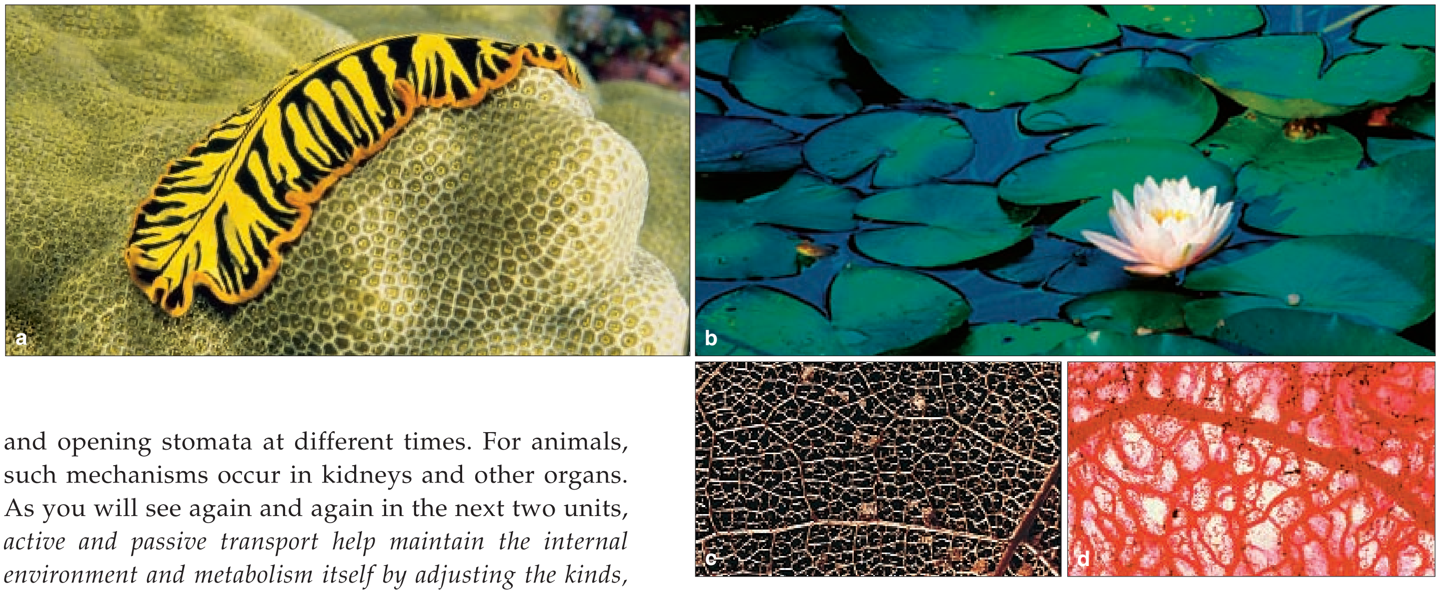


Figure 28.5 (**a**) Flatworm gliding through water, (**b**) waterlily leaves floating on water, (**c**) veins in a decaying dicot leaf, (**d**) human veins and capillaries. Which constraint has influenced these body plans and structures?

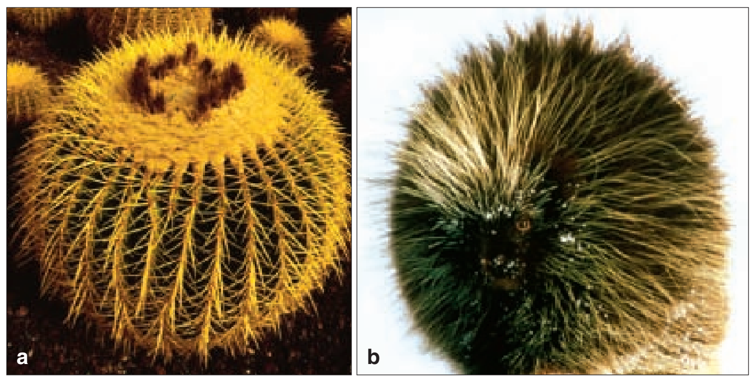


Figure 28.6 Protecting body tissues from predation: (**a**) Cactus spines. (**b**) Quills of a porcupine (*Erethizon dorsatum*).

and opening stomata at different times. For animals, such mechanisms occur in kidneys and other organs. As you will see again and again in the next two units, *active and passive transport help maintain the internal environment and metabolism itself by adjusting the kinds, amounts, and directional movements of substances.*

CELL-TO-CELL COMMUNICATION

Plants and animals show another major similarity in their structure and function. A number of their cells release signaling molecules that coordinate and also control events inside the body as a whole. Different signaling mechanisms guide how the plant or animal body grows, develops, and maintains itself. Section 28.5 has a good example of this.

ON VARIATIONS IN RESOURCES AND THREATS

A **habitat** is the place where individuals of a species normally live. Each has different resources and poses a unique set of challenges. What are its physical and chemical characteristics? Is water plentiful, with the right kinds and amounts of solutes? Is the habitat rich or poor in nutrients? Is it sunlit, shady, or dark? Is it warm or cool, hot or icy, windy or calm? How much does the outside temperature vary from day to night? How much do conditions vary with the seasons?

And what about biotic (living) components of the habitat? Which producers, predators, prey, pathogens, or parasites live there? Is competition for resources and reproductive partners fierce? Such ever changing variables promote diversity in form and function.

Even with all the diversity, we may still see similar responses to similar challenges. Sharp cactus spines or porcupine quills deter most animals that might eat a cactus or porcupine (Figure 28.6). Modified epidermal cells give rise to both spines and quills. Deliveries from vascular tissues and other body parts kept those cells alive. In return, by forming spines or quills and other defensive structures at the body's surface, epidermal cells help protect the vascular tissues and other body parts against outside threats.

Plant and animal cells function in ways that help ensure survival of the body as a whole. At the same time, tissues and organs that make up the body function in ways that allow the continued survival of individual living cells.

The connection between each cell and the body as a whole is evident in the requirements for—and contributions to—gas exchange, nutrition, internal transport, stability in the internal environment, and defense.

28.3 Homeostasis in Animals

LINKS TO SECTIONS 1.2, 6.4

In preparation for your trek through the next two units, focus again on what homeostasis means to survival.

Like other adult humans, your body consists of more than 65 trillion living cells. Each must draw nutrients from and dump wastes into the same fifteen liters of fluid—less than four gallons. Fluid not inside cells is *extracellular* fluid. Much is **interstitial fluid**, meaning it fills the spaces between cells and tissues. The rest is **plasma**, the fluid portion of blood. Interstitial fluid exchanges substances with cells and with blood.

Homeostasis, again, is a state in which the internal environment is being maintained within a range that cells can tolerate. Sensory receptors, integrators, and effectors are in charge of it. Collectively, they detect, process, and respond to information on *how things are* compared to preset points of *how they should be*.

Sensory receptors are cells or cell parts that detect stimuli, which are specific forms of energy. A kiss, for example, is a form of mechanical energy that changes pressure on the lips. Receptors in lip tissues translate a kiss into signals that reach the brain. The brain is an **integrator**, a central command post that receives and processes information about stimuli. It issues signals to **effectors**—muscles, glands, or both—that carry out suitable responses to the stimulation (Figure 28.7).

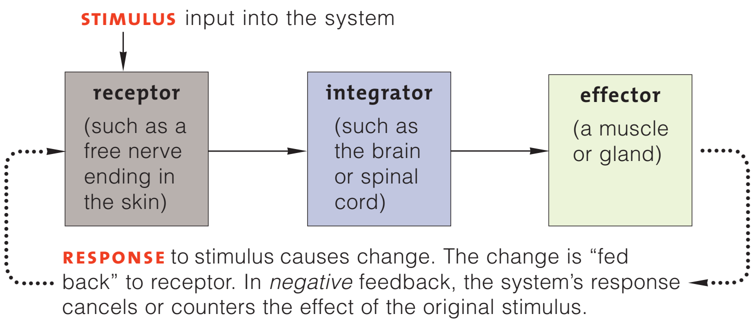
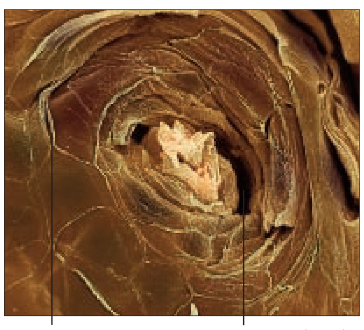


Figure 28.7 Three essential components of negative feedback systems in multicelled organisms. Figure 28.9 gives a specific example.

NEGATIVE FEEDBACK

Feedback mechanisms help control what goes on in cells (Section 6.4). They also are major homeostatic controls over how the multicelled body functions. By **negative feedback mechanisms**, some activity changes a specific condition in the internal environment, and if the condition changes past a certain point, a response reverses the change.

Think of a furnace with a thermostat. A thermostat senses the surrounding air temperature relative to a preset point on a thermometer built into the furnace's control system. When the temperature falls below the



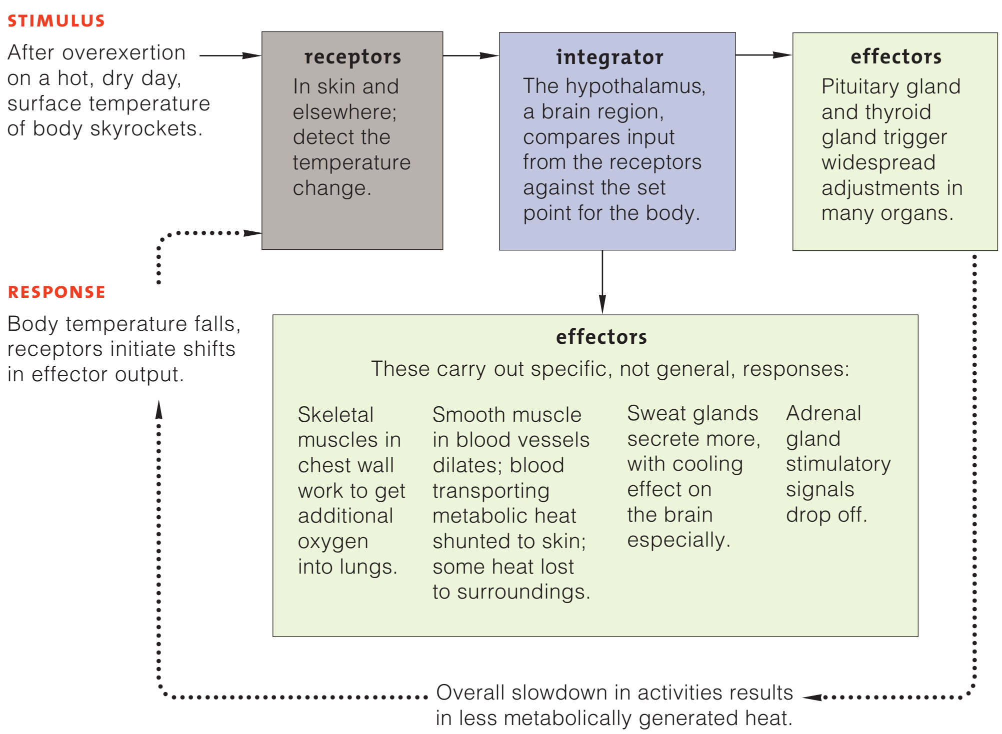


Figure 28.8 *Animated!* Major homeostatic controls over a human body's internal temperature. *Solid* arrows signify the main control pathways. *Dotted* arrows signify the feedback loop.

The scanning electron micrograph shows a sweat gland pore at the skin surface. Such glands are among the effectors for this control pathway.

preset point, it signals a switching mechanism, which turns on the furnace. When the air gets hot enough to match the preset level, the thermostat senses that match and signals the switch to shut off the furnace.

Similarly, feedback mechanisms help keep the internal body temperature of humans and many other mammals near 98.6°F (37°C) even during hot or cold weather. When someone runs on a hot summer day, the body becomes hot. Receptors trigger changes that slow down the entire body *and* its cells (Figure 28.8). Normally, such controls counter overheating. They curb activities that naturally generate metabolic heat, and give up excess heat to the surrounding air.

As another example, think about how we breathe to take in oxygen and get rid of carbon dioxide. Most of us live at low elevations, where we can get enough oxygen. The brain is responsive to receptors that are sensitive to how much carbon dioxide is dissolved in blood. It compares receptor signals against a set point for what the carbon dioxide level is supposed to be. It calls for adjustments in breathing and other activities that can shift the concentration of carbon dioxide in blood so that it is more in line with the set point.

Above 3,300 meters (10,000 feet), oxygen is scarce (Figure 28.9). Its level in blood declines. Receptors sensitive to the oxygen level in blood signal the brain, which responds by making us hyperventilate (breathe faster and deeper than usual). If the level remains too low, shortness of breath, heart palpitations, headaches, nausea, and vomiting may follow. These are warnings that cells are screaming for oxygen.

POSITIVE FEEDBACK

In certain situations, **positive feedback mechanisms** operate. These controls initiate a chain of events that *intensify* change from an original condition, and after a limited time, the intensification reverses the change. Positive feedback mechanisms are usually associated with instability in a system.

For instance, rapid flows of sodium ions across the plasma membrane of neurons help the body send and receive signals quickly. A suitable signal opens a few sodium channels across a neuron's membrane. Ions flow into the neuron, and the increased concentration inside makes more channels open, then more, until sodium ions flood inside. Such ion flows start the "messages" that travel along a neuron's surface.

As another example, during labor, the fetus exerts pressure on the wall of the chamber enclosing it, the uterus. Pressure induces the production and secretion of a hormone, oxytocin, that makes muscle cells in the wall contract. Contractions exert pressure on the fetus, which puts pressure on the wall to expand, and so on until the fetus is expelled from the mother's body.

Figure 28.9 A climber near the summit of Mount Everest, where the normal act of breathing is not enough to sustain the human body.

We have been introducing a pattern of detecting, evaluating, and responding to the flow of information about the internal and external environments. During this activity, organ systems work together. Soon, you will be asking these questions about their operation:

1. Which physical or chemical aspects of the internal environment are organ systems working to maintain?
2. How are organ systems kept informed of change?
3. By what means do they process the information?
4. What mechanisms are set in motion in response?

As you will read in Unit Six, organ systems of nearly all animals are under neural and endocrine control.

The internal environment is all the fluid not inside the body's cells. It consists of interstitial fluid and plasma, the fluid portion of blood.

Homeostatic controls, such as negative feedback and positive feedback mechanisms, help maintain physical and chemical aspects of the body's internal environment within ranges that its individual cells can tolerate.

28.4 Does Homeostasis Occur in Plants?

LINKS TO SECTIONS 23.7, 24.6

Plants differ from animals in important respects. Even so, they, too, have controls over their internal environment.

Direct comparisons between plants and animals are not always possible. In all young plants, new tissues arise at the tips of actively growing roots and shoots. In animal embryos, tissues form all through the body. Plants do not have a centralized integrator that serves as the equivalent of an animal brain. They do have some decentralized mechanisms that can protect the internal environment and work to keep the body as a whole functioning. Later chapters explain how, but two simple examples here will make the point.

WALLING OFF THREATS

Unlike people, trees consist mostly of dead and dying cells. Also unlike people, trees cannot run away from attacks. When a pathogen infiltrates their tissues, trees cannot unleash infection-fighting phagocytic cells in response, because they have none. However, plants do have **system acquired resistance** to infections and to injured tissues. This mechanism starts with signaling molecules that cells release in an affected tissue. These particular signals induce the synthesis of defensive compounds. Signals also diffuse to undamaged tissues farther away. They induce cells to produce and release compounds that will protect tissues from attack for days or months to come. Synthetic versions of organic compounds with roles in systemic defenses are now being developed and used to boost disease resistance in crops and ornamental plants.

Also, most trees protect the internal environment by walling off wounds, unleashing phenols and other toxic compounds, and often secreting resins. A heavy flow of gooey compounds saturates and protects bark and wood at an attack site. It also can seep into soil around roots. Some toxins are so potent that they also kill cells of the tree itself. As a result, compartments form around injured, infected, or poisoned sites, and new tissues grow right over them. This plant response to attack is called **compartmentalization**.

Drill holes into a tree species that makes a strong compartmentalization response and it quickly walls off that wound (Figure 28.10). In a species that makes a moderate response, decomposers that cause wood to decay expand farther, into tissues more distant from the holes. Drill holes into a weak compartmentalizer, and decomposers will cause massive decay.

Even strong compartmentalizers live only so long. After they form too many walls, they shut off the flow of water and solutes to their living cells. You may ask, What about a bristlecone pine? One was almost 5,000 years old. Such trees live in habitats that are too harsh or remote to favor the survival of most pathogens, so they are not attacked much. They spend most of the year in snow and the rest of it growing slowly under intense radiation from the sun (Section 23.7).

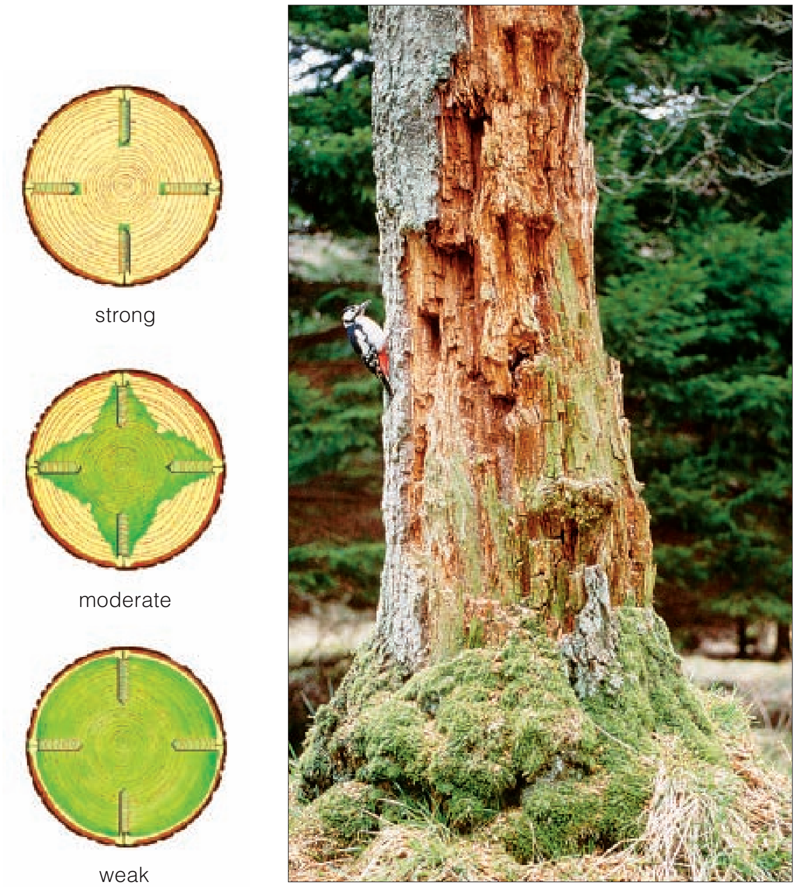


Figure 28.10 ***Animated!*** You think it's easy being a tree? Drilling patterns for an experiment to test compartmentalization responses. From top to bottom, the decay patterns (*green*) in stems of three species of trees that make strong, moderate, or weak compartmentalizing responses.

SAND, WIND, AND THE YELLOW BUSH LUPINE

Anybody who has tiptoed barefoot across sand near the coast on a hot, dry day has a tangible clue to why few plants grow in it. One exception is the yellow bush lupine, *Lupinus arboreus* (Figure 28.11).

L. arboreus is native to warm, dry areas of Central and Southern California. It is a hardy colonizer of soil exposed by fires or abandoned after being cleared for agriculture. Like all other legumes, this species has nitrogen-fixing symbionts in its young roots (Section 24.6). The interaction gives it a competitive edge in

Figure 28.11 Yellow bush lupine, *Lupinus arboreus*, in a sandy shore habitat. On hot, windy days, its leaflets fold up longitudinally along the crease that runs down their center. This helps minimize evaporative water loss.

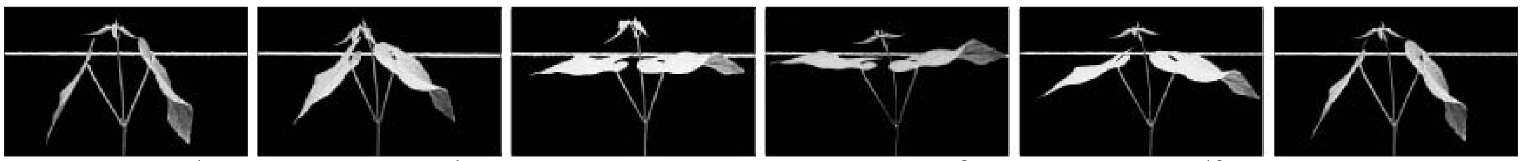


Figure 28.12 ***Animated!*** Observational test of rhythmic leaf movements by a young bean plant (*Phaseolus*). Physiologist Frank Salisbury kept the plant in darkness for twenty-four hours. Its leaves kept on folding and unfolding independently of sunrise (6 A.M.) and sunset (6 P.M.).

nitrogen-deficient soil. In the early 1900s, this species was planted in northern California to stabilize coastal dunes. Unfortunately, it is too successful in its new habitat. It outgrows and displaces native plants.

One big environmental challenge near the beach is the lack of fresh water. Leaves of a yellow bush lupine are structurally adapted for water conservation. Each leaf has a surprisingly thin cuticle, but a dense array of fine epidermal hairs projects above it, particularly on lower leaf surfaces. Collectively, all of the hairs trap moisture escaping from stomata. The trapped, moist air slows evaporation and helps maintain water levels inside the leaf at levels that best favor metabolism.

These leaves make homeostatic responses to the environment. They fold along their length, like two parts of a clam shell, and resist the moisture-sucking force of the wind. Each folded, hairy leaf is better at stopping moisture loss from stomata (Figure 28.11).

Leaf folding by *L. arboreus* is a controlled response to changing conditions. When winds are strong and the potential for water loss is greatest, the leaves fold tightly. The least-folded leaves are close to the plant's center or on the side most sheltered from the wind. Folding is a response to heat as well as to wind. When air temperature is highest during the day, leaves fold at an angle that helps reflect the sun's rays from their surface. The response minimizes heat absorption.

ABOUT RHYTHMIC LEAF FOLDING

In case you think leaf folding couldn't possibly be a coordinated response, take a look at the bean plant in Figure 28.12. Like some other plants, it holds its leaves horizontally during the day but folds them closer to a stem at night. Keep the plant in full sun or darkness for a few days and it will continue to move its leaves in and out of the "sleep" position, independently of sunrise and sunset. The response might help reduce heat loss at night, when air cools, and so maintain the plant's internal temperature within tolerable limits.

Rhythmic leaf movements are just one example of a **circadian rhythm**, a biological activity repeated in cycles that each last for close to twenty-four hours. Circadian means "about a day." As you will see in a later chapter, a pigment molecule called phytochrome may be part of a control mechanism over leaf folding.

Control mechanisms that help maintain homeostasis are at work in plants, although they are not governed from central command posts as they are in most animals.

System acquired resistance, compartmentalization, and rhythmic leaf movements in response to environmental challenges are examples of these mechanisms.

28.5 How Cells Receive and Respond to Signals

LINKS TO SECTIONS 4.9, 5.2, 9.4, 22.12

Signal reception, transduction, and response—this is a fancy way of saying cells chatter among themselves in ways that bring about changes in their activities.

Reflect on Section 4.9, the overview of how adjoining cells communicate as by plasmodesmata in plants and gap junctions in animals. Also think back on how free-living *Dictyostelium* cells issue signals that induce them to converge and make a spore-bearing structure. They do so in response to dwindling supplies of food, an environmental cue for change (Section 22.12).

In big multicelled organisms, one cell type signals others in response to cues from both the internal and external environment. Local and long-distance signals can trigger local and regional changes in metabolism, gene expression, growth, and development.

Molecular mechanisms by which cells "talk" to one another evolved early in the history of life. They often have three parts. *First*, a specific receptor is activated, as by reversibly binding a signaling molecule. *Second*, the signal is transduced—it is converted into a form that can operate inside the cell. *Third*, the cell makes a functional response to the signal (Figure 28.13*a*).

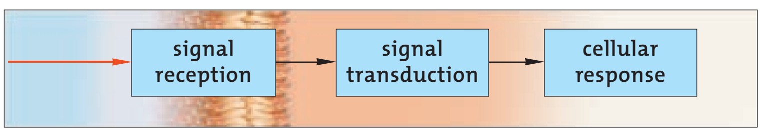
Most receptors are membrane proteins of the sort shown in Section 5.2. An activated receptor starts the signal transduction. It may activate an enzyme that in turn activates many molecules of a different enzyme, which activates many molecules of another kind, and so on. These chains of cascading reactions inside the cell greatly amplify the original signal.

In the next two units, you will come across diverse cases of signal reception, transduction, and response. For now, consider this example to get a sense of the kinds of events that the signals set in motion.

The first cell of a new multicelled individual holds marching orders that guide its descendants through growth, development, reproduction, and often death. As part of that program, many cells heed calls to self-destruct when their function is over. **Apoptosis** is the process of programmed cell death. It starts with signals that unleash proteases and other digestive enzymes, which each body cell produces and stockpiles (Figure 28.13*b*). Proteases chop up structural proteins, such as the building blocks of cytoskeletal elements and of proteins that structurally organize DNA. Nucleases, enzymes that snip nucleic acids, are also stockpiled.

A cell undergoing apoptosis shrinks away from its neighbors in the tissue. Its surface bubbles in and out. Its chromosomes bunch up near the nuclear envelope. The nucleus and then the cell break apart. Phagocytic cells that patrol and protect tissues engulf dying cells and their remnants. Lysosomes inside the phagocytes digest engulfed bits, which are recycled.

Many cells committed suicide as your hands were developing (Section 9.4). Each hand starts forming as a paddlelike structure. Normally, apoptosis in linear rows of cells divides the paddle into fingers within a



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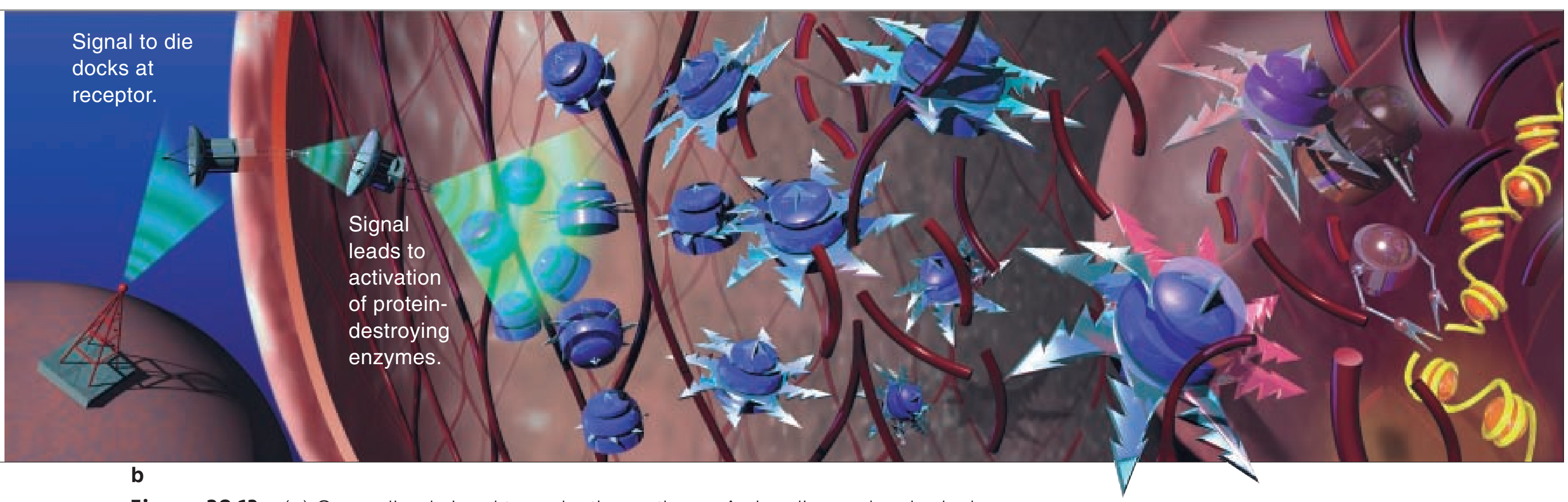

b

Figure 28.13 (**a**) Generalized signal transduction pathway. A signaling molecule docks at a membrane receptor. The signal activates enzymes or other cytoplasmic components that cause changes in metabolism, gene expression, or membrane properties. (**b**) Artist's depiction of a suicidal cell. Normally, body cells self-destruct when they finish their functions or become infected or cancerous, which could threaten the body as a whole.

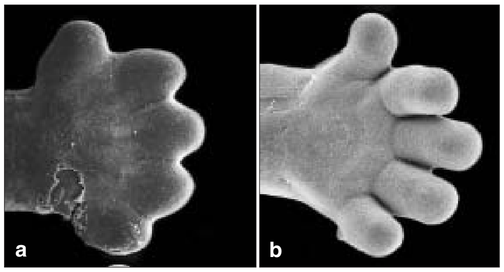

Figure 28.14 ***Animated!*** Formation of human fingers. (**a**) Forty-eight days after fertilization, tissue webs connect embryonic digits. (**b**) Three days later, after apoptosis by cells making up the tissue webs, the digits are separated.

Figure 28.15 Digits that remained attached when embryonic cells did not commit suicide on cue.

few days (Figure 28.14). When the cells do not die on cue, the paddle does not split properly (Figure 28.15).

The timing of programmed cell death is usually predictable. For instance, keratinocytes are cells that last about three weeks. Collectively, the dead ones form protective layers; you can see some of them in Figure 33.14. Keratinocytes can be induced to die ahead of schedule. So can other cells that are supposed to last a lifetime. All it takes is receptors for molecular signals that can call up the enzymes of death.

Control genes suppress or trigger programmed cell death. One gene, *bcl-2,* helps keep normal body cells from dying before their time. In certain cancers, this gene has mutated and cells do not respond to signals to die. Apoptosis is no longer a control option.

What about plants? The controlled death of xylem cells creates walled pipelines for water. Also, when a tissue is being attacked, signals may trigger the death of nearby cells in a pattern that walls off the threat.

Plant and animal cells communicate with one another by secreting signaling molecules into extracellular fluid and selectively responding to signals from other cells.

Communication involves receiving signals, transducing them, and inducing change in a target cell's activity.

Signal transduction requires membrane receptors and other membrane proteins. It often involves a cascade of reactions that amplify the initial signal.

http://biology.brookscole.com/starr11

Summary

Section 28.1 Anatomy is the study of the multicelled body's form. Physiology is the study of how that body functions in the environment. The structure of most body parts correlates with current or past functions.

A plant or animal's structural organization emerges during growth and development. Each living cell carries out many metabolic functions that keep it alive. At the same time, cells are organized in tissues, organs, and often organ systems. These structural units function in coordinated ways in the performance of specific tasks.

BiologyNow

Investigate the structural organization of a tomato plant with the interaction on BiologyNow.

Section 28.2 Plants and animals have responded in similar ways to environmental challenges, such as the constraint imposed by the surface-to-volume ratio.

Plants and animals exchange gases with the outside environment, transport substances to and from cells, and maintain water and solute concentrations of their internal environment at tolerable levels. They all have mechanisms of integrating and controlling body parts in ways that favor survival of the whole organism. They also have mechanisms for responding to signals from other cells and to signals or cues from the outside.

Section 28.3 In all complex multicelled organisms, homeostasis is a state in which the body's internal environment is being maintained within a range that individual cells can tolerate.

In animal cells, sensory receptors, integrators, and effectors interact in ways that maintain these tolerable conditions, often by way of feedback loops.

With negative feedback mechanisms, a change in a certain aspect of the internal environment triggers a response that brings about the reversal of the change. For example, one mechanism corrects deviations from a set point for the body's inner (core) temperature. Another mechanism corrects deviations from the set point for the concentration of carbon dioxide in blood.

With positive feedback mechanisms, a change in the internal environment leads to a response that intensifies the condition that caused it. This type of mechanism causes the expulsion of the fetus during childbirth.

BiologyNow

Observe the effects of negative feedback on temperature control in humans with the animation on BiologyNow.

Section 28.4 Plants have decentralized mechanisms of homeostasis, such as systemic resistance, that maintain the internal environment and help ensure their survival.

Many species of trees also wall off infected or injured tissues by secreting resins and toxins. This defensive response is called compartmentalization. Some plants respond to changes in environmental conditions by folding their leaves closer to the stem. Rhythmic leaf

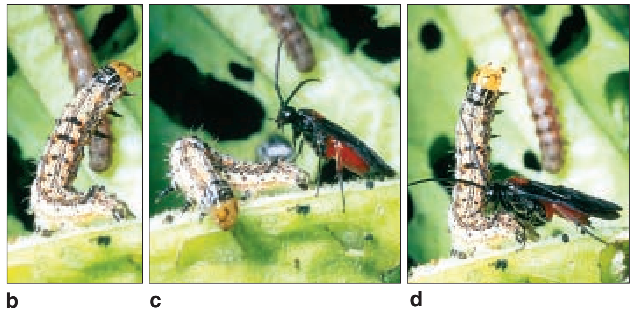

Figure 28.16 (**a**) Consuelo De Moraes studies plant stress responses. (**b**,**c**) A caterpillar chewing on tobacco causes the plant to secrete chemicals that attract a wasp. (**d**) The wasp grabs the caterpillar and lays an egg inside it.

folding is a circadian rhythm that apparently helps a plant maintain its internal temperature.

Biology Now

Learn about plant defense mechanisms with the animation on BiologyNow.

Section 28.5 Cell-to-cell communication involves signal reception, signal transduction, and a response by a target cell. Many signals are transduced by membrane proteins that trigger reactions in the cell. Reactions may alter the activity of genes or enzymes that take part in cellular events. An example is a signal that unleashes the protein-cleaving enzymes of apoptosis; a target cell self-destructs.

Biology Now

See the formation of a human hand with the animation on BiologyNow.

Self-Quiz

Answers in Appendix II

1. An increase in the number, size, and volume of plant cells or animal cells is called ________ .
   a. growth
   b. development
   c. differentiation
   d. all of the above

2. The internal environment consists of ________ .
   a. all body fluids
   b. all fluids in cells
   c. all body fluids outside cells
   d. interstitial fluid

3. ________ influences the concentrations of water and solutes in the internal environment.
   a. Diffusion
   b. Active transport
   c. Passive transport
   d. all are correct

4. Cell communication typically involves signal ________ .
   a. reception
   b. transduction
   c. response
   d. all are correct

5. Match the terms with their most suitable description.
   ____ circadian rhythm
   ____ homeostasis
   ____ apoptosis
   ____ negative feedback
   a. programmed cell death
   b. 24-hour or so cyclic activity
   c. stable internal environment
   d. an activity changes some condition, then the change triggers its own reversal

Additional questions are available on **Biology Now™**

Critical Thinking

1. Many plants protect themselves with thorns or toxins or nasty-tasting chemicals that deter plant-eating animals. Some get help from wasps.

Consuelo De Moraes, currently at Pennsylvania State University, studies interactions among plants, caterpillars, and parasitoid wasps. *Parasitoids* are a special class of parasites; their larvae eat a host from the inside out.

When a caterpillar chews on a tobacco plant leaf, it secretes a lot of saliva. Some chemicals in its saliva are an external signal that triggers a chemical response from leaf cells. The cells release certain molecules that diffuse through the air. Parasitoid wasps follow the concentration gradient to the stressed leaves. They attack a caterpillar, and each wasp deposits one egg inside it. The wasp eggs grow, develop, and become caterpillar-munching larvae (Figure 28.16).

As De Moraes discovered, plant responses are highly specific. Leaf cells release different chemicals in response to different caterpillar species. Each chemical attracts only the wasps that parasitize the particular kind of caterpillar that triggers the chemical's release.

Are the plants "calling for help"? Not likely. Give a possible explanation for this plant–wasp interaction in terms of cause, effect, and natural selection theory.

2. The Arabian oryx (*Oryx leucoryx*), an endangered antelope, evolved in the harsh deserts of the Middle East. Most of the year there is no free water, and temperatures routinely reach 117°F (47°C). The most common tree in the region is the umbrella thorn tree (*Acacia tortilis*). List common challenges that the oryx and the acacia face. Also research and report on the morphological, physiological, and behavioral responses of both organisms.

3. In the summer of 2003, a record heat wave lasted for weeks and caused the death of more than 5,000 people in France. The elderly and very young were at greatest risk. High humidity increases the chance of heat-related illness because it reduces the rate of evaporative cooling. So does tight clothing that does not "breathe," like the uniform Korey Stringer wore during his last practice. Other risk factors are obesity, poor circulation, dehydration, and alcohol intake. Using Figure 28.8 as a reference, briefly suggest how each factor may overwhelm homeostatic controls over the body's internal temperature.

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V How Plants Work

The sacred lotus, Nelumbo nucifera, *busily doing what its ancestors did for well over 100 million years—flowering spectacularly during the reproductive phase of its life cycle.*