leaves the body through the anus as feces. The breakdown activities that begin in the mouth are completed in the small intestine. From that point on, the major function of the digestive system is to reclaim water. The liver is considered a digestive organ because the bile it produces helps to break down fats. The pancreas, which delivers digestive enzymes to the small intestine, also is functionally a digestive organ.

Urinary System

The body produces wastes as by-products of its normal functions, and these wastes must be disposed of. One type of waste contains nitrogen (examples are urea and uric acid), which results when the body cells break down proteins and nucleic acids. The **urinary system** removes the nitrogen-containing wastes from the blood and flushes them from the body in urine. This system, often called the *excretory system*, is composed of the kidneys, ureters, bladder, and urethra. Other important functions of this system include maintaining the body's water and salt (electrolyte) balance and regulating the acid-base balance of the blood.

Reproductive System

The **reproductive system** exists primarily to produce offspring. The testes of the male produce sperm. Other male reproductive system structures are the scrotum, penis, accessory glands, and the duct system, which carries sperm to the outside of the body. The ovaries of the female produce eggs, or ova; the female duct system consists of the uterine tubes, uterus, and vagina. The uterus provides the site for the development of the fetus (immature infant) once fertilization has occurred.

DID YOU GET IT?

3. At which level of structural organization is the stomach? At which level is a glucose molecule?
4. Which organ system includes the trachea, lungs, nasal cavity, and bronchi?

For answers, see Appendix D.

Maintaining Life

✓ List eight functions that humans must perform to maintain life.

✓ List the five survival needs of the human body.

Necessary Life Functions

Now that we have introduced the structural levels composing the human body, a question naturally follows: What does this highly organized human body do? Like all complex animals, human beings maintain their boundaries, move, respond to environmental changes, take in and digest nutrients, carry out metabolism, dispose of wastes, reproduce themselves, and grow. We will discuss each of these necessary life functions briefly here and in more detail in later chapters.

Organ systems do not work in isolation; instead, they work together to promote the well-being of the entire body (**Figure 1.3**). Because this theme is emphasized throughout this book, it is worthwhile to identify the most important organ systems contributing to each of the necessary life functions. Also, as you read through this material, you may want to refer back to the more detailed descriptions of the organ systems provided on pp. 3 through 7 and in Figure 1.2.

Maintaining Boundaries

Every living organism must be able to maintain its boundaries so that its "inside" remains distinct from its "outside." Every cell of the human body is surrounded by an external membrane that contains its contents and allows needed substances in while generally preventing entry of potentially damaging or unnecessary substances. The body as a whole is also enclosed by the integumentary system, or skin. The integumentary system protects internal organs from drying out (which would be fatal), from bacteria, and from the damaging effects of heat, sunlight, and an unbelievable number of chemical substances in the external environment.

Movement

Movement includes all the activities promoted by the muscular system, such as propelling ourselves from one place to another (by walking, swimming, and so forth) and manipulating the external environment with our fingers. The skeletal system provides the bones that the muscles pull on as they work. Movement also occurs when substances such as blood, foodstuffs, and urine are propelled through the internal organs of the cardiovascular, digestive, and urinary systems, respectively.

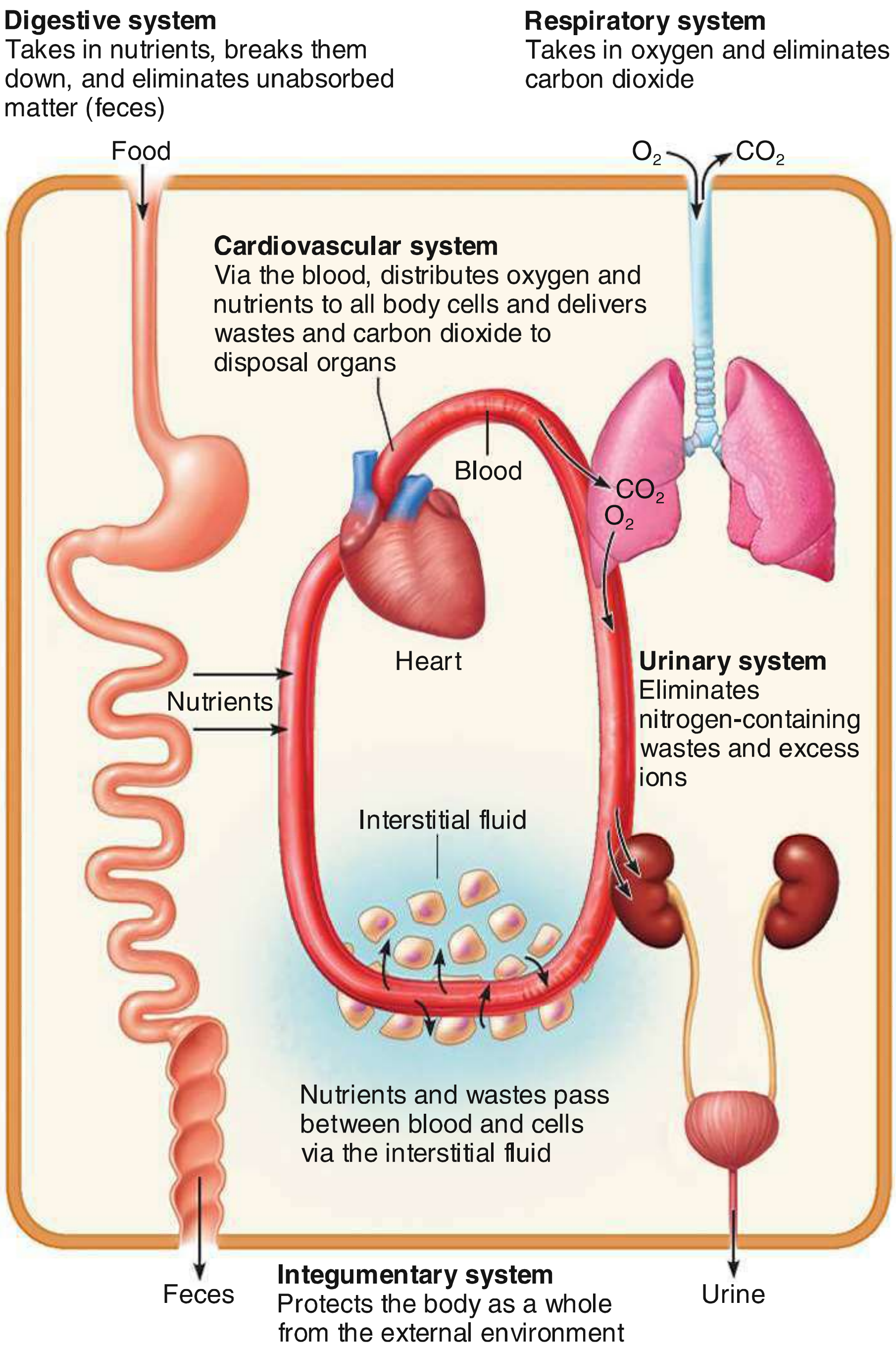


Figure 1.3 **Examples of selected interrelationships among body organ systems.**

Responsiveness

Responsiveness, or **irritability,** is the ability to sense changes (stimuli) in the environment and then to react to them. For example, if you cut your hand on broken glass, you involuntarily pull your hand away from the painful stimulus (the broken glass). You do not need to think about it—it just happens! Likewise, when the amount of carbon dioxide in your blood rises to dangerously high levels, your breathing rate speeds up to blow off the excess carbon dioxide.

Because nerve cells are highly irritable and can communicate rapidly with each other via electrical impulses, the nervous system bears the major responsibility for responsiveness. However, all body cells are irritable to some extent.

Digestion

Digestion is the process of breaking down ingested food into simple molecules that can then be absorbed into the blood. The nutrient-rich blood is then distributed to all body cells by the cardiovascular system. In a simple, one-celled organism such as an amoeba, the cell itself is the "digestion factory," but in the complex, multicellular human body, the digestive system performs this function for the entire body.

Metabolism

Metabolism is a broad term that refers to all chemical reactions that occur within body cells. It includes breaking down complex substances into simpler building blocks, making larger structures from smaller ones, and using nutrients and oxygen to produce molecules of adenosine triphosphate (ATP), the energy-rich molecules that power cellular activities. Metabolism depends on the digestive and respiratory systems to make nutrients and oxygen available to the blood and on the cardiovascular system to distribute these needed substances throughout the body. Metabolism is regulated chiefly by hormones secreted by the glands of the endocrine system.

Excretion

Excretion is the process of removing *excreta* (ek-skre′tah), or wastes, from the body. If the body is to continue to operate as we expect it to, it must get rid of the nonuseful substances produced during digestion and metabolism. Several organ systems participate in excretion. For example, the digestive system rids the body of indigestible food residues in feces, and the urinary system disposes of nitrogen-containing metabolic wastes in urine.

Reproduction

Reproduction, the production of offspring, can occur on the cellular or organismal level. In cellular reproduction, the original cell divides, producing two identical daughter cells that may then be used for body growth or repair. Reproduction of the human organism, or making a whole new person, is the task of the organs of the reproductive system, which produce sperm and eggs. When a sperm unites with an egg, a fertilized egg forms, which then develops into a baby within the mother's body. The function of the reproductive system is regulated very precisely by hormones of the endocrine system.

Growth

Growth is an increase in size, usually accomplished by an increase in the number of cells. For growth to occur, cell-constructing activities must occur at a faster rate than cell-destroying ones. Hormones released by the endocrine system play a major role in directing growth.

Survival Needs

The goal of nearly all body systems is to maintain life. However, life is extraordinarily fragile and requires that several factors be available. These factors, which we will call *survival needs,* include nutrients (food), oxygen, water, and appropriate temperature and atmospheric pressure.

Nutrients, which the body takes in through food, contain the chemicals used for energy and cell building. Carbohydrates are the major energy-providing fuel for body cells. Proteins and, to a lesser extent, fats are essential for building cell structures. Fats also cushion body organs and provide reserve fuel. Minerals and vitamins are required for the chemical reactions that go on in cells and for oxygen transport in the blood.

All the nutrients in the world are useless unless **oxygen** is also available. Because the chemical reactions that release energy from foods require oxygen, human cells can survive for only a few minutes without it. Approximately 20 percent of the air we breathe is oxygen. It is made available to the blood and body cells by the cooperative efforts of the respiratory and cardiovascular systems.

Water accounts for 60 to 80 percent of body weight. It is the single most abundant chemical substance in the body and provides the fluid base for body secretions and excretions. We obtain water chiefly from ingested foods or liquids and we lose it by evaporation from the lungs and skin and in body excretions.

If chemical reactions are to continue at life-sustaining levels, **normal body temperature** must be maintained. As body temperature drops below 37°C (98°F), metabolic reactions become slower and slower and finally stop. When body temperature is too high, chemical reactions proceed too rapidly, and body proteins begin to

(Continues on page 12)

Medical Imaging: Illuminating the Body

By bombarding the body with energy, new scanning techniques can reveal the structure of internal organs and wring out information about the private and, until now, secret working of their molecules. These new imaging techniques are changing the face of medical diagnosis.

Until about 50 years ago, the magical but murky X ray was the only means of peering into a living body. What X rays did and still do best was visualize hard, bony structures and locate abnormally dense structures (tumors, tuberculosis nodules) in the lungs. The 1950s saw the birth of nuclear medicine, which uses radioisotopes to scan the body, and ultrasound techniques. In the 1970s, CT, PET, and MRI scanning techniques were introduced.

The best known of new imaging devices is **computed tomography (CT)** (formerly called *computerized axial tomography, or CAT*) a refined version of X ray. A CT scanner confines its beam to a thin slice of the body, about as thick as a dime, and ends the confusion resulting from images of overlapping structures seen in conventional X-ray images. As the patient is slowly moved through the doughnut-shaped CT machine, its X-ray tube rotates around the body. Different tissues absorb the radiation in varying amounts. The device's computer translates this information into a detailed, cross-sectional picture of the body region scanned; see photo (a). CT scans are at the forefront in evaluating most problems that affect the brain and abdomen, and their clarity has all but eliminated exploratory surgery. Special ultrafast CT scanners have produced a technique called **dynamic spatial reconstruction (DSR),** which provides three-dimensional images of body organs from any angle.

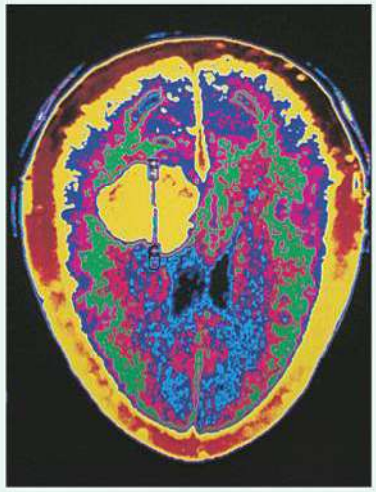
It also allows their movements and changes in their internal volumes to be observed at normal speed, in slow motion, and at a specific moment in time. The greatest value of DSR has been to visualize the heart beating and blood flowing through blood vessels. This allows medical personnel to assess heart defects, constricted blood vessels, and the status of coronary bypass grafts.

Another computer-assisted X-ray technique is **digital subtraction angiography (DSA)** (angiography = vessel pictures). This technique provides an unobstructed view of diseased blood vessels; see photo (b). Conventional radiographs are taken before and after a contrast medium is injected into an artery. Then the computer subtracts the "before" image from the "after" image, eliminating all traces of body structures that obscure the vessel. DSA is often used to identify blockages in the arteries that supply the heart wall and the brain; see photo (b).

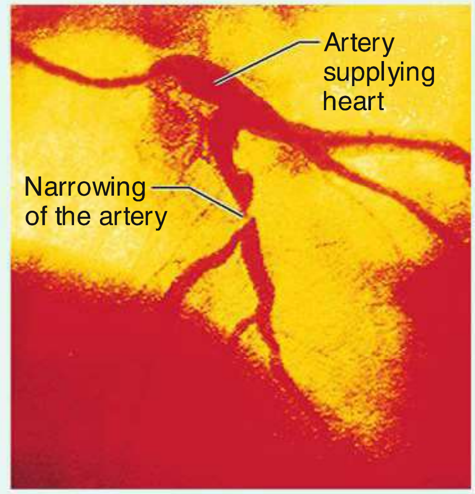
Just as the X ray spawned "new technologies," so did nuclear medicine in the form of **positron emission tomography (PET).** PET excels in observing metabolic processes. After receiving an injection of short-lived radioisotopes that have been tagged to biological molecules (such as glucose), the patient is positioned in the PET scanner. As the radioisotopes are absorbed by the most active brain cells, high-energy gamma rays are produced. The computer analyzes the gamma emission and produces a picture of the brain's biochemical activity in vivid colors. PET's greatest clinical value has been its ability to provide insights into brain activity in people affected by mental illness, Alzheimer's disease, and epilepsy. Currently PET can reveal signs of trouble in those with undiagnosed Alzheimer's disease (AD) because regions of beta-amyloid accumulation (a defining characteristic of AD) show up in brilliant red and yellow, as in photo (c). PET scans can also help to predict who may develop AD in the future.

Ultrasound imaging, or **ultrasonography,** has some distinct advantages over the approaches described so far. The equipment is inexpensive, and it employs high-frequency sound waves (ultrasound) as its energy source. Ultrasound, unlike ionizing forms of radiation, has no harmful effects on living tissues (as far as we know). The body is probed with pulses of sound waves, which cause echoes when reflected and scattered by body tissues. The echoes are analyzed by computer to construct visual images of body organs of interest. Because of its safety, ultrasound is the imaging technique of choice for obstetrics, that is, for determining fetal age and position and locating the placenta (see d). Because sound waves have very low penetrating power and are rapidly scattered in air, sonography is of little value for looking at air-filled structures (the lungs) or those surrounded by bone (the brain and spinal cord).

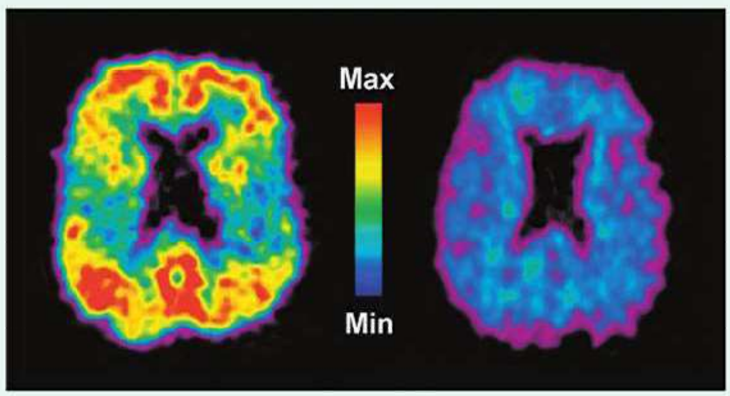
Another technique that depends on nonionizing radiation is **magnetic resonance imaging (MRI),** which uses magnetic fields up to 60,000 times stronger than Earth's to pry information from the body's tissues.



(a) CT scan showing a brain tumor (oval area on right side of brain).



(b) DSA image of arteries supplying the heart.



(c) In a PET scan, regions of beta-amyloid accumulation "light up" (red-yellow) in an Alzheimer's patient (*left*) but not in a healthy person (*right*).

(d) Sonogram of a fetus.

The patient lies in a chamber within a huge magnet. Hydrogen molecules spin like tops in the magnetic field, and their energy is enhanced by radio waves. When the radio waves are turned off, the energy is released and translated by the computer into a visual image (see Figure 1.6, p. 18). MRI is immensely popular because it can do many things a CT scan cannot. Dense structures do not show up in MRI, so bones of the skull and/or vertebral column do not impair the view of *soft tissues* such as the brain. MRI is also particularly good at detecting degenerative disease of various kinds. Multiple sclerosis plaques, for example, do not show up well in CT scans but are dazzlingly clear in MRI scans.

Until recently, trying to diagnose asthma and other lung problems has been off limits to MRI scans because the lungs have a low water content. However, an alternate tack—filling the lungs with a gas that can be magnetized—has yielded spectacular pictures of the lungs in just the few seconds it takes the patient to inhale, hold the breath briefly, and then exhale.

A variation of MRI called **magnetic resonance spectroscopy (MRS)** maps the distribution of elements other than hydrogen to reveal more about how disease changes body chemistry. In 1992, MRI technology leaped forward with the development of the **functional MRI (fMRI),** which allows tracking of blood flow into the brain in real time. Until then, matching thoughts, deeds, and disease to corresponding brain activity had been the sole domain of PET. Because functional MRI does not require injections of tracer elements, it provides another, perhaps more desirable, alternative. Despite its advantages, the powerful clanging magnets of the MRI present some thorny problems. For example they can "suck" metal objects, such as implanted pacemakers and loose tooth fillings, through the body. Also, there is no convincing evidence that such magnetic fields are risk free.

As you can see, modern medical science has some remarkable diagnostic tools at its disposal. CT and PET scans account for about 25 percent of all imaging. Ultrasonography, because of its safety and low cost, is the most widespread of the new techniques. Conventional X rays remain the workhorse of diagnostic imaging techniques and still account for more than half of all imaging currently done.

break down. At either extreme, death occurs. Most body heat is generated by the activity of the skeletal muscles.

The force exerted on the surface of the body by the weight of air is referred to as **atmospheric pressure.** Breathing and the exchange of oxygen and carbon dioxide in the lungs depend on appropriate atmospheric pressure. At high altitudes, where the air is thin and atmospheric pressure is lower, gas exchange may be too slow to support cellular metabolism.

The mere presence of these survival factors is not sufficient to maintain life. They must be present in appropriate amounts as well; excesses and deficits may be equally harmful. For example, the food ingested must be of high quality and in proper amounts; otherwise, nutritional disease, obesity, or starvation is likely.

DID YOU GET IT?

5. In addition to being able to metabolize, grow, digest food, and excrete wastes, what other functions must an organism perform if it is to survive?
6. Oxygen is a survival need. Why is it so important?

For answers, see Appendix D.

Homeostasis

✓ Define *homeostasis,* and explain its importance.

✓ Define *negative feedback,* and describe its role in maintaining homeostasis and normal body function.

When you really think about the fact that your body contains trillions of cells in nearly constant activity, and that remarkably little usually goes wrong with it, you begin to appreciate what a marvelous machine your body really is. The word **homeostasis** (ho″me-o-sta′sis) describes the body's ability to maintain relatively stable internal conditions even though the outside world is continuously changing. Although the literal translation of *homeostasis* is "unchanging" (*homeo* = the same; *stasis* = standing still), the term does not really mean an unchanging state. Instead, it indicates a *dynamic* state of equilibrium, or a balance in which internal conditions change and vary but always within relatively narrow limits.

In general, the body demonstrates homeostasis when its needs are being adequately met and it is functioning smoothly. Virtually every organ system plays a role in maintaining the constancy of the internal environment. Adequate blood levels of vital nutrients must be continuously present, and heart activity and blood pressure must be constantly monitored and adjusted so that the blood is propelled with adequate force to reach all body tissues. Additionally, wastes must not be allowed to accumulate, and body temperature must be precisely controlled.

Homeostatic Controls

Communication within the body is essential for homeostasis and is accomplished chiefly by the nervous and endocrine systems, which use electrical signals delivered by nerves or bloodborne hormones, respectively, as information carriers. The details of how these two regulating systems operate are the subjects of later chapters, but we explain the basic characteristics of the neural and hormonal control systems that promote homeostasis here.

Regardless of the factor or event being regulated (this is called the *variable*), all homeostatic control mechanisms have at least three components (**Figure 1.4**). The first component is a **receptor.** Essentially, it is some type of sensor that monitors and responds to changes in the environment. It responds to such changes, called *stimuli,* by sending information (input) to the second element, the *control center*. Information flows from the receptor to the control center along the *afferent pathway*. (It may help to remember that information traveling along the *afferent* pathway *approaches* the control center.)

The **control center,** which determines the level (set point) at which a variable is to be maintained, analyzes the information it receives and then determines the appropriate response or course of action.

The third component is the **effector,** which provides the means for the control center's response (output) to the stimulus. Information flows from the control center to the effector along the *efferent pathway*. (*Efferent* information *exits* from the control center.) The results of the response then *feed back* to influence the stimulus, either by depressing it (negative feedback), so that the whole control mechanism is shut off; or by enhancing it (positive feedback), so that the reaction continues at an even faster rate.