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Chapter **1**

Focusing on the Framework of Anatomy and Physiology

Human anatomy is the science of the human body's structures — things that can be touched, weighed, or analyzed. Human physiology is the chemistry and physics of these structures, including how they all work together to support the processes of life in each individual.

If you put these two subjects together, you have the means of understanding your body on a whole new level. This chapter sets up your study of anatomy and physiology by shining a light on the very framework of the subjects, from key terminology and the levels of organization within an organism to descriptions of metabolism and homeostasis.

Looking at the Science of Anatomy and Physiology

Human anatomy and physiology are closely related to *biology*, which is the science of living beings and their relationships with the rest of the universe, including all other living beings. If you've studied biology, you understand the basics of how organisms operate. Anatomy and physiology narrow the science of biology by looking at the specifics of one species: *Homo sapiens*.



REMEMBER

Anatomy is structure; physiology is function. You can't talk about one without talking about the other.

Fitting anatomy and physiology into science

Biologists take for granted that human anatomy and physiology evolved from the anatomy and physiology of ancient forms. These scientists base their work on the assumption that every structure and process, no matter how tiny in scope, must somehow contribute to the survival of the individual. So each process — and the structures within which the chemistry and physics of the process actually happen — must help keep the individual alive and meeting the relentless challenges of a continually changing environment. Evolution favors processes that work.

Human *pathophysiology* is the science of “human anatomy and physiology gone wrong.” (The prefix *path-* is Greek for “suffering.”) It's the interface of human biology and medical science. *Clinical medicine* is the application of medical science to alleviate an anatomical or physiological problem in an individual human.

Breaking down the subsets of anatomy

The science of anatomy features the following major subsets (throughout this book, you encounter some information from each one):

- » **Gross anatomy:** The study of the large parts of any animal body that can be seen with the unaided eye. (We concentrate on this aspect of anatomy in this book.)
- » **Histologic anatomy:** The study of different tissue types and the cells that comprise them. Histologic anatomists use a

variety of microscopes to study these cells and tissues that make up the body.

- » **Developmental anatomy:** The study of the life cycle of the individual, from fertilized egg through adulthood, senescence (aging), and death. Body parts change throughout the life span.
- » **Comparative anatomy:** The study of the similarities and differences among the anatomical structures of different species, including extinct species. This subject is closely related to evolutionary biology. Information from comparative anatomy helps scientists understand the human body's structures and processes. For example, the comparative anatomy of humans and living and extinct apes elucidates the structures in the human limbs that enable the bipedal posture.

Familiarizing Yourself with Anatomical Jargon

Jargon is a set of words and phrases that people who know a lot about a particular subject use to talk together. You can find jargon in every field (scientific or not), every workplace, every town, and every home. Families and close friends almost always use jargon in conversations with one another. Plumbers use jargon to communicate about plumbing. Anatomists and physiologists use jargon and technical terminology, much of which is shared with medicine and other fields of biology, especially human biology.

Scientists try to create terminology that's precise and easy to understand by developing it systematically. That is, they create new words by putting together existing and known elements. They use certain syllables or word fragments over and over to build new terms.



REMEMBER

With a little help from this book, you can start recognizing some of these fragments. Then you can put the meanings of different fragments together and accurately guess the meaning of a term you've never seen before, just as you can understand a sentence you've never read before. Table 1-1 gets you started by listing some word fragments related to the organ systems we cover in this book.

TABLE 1-1 Technical Anatomical Word Fragments

Body System	Root or Word Fragment	Meaning
Skeletal system	os-, oste-	bone
	arth-	joint
Muscular system	myo-	muscle
	sarco-	flesh
Integument	derm-	skin
Nervous system	neur-	nerve
Endocrine system	aden-	gland
	estr-	steroid
Circulatory system	card-	heart (muscle)
	angi-	vessel
	hema-	blood
	arter-	artery
	ven-	venous
	erythro-	red
Respiratory system	pulmon-	lung
	bronch-	windpipe
Digestive system	gastr-	stomach
	enter-	intestine
	dent-	teeth
	hepat-	liver
Urinary system	ren-	kidney
	neph-	kidney
	ur-	urinary

Body System	Root or Word Fragment	Meaning
Immune system	lymph-	lymph
	leuk-	white
	-itis	inflammation
Reproductive system	vagin-	vagina
	uter-	uterine

You may be asking why you should always have to parse and put back together terms like *iliohypogastric*. A key reason is the contrast between the preciseness with which scientists must name and describe the things they talk about in a scientific context and the relative vagueness and changeability of terms in plain English. Terms that people use in common speech are understood slightly differently by different people, and the meanings are always undergoing change.

Not so long ago, for example, no one speaking plain English used the term *laptop* to refer to a computer or *hybrid* to talk about a car. It's possible that, not many years from now, almost no one will understand what people meant by those words. In contrast, scientific Greek and Latin stopped changing centuries ago: *ilio*, *hypo*, and *gastro* have the same meanings now as they did 200 years ago.

Problems can come up when the specialists who use the jargon want to communicate with someone outside their field. The specialists must translate their message into more common terms to communicate it. Problems can also come up when someone approaching a field, such as a student, fails to make progress understanding and speaking the field's jargon. This book aims to help you make the necessary progress.



TIP

Every time you come across an anatomical or physiological term that's new to you, pull it apart to see whether any of its fragments are familiar. Using this knowledge, go as far as you can in guessing the meaning of the whole term. After studying Table 1-1, you should be able to make some pretty good guesses.

Arranging Organisms by Levels of Organization

Anatomy and physiology focus on the different levels of the *organism*, or the individual body. The life processes of the organism are built and maintained at the following several physical levels, known as *levels of organization*:

- » The cellular level
- » The tissue level
- » The organ level
- » The organ system level
- » The organism level

You can see all these levels in Figure 1-1. In this section, we review these levels, starting with the smallest.

Level I: The cellular level

If you examine a sample of any human tissue under a microscope, you see cells, possibly millions of cells. All living things are made of cells. In fact, having a cellular level of organization is inherent in any definition of *organism*. We discuss the cellular level of organization in some detail in Chapter 2.

Level II: The tissue level

A *tissue* is a structure made of many cells — usually several different kinds of cells — that performs a specific function. Tissues are divided into four classes:

- » **Connective tissue** serves to support body parts and bind them together.
- » **Epithelial tissue** (epithelium) lines the inside of organs within the body and covers the body. The outer layer of the skin is made up of epithelial tissue.
- » **Muscle tissue** is found in the muscles, which allow your body parts to move; in the walls of hollow organs to help move their contents along; and in the heart to move blood along via the acts of contraction and relaxation. (Find out more about muscles in Chapter 3.)

» **Nervous tissue** transmits impulses and forms nerves. Brain tissue is nervous tissue. (We talk about the nervous system in Chapter 9.)

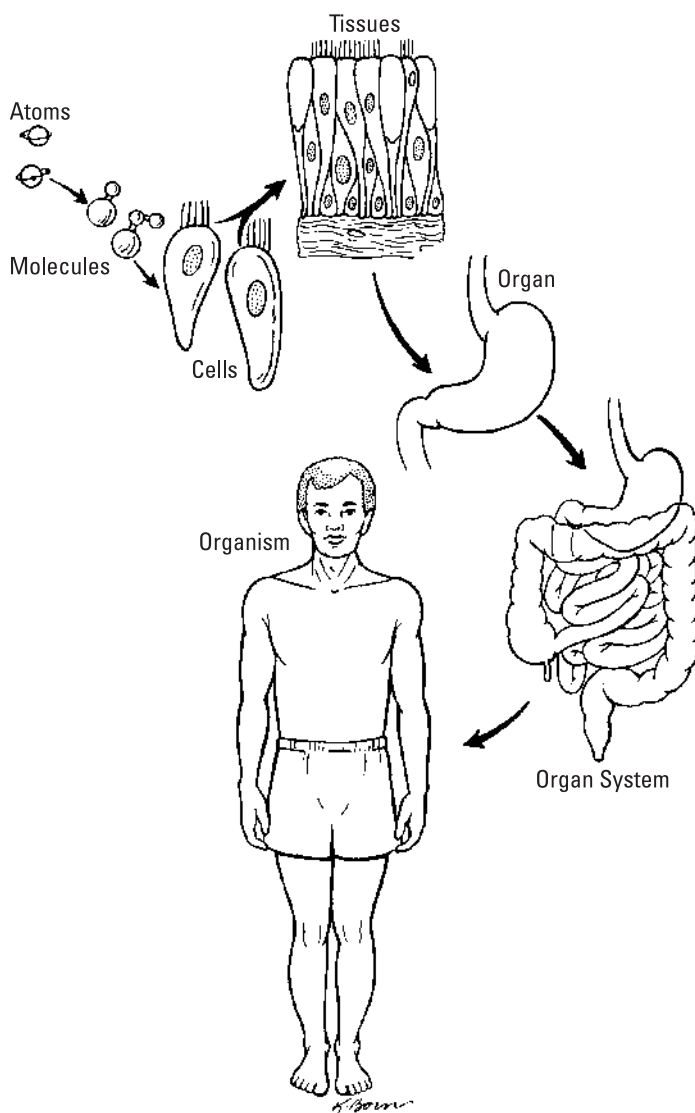


FIGURE 1-1: Levels of organization in the human body.

Level III: The organ level

An *organ* is a part of the body that performs a specialized physiological function. For example, the stomach is an organ that has the specific physiological job of breaking down food. By definition, an organ is made up of at least two different tissue types; many organs contain tissues of all four types. Although we can name and describe all four tissue types that make up all organs, as we do in the preceding section, listing all the organs in the body wouldn't be so easy.



REMEMBER

The organs that “belong” to one system can have functions integral to another system. In fact, most organs contribute to more than one system. The blood vessels are an excellent example: They serve as a transportation network, delivering nutrients produced by the digestive system to the skeletal muscles to provide energy for locomotion and to a woman's uterus to support her developing fetus. These vessels also remove the byproducts of the energy consumed in locomotion and by the fetus in development and carry them to the organs of the urinary system for excretion.

Level IV: The organ system level

Human anatomists and physiologists have divided the human body into *organ systems*, groups of organs that work together to meet a major physiological need. For example, the digestive system is one of the organ systems responsible for obtaining energy from the environment. Other organ systems include the musculoskeletal system, the integument, and the nervous system. (The chapter structure of this book is based on the definition of organ systems.)

Level V: The organism level

This level consists of the whole enchilada — the real “you.” As anatomists study organ systems, organs, tissues, and cells, they're always looking at things from the organism level.

Metabolism: Keeping Body Processes in Motion

Even when your outside is staying still, your insides are moving. Day and night, your muscles twitch and contract and maintain “tone.” Your heart beats. Your blood circulates. Your diaphragm

moves up and down with every breath. Nerve impulses travel. Your brain keeps tabs on everything. You think. Even when you're asleep, you dream (a form of thinking). Your intestines push the food you ate hours ago along your alimentary canal. Your kidneys filter your blood and make urine. Your sweat glands open and close. Your eyes blink, and even during sleep, they move. Men produce sperm. Women move through the menstrual cycle. The processes that keep you alive are always active.

You can thank *metabolism* — the chemical reactions occurring in the body — for keeping these many processes going. These chemical reactions consist of *anabolic reactions*, which create things (molecules), and *catabolic reactions*, which break things down. Your body performs both anabolic and catabolic reactions at the same time and around the clock to keep you alive and functioning.



TIP

To keep the meanings of anabolic and catabolic clear in your mind, associate the word *catabolic* with the word *catastrophic* to remember that catabolic reactions break down products. Then you'll know that anabolic reactions create products.

The following sections describe the reactions that your cells undergo to convert fuel to usable energy.

Seeing why your cells metabolize

Every cell in your body is like a tiny factory, converting raw materials to useful molecules, such as proteins and thousands of other products, many of which we discuss throughout this book. The raw materials (nutrients) come from the food you eat, and the cells use those nutrients in metabolic reactions. During these reactions, some of the energy from catabolized (broken down) nutrients is used to generate a compound called *adenosine triphosphate* (ATP). Whenever ATP is catabolized, it releases energy that the cell can use.



REMEMBER

So here's how it works: Nutrients are catabolized, ATP is formed (anabolized), and ATP is catabolized when needed. This principle of linked anabolic and catabolic reactions is one of the cornerstones of human physiology and is required to maintain life. Cellular metabolism also makes waste products that must be removed (exported) from the cell and ultimately from the body.

Understanding the process behind cellular metabolism

The reactions that convert fuel to usable energy (ATP molecules) include glycolysis, aerobic respiration (the Krebs cycle), anaerobic respiration, and oxidative phosphorylation. Together these reactions are referred to as *cellular respiration*. These are complex pathways, so expect to take some time to understand them. Refer to Figure 1-2 as many times as necessary to make sure you understand what happens in cellular respiration.

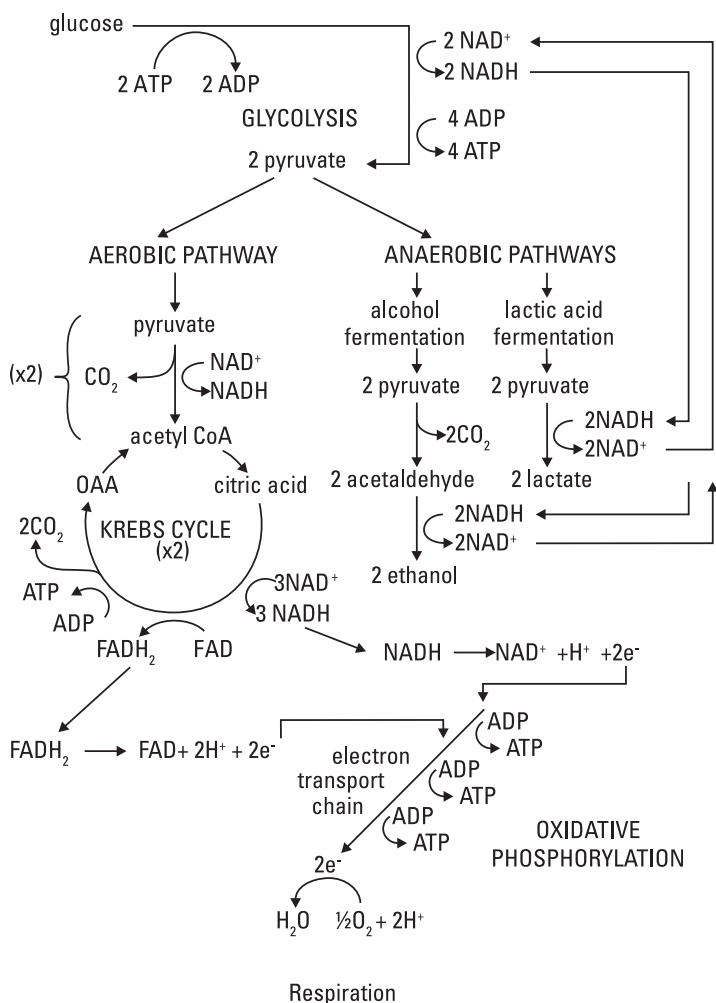


FIGURE 1-2: The group of reactions that convert energy from fuel into ATP.

Glycolysis, the process that breaks down glucose, occurs in the *cytoplasm* (fluid portion) of every cell. Pyruvic acid, the product of glycolysis, moves from the cytoplasm into the cellular organelle called the *mitochondrion*, the cell's powerhouse. The *Krebs cycle*, also called the *tricarboxylic acid cycle* or the *citric acid cycle*, takes place in the mitochondrion.

At the completion of the Krebs cycle, the high-energy molecules that are created during the cycle move into the *membrane* of the mitochondrion, where they're passed down the electron transport chain. At the end of that chain, the molecules are used to form ATP from adenosine diphosphate (ADP) and inorganic phosphate (P_i), and water is released.



REMEMBER

ATP is the cell's energy currency. Just as you can't keep spending money without earning some money to replenish your supply, your body can't keep expending energy without taking in more fuel. When the cell needs energy to fuel its metabolism, it pays with ATP molecules. See Figure 1-3 for the chemical structure of the ATP and related ADP molecules.

The sections that follow break down each chemical reaction that plays a role in *cellular respiration* — glycolysis, Krebs cycle, and oxidative phosphorylation.

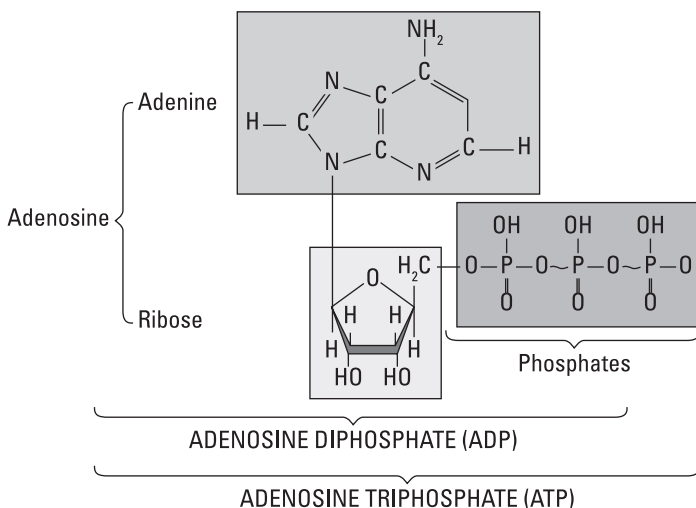


FIGURE 1-3: The chemical structure of ADP and ATP.

Glycolysis

Starting at the top of Figure 1-3, you can see that glucose — the smallest molecule that a carbohydrate can be broken into during digestion — goes through the process of *glycolysis*, which starts cellular respiration and uses some energy (ATP) itself. Glycolysis occurs in the cytoplasm and doesn't require oxygen.



REMEMBER

Two molecules of ATP are required to start each molecule of glucose rolling down the glycolytic pathway; although four molecules of ATP are generated during glycolysis, the net production of ATP is two molecules. In addition to the two ATPs, two molecules of *pyruvic acid* (also called *pyruvate*) are generated. The pyruvate molecules then move into a mitochondrion and enter the Krebs cycle.

Krebs cycle

The *Krebs cycle* is a major biological pathway in the metabolism of every multicellular organism. It's an *aerobic pathway*, requiring oxygen.

As the pyruvate enters the mitochondrion, a molecule of a compound called *nicotinamide adenine dinucleotide* (NAD^+) joins it. NAD^+ is an electron carrier (that is, it carries energy), and it gets the process moving by bringing some energy into the pathway. The NAD^+ provides enough energy that when it joins with pyruvate, carbon dioxide is released, and the high-energy molecule NADH is formed. The product of the overall reaction is *acetyl coenzyme A* (acetyl CoA), which is a carbohydrate molecule that puts the Krebs cycle in motion.



REMEMBER

Cycles are endless. Products of some reactions in the cycle are used to keep the cycle going. An example is acetyl CoA: It's a product of the Krebs cycle, yet it also helps initiate the cycle. With the addition of water and acetyl CoA, *oxaloacetic acid* (OAA) is converted to *citric acid*. Then, a series of reactions proceeds through the cycle.

Oxidative phosphorylation

Oxidative phosphorylation, which uses high energy electrons to produce ATP, is also called the *respiratory chain* and the *electron transport chain*. The electron carriers produced during the Krebs cycle — NADH and FADH_2 — are created when NAD^+ and FAD ,

respectively, are reduced. When a substance is *reduced*, it gains electrons; when it's *oxidized*, it loses electrons.

So NADH and FADH₂ are compounds that have gained electrons and, therefore, energy. In the respiratory chain, oxidation and reduction reactions occur repeatedly as a way of transporting energy. At the end of the chain, oxygen atoms accept the electrons, producing water. (Water from metabolic reactions isn't a significant contributor to the water needs of the body.)

As NADH and FADH₂ pass down the respiratory (or electron transport) chain, they lose energy as they become oxidized and reduced, oxidized and reduced, oxidized and. . . It sounds exhausting, doesn't it? Well, their energy supplies become exhausted for a good cause.

The energy that these electron carriers lose is used to add a molecule of phosphorus to adenosine *diphosphate* (ADP) to make it adenosine *triphosphate* — the coveted ATP. And ATP is the goal for converting the energy in food to energy that the cells in the body can use. For each NADH molecule that's produced in the Krebs cycle, three molecules of ATP can be generated. For each molecule of FADH₂ that's produced in the Krebs cycle, two molecules of ATP are made.



REMEMBER

Theoretically, the entire process of aerobic cellular respiration — glycolysis, Krebs cycle, and oxidative phosphorylation — generates a total of 38 ATP molecules from the energy in one molecule of glucose: 2 from glycolysis, 2 from the Krebs cycle, and 34 from oxidative phosphorylation. However, this theoretical yield is never quite reached because processes, especially biological processes, are never 100 percent efficient. In the real world, usually around 29 to 30 ATP molecules per glucose molecule are expected.

Anaerobic respiration

Sometimes oxygen isn't present, but your body still needs energy. During these rare times, a backup system, an *anaerobic pathway* (called *anaerobic* because it proceeds in the absence of oxygen) exists. Lactic acid fermentation generates NAD⁺ so that glycolysis, which results in the production of two molecules of ATP, can continue. However, if the supply of NAD⁺ runs out, glycolysis can't occur, and ATP can't be generated.

Balancing Bodily Reactions with Homeostasis

Chemical reactions aren't random events. Any reaction takes place only when all the conditions are right for it: All the required reagents and catalysts are close together in the right quantities; the fuel for the reaction is present, in sufficient amount and in the right form; and the environmental variables are all within the right range, including the temperature, salinity, and pH.

The complicated chemistry of life is extremely sensitive to the environmental conditions; the environment is the body itself. *Homeostasis* is the term physiologists use to mean the subset of metabolic reactions that keep the internal environment of the body in a state conducive to the chemical reactions that maintain your life.

The following sections look at a few important physiological variables and how the mechanisms of homeostasis keep them in the optimum range in common, everyday situations.



REMEMBER

Because homeostatic reactions are metabolic actions, they require energy.

Regulating body temperature

All metabolic reactions in all organisms require that the temperature of the body be within a certain range. But humans, the land-loving creatures that they are, are often subjected to large and sudden temperature changes in their environments.

The key solution to this problem is called *homeothermy*, or warm-bloodedness, which is described as the maintenance of body temperature at a relatively constant level regardless of the ambient temperature. The large number of mitochondria per cell that humans possess enables a high rate of metabolism, which in turn generates a lot of heat. Warm-blooded animals must ingest a large quantity of food frequently to fuel their higher metabolism.



REMEMBER

Regulating body temperature requires a steady supply of fuel (glucose) to the mitochondrial furnaces.

Another way warm-blooded animals control their body temperatures is by employing adaptations that conserve the heat generated by metabolism within the body in cold conditions or dissipate that heat out of the body in overly warm conditions. A few of the specific adaptations humans use to hold their internal temperatures constant are

- » **Sweating:** Sweat glands in the skin open to dissipate heat by evaporative cooling of water from the skin. They close to conserve heat. Sweat glands are opened and closed by the actions of muscles at the base of the gland deep under the skin.
- » **Blood circulation:** Blood vessels close to the skin dilate (enlarge) to dissipate heat in the blood through the skin. They constrict (narrow) to conserve heat. Your skin flushes (reddens) when you're hot because that's the color of your blood visible at the surface of your skin.
- » **Muscle contraction:** When sweating and blood vessel constriction aren't enough to conserve heat in cold conditions, your muscles begin to contract automatically to generate more heat. This reaction is often referred to as *shivering*.
- » **Insulation:** Mammals and birds evolved insulating structures on their body surfaces (hair and feathers, respectively) and regions of fatty tissue under the skin. Humans alone employ the cultural adaptation of clothing.

Maintaining a fluid balance

A watery environment is part of the requirements for a great proportion of metabolic reactions. (The rest need a lipid, or fatty, environment.) The body contains a lot of water. You have water in your blood, in your cells, in the spaces between your cells, in your digestive organs, here, there, and everywhere. Not pure water, though. The water in your body is a solvent for thousands of different ions and molecules (solutes). The quantity and quality of the solutes change the character of the solution.



Because solutes are constantly entering and leaving the solution as they participate in or are generated by metabolic reactions, the characteristics of the watery solution must remain within certain bounds for the reactions to continue. The following fluid-balance homeostasis mechanisms have evolved:

» **The thirst reflex:** Water passes through your body constantly: mainly, in through your mouth and out through various organ systems, including the skin, the digestive system, and the urinary system. If the volume of water falls below the optimum level (resulting in dehydration), the mechanisms of homeostasis intrude on your conscious brain to make you uncomfortable. You feel thirsty. You ingest something watery. Your fluid balance is restored, and your thirst reflex leaves you alone.

» **The ability to change the composition of urine:** The kidney is a complex organ that has the ability to measure the concentration of many solutes in the blood, including sodium, potassium, and calcium. The kidney can measure the volume of water in the body by sensing the pressure of the blood as it flows through. The greater the volume of water, the higher the blood pressure.

If changes must be made to bring the volume and composition of the blood back into the ideal range, the various structures of the kidney incorporate more or less water, sodium, potassium, and so on into the urine. This process explains why your urine is paler or darker at different times.

Examining blood glucose concentration

Glucose, the fuel of all cellular processes, is distributed to all cells dissolved in the blood. The concentration of glucose in the blood must be high enough to ensure that the cells have enough fuel. However, extra glucose beyond the immediate needs of the cells can harm many important organs and tissues, especially where the vessels are tiny, as in the retina of the eye, the extremities (hands and, especially, feet), and the kidneys.

The amount of glucose in the blood is controlled mainly by the intestines and by insulin. *Insulin* is a hormone released from the pancreas, an endocrine gland, into the blood in response to increased blood glucose levels.



Most cells have receptors that bind the insulin, which increases the activity of glucose transporters in the cell membrane. Glucose is removed from the blood and into storage, mostly within the cells of the liver, the muscles (where it's stored as glycogen, the form of fuel your muscles use), and the fat cells of the adipose tissue. At times when your intestines aren't releasing much glucose, such as some hours after a meal, the production of insulin is suppressed, and the stored glucose is released into the blood again.

Gauging variables that keep the body balanced

How does the pancreas know when to release insulin and how much is enough? How does the kidney know when the salt content of the blood is too high or the volume of the blood is too low? What tells the sweat glands to open and close to cool the body or retain heat? The answer in these and many other situations related to homeostasis is this: The detection of threats to homeostasis and the response of organs to counter the threats involve an intricate system of communications between parts of the nervous, circulatory, and endocrine systems.

Here's the general process of how this communication works:

- 1. Receptors (sensors) in the blood vessels detect the state of the blood.**

Some receptors detect temperature, some pressure (volume), some the concentration of glucose, and many others detect different variables.

- 2. The receptors send their data through the nervous system to the brain, where an endocrine gland called the *hypothalamus* resides.**

The hypothalamus is sometimes called the *master gland* because it controls homeostasis by acting on other glands, notably the *pituitary gland*.

- 3. The endocrine system makes and releases hormones that travel through the blood to the tissues and organs and cause them to change their behavior in ways that restore the variables to their optimum physiological range.**

Hormones are substances of great power and subtlety.

