YOUR BODY How It Works

Cells, Tissues, and Skin

Douglas Light

INTRODUCTION
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How It Works

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- Cells, Tissues, and Skin
- The Circulatory System
- Human Development
- The Immune System
- The Reproductive System
- The Respiratory System

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Introduction

The human body is an incredibly complex and amazing structure. At best, it is a source of strength, beauty, and wonder. We can compare the healthy body to a well-designed machine whose parts work smoothly together. We can also compare it to a symphony orchestra in which each instrument has a different part to play. When all of the musicians play together, they produce beautiful music.

From a purely physical standpoint, our bodies are made mainly of water. We are also made of many minerals, including calcium, phosphorous, potassium, sulfur, sodium, chlorine, magnesium, and iron. In order of size, the elements of the body are organized into cells, tissues, and organs. Related organs are combined into systems, including the musculoskeletal, cardiovascular, nervous, respiratory, gastrointestinal, endocrine, and reproductive systems.

Our cells and tissues are constantly wearing out and being replaced without our even knowing it. In fact, much of the time, we take the body for granted. When it is working properly, we tend to ignore it. Although the heart beats about 100,000 times per day and we breathe more than 10 million times per year, we do not normally think about these things. When something goes wrong, however ,our bodies tell us through pain and other symptoms. In fact, pain is a very effective alarm system that lets us know the body needs attention. If the pain does not go away, we may need to see a doctor. Even without medical help, the body has an amazing ability to heal itself. If we cut ourselves, the blood clotting system works to seal the cut right away, and the immune defense system sends out special blood cells that are programmed to heal the area.

During the past 50 years, doctors have gained the ability to repair or replace almost every part of the body. In my own field of cardiovascular surgery, we are able to open the heart and repair its valves, arteries, chambers, and connections. In many cases, these repairs can be done through a tiny "keyhole" incision that speeds up patient recovery and leaves hardly any scar. If the entire heart is diseased, we can replace it altogether, either with a donor heart or with a mechanical device. In the future, the use of mechanical hearts will probably be common in patients who would otherwise die of heart disease.

Until the mid-twentieth century, infections and contagious diseases related to viruses and bacteria were the most common causes of death. Even a simple scratch could become infected and lead to death from "blood poisoning." After penicillin and other antibiotics became available in the 1930s and 40s, doctors were able to treat blood poisoning, tuberculosis, pneumonia, and many other bacterial diseases. Also, the introduction of modern vaccines allowed us to prevent childhood illnesses, smallpox, polio, flu, and other contagions that used to kill or cripple thousands.

Today, plagues such as the "Spanish flu" epidemic of 1918–19 , which killed 20 to 40 million people worldwide, are unknown except in history books. Now that these diseases can be avoided, people are living long enough to have long-term (chronic) conditions such as cancer, heart failure, diabetes, and arthritis. Because chronic diseases tend to involve many organ systems or even the whole body, they cannot always be cured with surgery. These days, researchers are doing a lot of work at the cellular level, trying to find the underlying causes of chronic illnesses. Scientists recently finished mapping the human genome, which is a set of coded "instructions" programmed into our cells. Each cell contains 3 billion "letters" of this code. By showing how the body is made, the human genome will help researchers prevent and treat disease at its source, within the cells themselves.

The body's long-term health depends on many factors, called risk factors. Some risk factors, including our age, sex, and family history of certain diseases, are beyond our control. Other important risk factors include our lifestyle, behavior, and environment. Our modern lifestyle offers many advantages but is not always good for our bodies. In western Europe and the United States, we tend to be stressed, overweight, and out of shape. Many of us have unhealthy habits such as smoking cigarettes, abusing alcohol, or using drugs. Our air, water, and food often contain hazardous chemicals and industrial waste products. Fortunately, we can do something about most of these risk factors. At any age, the most important things we can do for our bodies are to eat right, exercise regularly, get enough sleep, and refuse to smoke, overuse alcohol, or use addictive drugs. We can also help clean up our environment. These simple steps will lower our chances of getting cancer, heart disease, or other serious disorders.

These days, thanks to the Internet and other forms of media coverage, people are more aware of health-related matters. The average person knows more about the human body than ever before. Patients want to understand their medical conditions and treatment options. They want to play a more active role, along with their doctors, in making medical decisions and in taking care of their own health.

I encourage you to learn as much as you can about your body and to treat your body well. These things may not seem too important to you now, while you are young, but the habits and behaviors that you practice today will affect your physical well-being for the rest of your life. The present book series, YOUR BODY: HOW IT WORKS, is an excellent introduction to human biology and anatomy. I hope that it will awaken within you a lifelong interest in these subjects.

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Cells:
The Basis of Life

Cells are the basic units of all living organisms. Some living creatures, such as bacteria and protozoans, consist of only a single cell. In contrast, complex organisms like human beings may be composed of over 75 trillion cells! Just one drop of human blood contains about 5 million red blood cells.

CELLS VARY WIDELY IN SIZE AND SHAPE

Although most cells are microscopic, they vary widely in size. For instance, sperm cells are only about 2 **micrometers** (1/12,000th of an inch) big, whereas some nerve cells are over a meter (3 feet) in length (for example, a single nerve cell connects the spinal cord in your lower back to the little toe).

Cells also vary in shape, which reflects their particular function. *Nerve* cells, for example, have long threadlike extensions that are used to transmit impulses form one part of the body to another. *Epithelial* cells that compose the outer layers of the skin can be flattened and tightly packed like floor tiles, enabling them to protect underlying cells. *Muscle* cells, designed to generate force by contracting, can be slender, rod-shaped structures. Red blood cells, which carry oxygen from the lungs to virtually every cell in the body, are **biconcave** and disk-shaped (Figure 1.1). whereas some kidney cells resemble a cube. All in all, the human body has over 200 different types of cells.

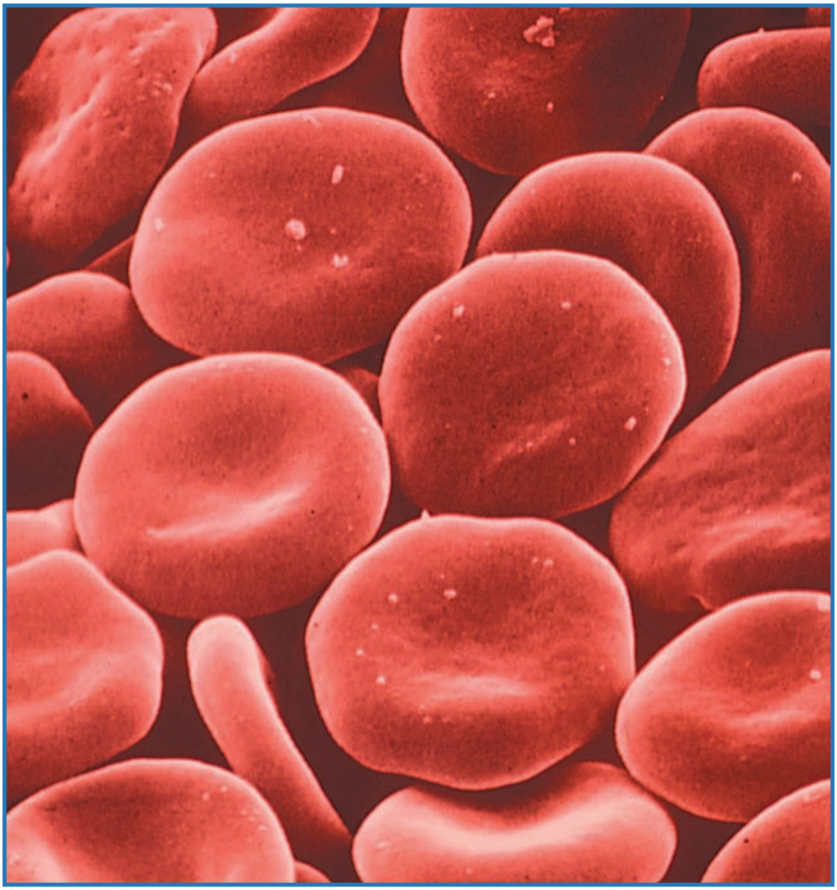

Figure 1.1 There are over 200 different types of cells in the body, and they come in all shapes and sizes. Red blood cells, for example, as pictured here, are biconcave disks. This unique shape allows them to efficiently carry oxygen for distribution throughout the body.

THE DISCOVERY OF CELLS

Because of their small size, the discovery of cells and their structure had to wait for the invention of the microscope. During the mid-seventeenth century, the English scientist Robert Hooke looked at thinly sliced cork with a simple microscope. He observed tiny compartments, which he termed "*cellulae*," the Latin word for small rooms; hence the origin of the biological term *cell* (technically speaking, he actually observed the walls of dead plant cells, but no one at that time thought of cells as being dead or alive). In the late seventeenth century, the Dutch shopkeeper Anton van Leeuwenhoek constructed lenses that provided clarity and magnification not previously possible. With these new lenses, he observed very small "*animalcules*" from scrapings of tartar from his own teeth, as well as **protozoans** from a variety of water samples.

In the early nineteenth century, the German botanist

WHY ARE CELLS SMALL?

Why are most cells microscopic in size? It turns out that there are physical constraints placed on cells, which are determined by their *surface area-to-volume ratio*. This is because an object's volume increases with the cube of its diameter. However, the surface area only increases with the square of the diameter. In other words, as a cell grows in size, the volume increases faster than the surface area. For example, if a cell grows four times in diameter, then its volume would increase by 64 times (4^3), whereas its surface area only by 16 times (4^2). In this example, the plasma membrane would therefore have to serve four times as much cytoplasm as it did previously. Thus, if a cell were to grow unchecked, it would soon reach a point where the inward flow of nutrients and outward flow of waste products across the plasma membrane would not occur at a rate sufficient to keep the cell alive.

The importance of a large surface area for cells also is seen by the numerous in-foldings and out-foldings in the plasma membrane of many cell types. These folds dramatically increase the surface area relative to cell volume. This is especially important for cells that absorb large quantities of substances, such as those lining the small intestine and many cells in the kidneys.

Matthias Schleiden, who also studied cells with a microscope, proposed that the nucleus might have something to do with cell development. During the same time period, the German zoologist Theodor Schwann theorized that animals and plants consist of cells, and that cells have an individual life of their own. Rudolf Virchow, a German physiologist who studied cell growth and reproduction, suggested all cells come from pre-existing cells. His proposal was actually revolutionary for the time because it challenged the widely accepted theory of **spontaneous generation**, which held that living organisms arise spontaneously from nonliving material, such as garbage.

By the middle of the nineteenth century, the scientific community developed several generalizations, which today we term the **cell theory**. The cell theory includes three important principles. First, every living organism is composed of one or more cells. Second, cells are the smallest units that have the properties of life. Third, the continuity of life has a cellular basis.

Microscopes

Modern microscopes have dramatically increased our ability to observe cell structure. Light microscopes use two or more sets of highly polished glass lenses to bend light rays to illuminate

CELL THEORY

The cell theory, developed in the mid-nineteenth century, provided scientists with a clearer insight of the study of life. The cell theory involves the following three aspects:

1. **Every living organism is composed of one or more cells.**
2. **Cells are the smallest units that have the properties of life.**
3. **The continuity of life has a cellular basis.**

a specimen, thereby enlarging its image. Consequently, in order to be seen, a specimen must be thin enough for light to pass through it. Also, cells are 60-80% water, which is colorless and clear. This, in turn, makes it difficult to observe the various unpigmented structures of cells. This problem is overcome by exposing cells to a **stain** (dye), which colors some cell parts, but not others.

Unfortunately, staining usually kills cells. However, there are several types of microscopes designed to use *phase-contrast* or *Nomarksi optics*, which use light refraction to create contrast without staining. For instance, with Nomarski optics, a prism is used to split a beam of polarized light in two and project both beams through a specimen at slightly different angles. When the beams are later combined, they exhibit bright and dark interference patterns that highlight areas in cells that have differing thicknesses. These specialized optics obviously enhance the usefulness of light microscopes.

Two factors need to be considered when discussing microscopy: a microscope's ability to *magnify* images and its ability to *resolve* them. **Magnification** simply means making an image appear larger in size. **Resolution** refers to the ability to make separate parts look clear and distinguishable from one another, which becomes increasingly more difficult as magnification increases. Consequently, if a microscope magnified an image without providing sufficient resolution, the image would appear large but unclear.

Light microscopes have an inherent limitation regarding resolution because of the physical nature of light. Light, a form of **electromagnetic radiation**, has wave-like properties, where the wavelength refers to the distance between two wave crests (red light, for example, has a longer wavelength than violet light; 750 **nanometers** versus 400 nanometers, respectively). Therefore, if a cell structure is less than one-half the wavelength of illuminating light, it will not be able to disturb the light rays streaming past it. In other words, it will be invisible. As a result, light microscopes are not useful for observing objects smaller than several hundred nanometers.

Electron microscopes have a much greater resolving power because they use a beam of electrons to "illuminate" a specimen instead of light. Although electrons are particles, they also have wave-like properties, and a stream of electrons has a wavelength about 100,000 times shorter than that of visible light. This allows an electron microscope to resolve images down to about 0.5 nanometers in size. Because a beam of electrons cannot pass through glass, its path is focused by a magnetic field. In addition, specimens must be placed in a vacuum, otherwise molecules of air would deflect the electron beam.

There are two main kinds of electron microscopes. A **transmission electron microscope** (Figure 1.2) accelerates a beam of electrons through a specimen, which allows internal structures within a cell to be imaged. In contrast, a **scanning electron microscope** moves a narrow beam of electrons across a specimen that has been coated with a thin layer of metal. This method is ideally suited for imaging the surface of a specimen (Figure 1.3).

CHEMICAL CONSTITUENTS OF CELLS

Chemically, cells are mainly composed of four **elements**: carbon, hydrogen, oxygen, and nitrogen. Although these four **major elements** make up over 95% of a cell's structure, the lesser abundant **trace elements** also are important for certain cell functions (Figure 1.4). Iron, for instance, is needed to make *hemoglobin*, which carries oxygen in the blood. Blood clotting, and the proper formation of bones and teeth all require calcium. Iodine is necessary to make thyroid hormone, which controls the body's metabolic rate. A lack of iodine in the diet can lead to the formation of a

Figure 1.2 A transmission electron microscope (TEM) utilizes a beam of electrons to allow scientists to visualize the internal components of a cell. In addition, TEMs provide much greater resolution (clarity) and magnification than traditional light microscopes. The TEM pictured here is located at the University of New Mexico.

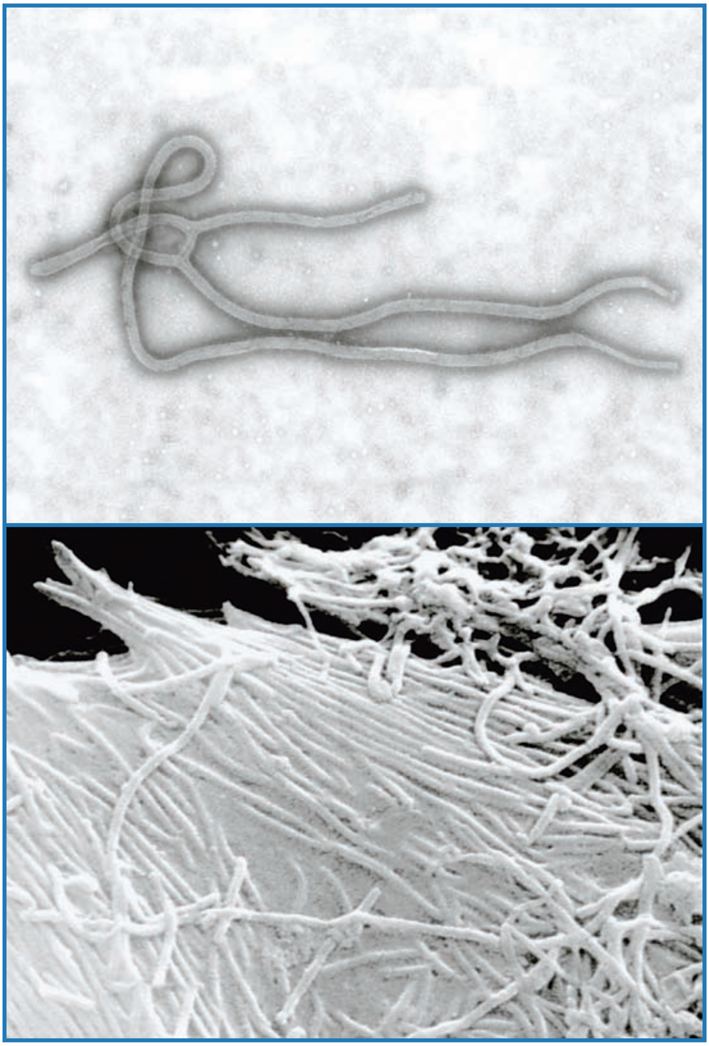

Figure 1.3 Like TEMs, scanning electron microscopes, or SEMs, utilize a beam of electrons to visualize specimens. However, SEMs provide a picture of the outside structure of a specimen, rather than its internal components. Pictured here are specimens of the Ebola virus. The picture on the top was taken with a transmission electron microscope. Note that the cell appears translucent and the inner components are visible. The picture on the bottom was taken with a scanning electron microscope, and only the surface of the specimen is visible.

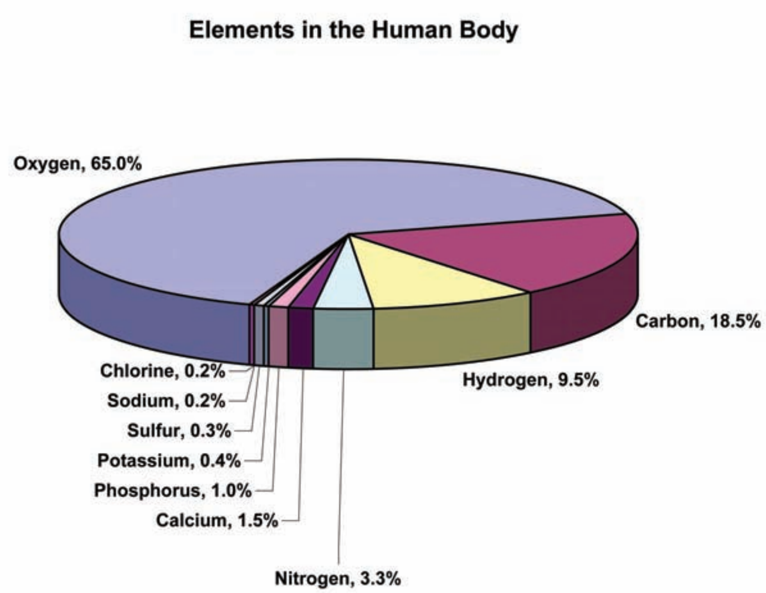

Figure 1.4 Oxygen, carbon, hydrogen, and nitrogen are all important components of cells and make up over 90% of a cell's structure. Calcium, phosphorus, and potassium are also found in cells, but in much smaller amounts and are known as trace elements. Figure 1.4 shows some of the more common elements found in cells and their approximate amounts.

goiter (an enlarged thyroid gland). Although goiters were relatively common in the past, they are less common today because dietary iodine can be obtained through the consumption of iodized salt. Sodium and potassium are also necessary elements, especially for the transmission of nerve impulses and for muscle contraction.

It is convenient to divide the chemicals that enter cells or are produced by them into two main groups: **organic** substances (those that contain carbon and hydrogen atoms), and **inorganic** substances (all the rest). The most abundant inorganic molecule in cells (and the entire body) is water. In fact, it accounts for about two-thirds of an adult human's weight. This helps explain why water is essential for life. Water is important as a **solvent** because many substances (**solutes**) dissolve in it. Also, water helps stabilize body temperature because, compared to most fluids, it can absorb a lot of heat before its temperature rises, and cells release a great amount of heat during normal **metabolism** (the sum total of all the chemical reactions taking place in the body). In addition to water, other inorganic substances found in cells include oxygen, carbon dioxide, and numerous inorganic salts, such as sodium chloride (ordinary table salt).

Organic substances in cells include **carbohydrates**, **lipids**, **proteins**, and nucleic acids. Carbohydrates, such as sugars and glycogen, provide much of the energy that cells require. Carbohydrates also provide materials to build certain cell structures. Lipids include compounds such as fats (primarily used to store energy), phospholipids (an important constituent of cell membranes), and cholesterol (used to synthesize steroid hormones, such as testosterone and estrogen). Proteins serve as structural materials and an energy source. In addition, most enzymes and many hormones are composed of protein. **Nucleic acids** form the genes found in DNA and also take part in protein synthesis.

STRUCTURE OF A GENERALIZED CELL

Although cells differ in many respects, they all have certain characteristics and structures in common. Consequently, it is possible to construct a generalized or *composite* cell (Figure 1.5). For human beings, our cells typically start out with three structures in common. They all have a **plasma membrane**, the thin outer boundary that separates the intracellular environment from the extracellular one. The plasma membrane therefore maintains cells as distinct entities. In