care provider. SEE ALSO Female Reproductive System; Male Reproductive System; Sexual Reproduction; Sexually Transmitted Diseases

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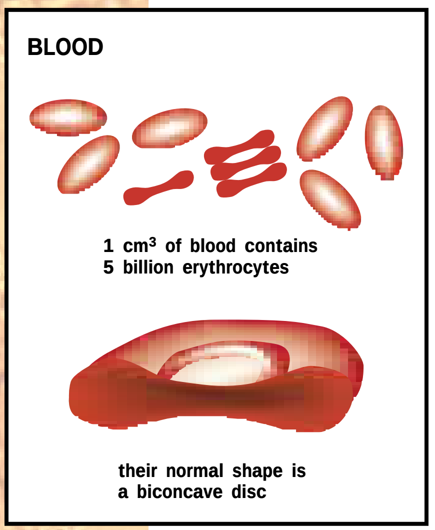
Blood



Erythrocytes (red blood cells) are very small cells, usually with no nucleus or internal membranes, and are stuffed full of the oxygen-binding protein hemoglobin.

Blood is the bodily fluid responsible for transport of materials and waste products throughout the body. It carries oxygen from and carbon dioxide to the lungs, nutrients from the digestive system or storage sites to tissues that require them, and waste products from the tissues to the liver for detoxification and to the kidneys for disposal. Blood delivers hormones to their sites of action and circulates numerous critical parts of the immune system throughout the body. Blood regulates its own **pH**, as well as that of the intercellular fluid in the body, and aids in **thermoregulation** by redistributing heat. Blood also carries the **proteins** and other factors it needs to clot, thereby preventing its own loss in the event of injury to the vessels in which it travels.

A human adult has 4 to 6 liters (1 to 1.5 gallons) of blood, approximately 92 percent of which is water. Nearly half its volume is red blood cells (RBCs, or erythrocytes). Proteins, sugars, salts, white blood cells, and platelets make up the remainder. The noncellular portion is termed plasma, while the cellular parts are collectively referred to as the formed elements. Blood forms in the bone marrow, a spongy tissue contained in the bones.

Red Blood Cells and Hemoglobin

Only a small amount of the oxygen needed for life can dissolve directly in plasma. Oxygen transport instead relies on red blood cells. At any one time, there are more than 25 trillion RBCs in circulation in an adult, more than the combined total of all other cell types in the body. As RBCs develop, they extrude their cell **nucleus**, so that at maturity they have almost nothing inside their membranes except the oxygen-carrying protein, **hemoglobin**. The absence of a nucleus contributes to the RBC's short life, as does the constant physical stress it experiences squeezing through capillaries that are narrower than it is. The average RBC circulates for approximately 120 days before being destroyed in the liver, bone marrow, or spleen. The iron from hemoglobin is recycled, while the cyclic nitrogen compound that holds it, called heme, is converted to bilirubin. Bilirubin is transported to the liver for elimination from the body as bile. Liver disease can cause jaundice, a yellowing of the skin due to bilirubin in the blood.

The iron in hemoglobin is critical for oxygen transport. Lack of dietary iron is one cause of anemia, a condition in which the blood cannot carry enough oxygen. The heme group binds oxygen tightly when the concentration of O_2 is high (as it is in the lungs), but quickly releases it when the concentration is low, as it is in the tissues. The iron can also bind carbon monoxide (CO), which is produced by car engines and other combustion sources. CO binds much more tightly than oxygen does and prevents oxygen binding, making CO a deadly poison.

pH measure of acidity or alkalinity; numbers below 7 are acid, above are basic

thermoregulation temperature regulation

protein complex molecule made from amino acids; used in cells for structure, signaling, and controlling reactions

nucleus membrane-bound portion of cell containing the chromosomes

hemoglobin oxygen-carrying protein complex in red blood cells

A genetic variant of the hemoglobin gene causes a single **amino acid** change in the hemoglobin molecule. This change causes the red blood cell to become sickle-shaped at low oxygen concentrations, so that it tends to become lodged in small capillaries, depriving tissues of oxygen. A person with one such variant hemoglobin gene does not suffer ill effects, but with two variants will develop sickle-cell anemia. Despite this, the sickling variant is common in populations historically exposed to malaria, because having one variant helps protect against malaria infection.

amino acid a building block of protein

CO_2 Transport and Blood Buffering

Carbon dioxide (CO_2) does not bind to iron, but rather to the protein portion of hemoglobin. CO_2 is a product of cell respiration, and is picked up in the tissues and transported to the lungs. Most of the CO_2 transported is actually in the form of bicarbonate **ion**, HCO_3^-. Bicarbonate is formed by the **enzyme** carbonic anhydrase, which is present in the red blood cells. This enzyme **catalyzes** the conversion of CO_2 and H_2O to carbonic acid (H_2CO_3), which immediately splits to form H^+ and HCO_3^-. Besides serving as a transport form of CO_2, HCO_3^- also participates in blood buffering. It can react with excess H^+ (acid ion) formed in other reactions. In this way, it prevents excess acidity in the blood. Similarly, HCO_3^- can react with excess OH^- (base ion) to form water and CO_3^{2-}, absorbing excess base. Along with phosphate, bicarbonate keeps the blood buffered at a pH of 7.4.

Nutrient Transport, Regulation, and Clotting

Blood also transports nutrients, hormones, and immune system components. Nutrients from the gut are dissolved directly in the plasma for transport, but are quickly shuttled to the liver for processing and storage of excess. Insulin and glucagon, hormones produced by the pancreas, control the level of blood sugar by promoting storage or release of **glucose**. The kidney performs the vital function of excreting excess salts and water, as well as metabolic wastes, helping to maintain blood levels of these substances within narrow limits. One waste product the kidneys cannot **excrete** is heat, produced by cell **metabolism** through out the body. Blood performs the vital function of carrying heat from the body core to the periphery, where it can be cooled before returning.

Hormones are released by **endocrine** organs directly into the bloodstream for wide and rapid circulation. White blood cells also use the circulatory system as a highway through the body, traveling in the blood until they exit in response to chemical signals from wounded or infected tissues. Platelets and clotting proteins in the blood work together to prevent blood loss when a vessel is broken. Clotting relies on chemical signals from damaged tissue and from platelets, and the activation of a complex cascade of more than a dozen different plasma proteins. SEE ALSO Blood Clotting; Heart and Circulation; Hormones; Respiration

Richard Robinson

ion an electrically charged particle

enzyme protein that controls a reaction in a cell

catalyze aid in the reaction of

glucose simple sugar that provides energy to animal cells and is the building block of cellulose in plants

excrete deposit outside of

metabolism chemical reactions within a cell

endocrine related to the system of hormones and glands that regulate body function

DREW, CHARLES (1904–1950)

African-American surgeon who invented a way to preserve blood plasma so that it could be stored. Drew's plasma saved the lives of thousands of Londoners during the Nazi bombings in World War II. But when the U.S. military refused to accept blood donated by black Americans, Drew resigned from his post as head of the Red Cross's "Plasma for Britain" program.

Nonspecific Defense

In animals, there are two types of defenses against foreign invaders: specific and nonspecific. Specific immune responses can distinguish among different invaders. The response is different for each invader. With nonspecific defenses, the protection is always the same, no matter what the invader may be. Whereas only vertebrates have specific immune responses, all animals have some type of nonspecific defense. Examples of nonspecific defenses include physical barriers, **protein** defenses, cellular defenses, inflammation, and fever.

protein complex molecule made from amino acids; used in cells for structure, signaling, and controlling reactions

Barriers

One way for an organism to defend itself against invasion is through barriers that separate the organism from its environment. Physical barriers such as the skin and **mucous membranes** mechanically regulate what enters the body. **Secretions** provide protection at the barrier as well. Mucus, for example, can trap potential invaders. Also, skin secretions are slightly **acidic**, inhibiting bacterial growth. Many body secretions (such as mucus, tears, and saliva) contain an **enzyme** called lysozyme that destroys bacteria.

mucous membrane outer covering designed to secrete mucus, often found lining cavities and internal surfaces

secretion material released from the cell

acidic having an excess of H^+ ions, and a low pH

enzyme protein that controls a reaction in a cell

Proteins

There are proteins that protect the body nonspecifically. Complement proteins are found in the blood. When they bind to an invader, they stimulate inflammation, **phagocytosis**, and destruction of the invader's membrane. Although complement proteins may bind to an invader directly, they are most effective when they bind to antibodies that are attached to an invader. Antibodies are part of the body's specific immune response.

Some immune cells and cells that are infected with viruses produce another set of proteins called **interferons**. Interferons send a warning to nearby cells. They help prevent infection by stimulating the production of antiviral proteins. Interferons also stimulate natural killer cells and macrophages.

phagocytosis engulfing of cells or large fragments by another cell, including immune system cells

interferons signaling molecules of the immune system

Cellular Defenses

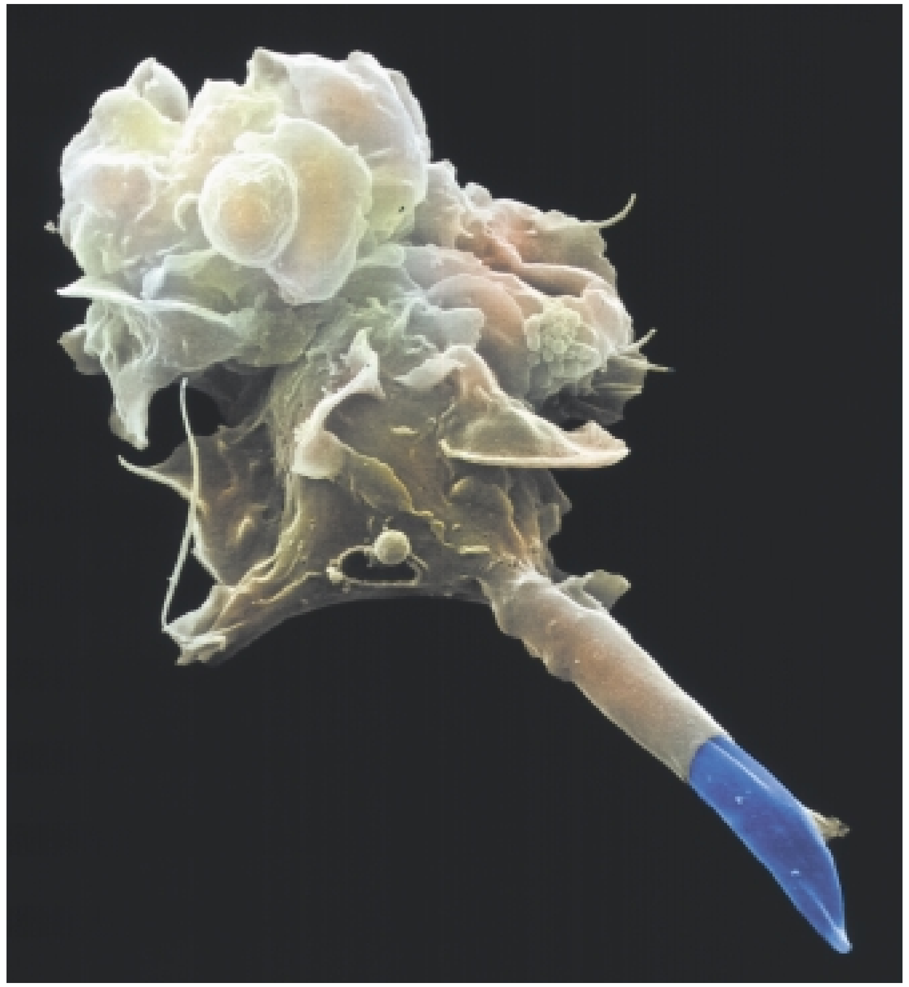
Natural killer cells and macrophages are examples of nonspecific cellular defenses. Natural killer cells are a class of lymphocytes that recognize abnormal cells (such as cancerous cells or virus-infected cells), attach to them, and release chemicals that destroy them.

Macrophages, neutrophils, and eosinophils are examples of phagocytes. In their attempt to defend the body, some phagocytes stay within a tissue and others travel freely throughout the body. However, all phagocytes are attracted to sites of tissue damage. In a process called phagocytosis, these cells surround debris or a foreign invader, bringing it inside the cell. The phagocyte then uses special enzymes to digest the material.

All animals have phagocytes that recognize and eliminate foreign invaders. For example, if a piece of one sponge is transplanted to a sponge from another colony, phagocytes in the sponges will attack and destroy each other. The same response can be observed in earthworms, **arthropods**, starfish, and all vertebrates. Scientist Elie Metchnikoff observed this process in starfish.

arthropods organisms with jointed appendages and exoskeletons, including insects, spiders, and crustaceans

In 1882 a scientist named Elie Metchnikoff stuck a thorn into a starfish larva. He observed starfish cells trying to destroy the thorn. His discovery was an important step in understanding nonspecific defenses in animals.



A colored scanning electron micrograph of a macrophage engulfing a parasite of the *Leishmania* genus. To defend the body, macrophages will surround a foreign invader, bring it inside the cell, then use enzymes to digest the material.

In vertebrates, some phagocytes are also important in stimulating specific immune responses. Additionally, phagocytosis is stimulated when the invaders are coated with antibodies. Consequently, phagocytes (like complement proteins) represent an important link between nonspecific and specific immunity.

Inflammation

Infection, mechanical force, chemicals, and extreme heat or cold can damage tissues, causing the nonspecific process of inflammation. The goal of inflammation is to clean up the damage and start the repair process. Inflammation begins when damaged tissues release chemical messengers such as histamine, **prostaglandins**, and leukotrienes. These chemicals cause nearby blood vessels to expand and become more leaky, allowing more blood flow to the damaged area. These chemicals also attract white blood cells (such as phagocytes) to the site to remove debris and foreign invaders. The results of these activities are easily observed when the skin is inflamed: swelling, redness, heat, and pain.

prostaglandins hormonelike molecules released by one cell that affect nearby cells, including smooth muscle

Fever

Another nonspecific protection against infection is the development of a fever. Either the invader or the response to an invader causes a part of the