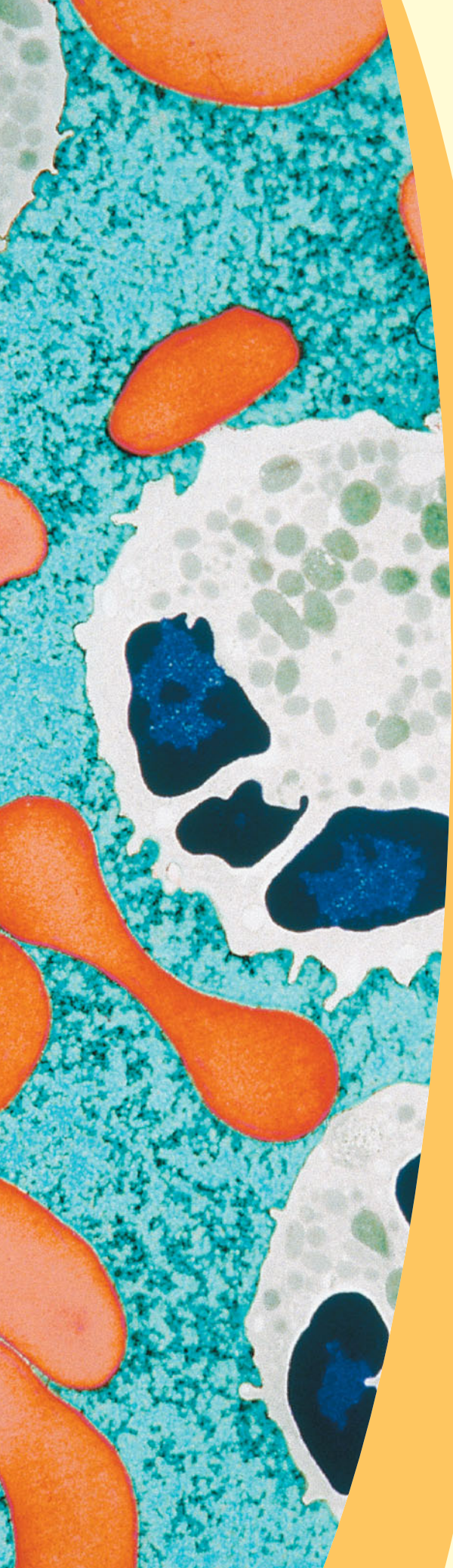


Blood 18

This chapter and the next three discuss the **circulatory system,** which is subdivided into the **cardiovascular system** (the blood, the heart, and the blood vessels: Chapters 18–20) and the **lymphatic system** (vessels that carry a fluid called lymph: Chapter 21). This chapter is devoted to **blood,** the fluid in the vessels of the cardiovascular system.

Blood is the river of life that surges within us, transporting nearly everything that must be carried from one place to another in the body. For thousands of years, blood was considered magical, an elixir that held the mystical force of life, because when it drained from the body, life departed as well. Today, blood retains an important role in clinical medicine. Blood carries molecular evidence of the body's activities, and examination of blood is essential in clinical assessment. Blood tests are used to screen for evidence of disease, recreational substance use, and nutritional status.

Blood circulation is initiated by the pumping action of the heart. Blood leaves the heart in *arteries,* which branch repeatedly

Blood cells, erythrocytes, and granulocytes (colored TEM).

until they become tiny *capillaries*. By diffusing across capillary walls, oxygen and nutrients leave the blood and enter body tissues, and carbon dioxide and cellular wastes diffuse from the tissues into the bloodstream. From the capillaries, the oxygen-deficient blood flows into *veins,* which return it to the heart. Blood is then pumped to the lungs, where it picks up oxygen and releases carbon dioxide, and then returns to the heart to be pumped throughout the body once again.

In addition to carrying respiratory gases and nutrients, blood transports hormones from the endocrine glands to their target organs and conveys cells of the body's defense system to sites where they can fight infection. As noted in Chapter 5, blood also helps to regulate body temperature; blood is diverted to or away from the skin to control the amount of body heat lost across the body surface.

This chapter will discuss (1) the cellular and noncellular components of blood, (2) the formation of blood cells, (3) some common disorders of blood, and (4) the embryonic formation of blood.

COMPOSITION OF BLOOD

- Name the basic components of blood, and define hematocrit.
- List some of the molecules in blood plasma.

Blood accounts for about 8% of body mass. Its volume is 5–6 liters (about 1.5 gallons) in adult men and 4–5 liters in women.

Although blood appears to the unaided eye as a thick, homogeneous liquid, microscopic examination reveals that it has both cellular and liquid components. Blood is a specialized type of connective tissue in which blood cells, called formed elements, are suspended in a fluid called plasma.

When a sample of blood is spun in a centrifuge, the heavier formed elements are packed down by centrifugal force, and the less dense *plasma* remains at the top of the tube **(Figure 18.1)**. The red mass at the bottom of the tube consists of *erythrocytes* (e-rith′ro-sīts; "red cells"), the red blood cells that transport important blood gases such as oxygen and carbon dioxide. The percentage of the blood volume that consists of erythrocytes, known as the **hematocrit** (hemat′o-krit; "blood fraction"), averages 45%. Normal hematocrit values vary. In healthy men, the hematocrit is 47% ± 5%, whereas in healthy women it is 42% ± 5%. Values tend to be slightly higher in newborns—between 42% and 68%.

A thin, gray layer called the **buffy coat** is present at the junction between the erythrocytes and the plasma. The buffy coat contains *leukocytes* (lu′ko-sīts; "white cells"), the white blood cells that act in various ways to protect the body, and *platelets (thrombocytes),* cell fragments that help stop bleeding. Leukocytes and platelets constitute less than 1% of the volume of blood, and plasma makes up the remaining 55% of whole blood.

Blood Plasma

Blood plasma is a straw-colored, sticky fluid. Although it is about 90% water, it contains over 100 different kinds of molecules, including ions such as sodium (Na^+) and chloride (Cl^-); nutrients such as simple sugars, amino acids, and lipids; wastes such as urea, ammonia, and carbon dioxide; and oxygen, hormones, and vitamins. Plasma also contains three main types of proteins: **albumin** (al-bu′min), **globulins** (glob′u-lins), and **fibrinogen** (fi-brin′o-jen). Albumin helps keep water from diffusing out of the bloodstream into the extracellular matrix of tissues. The globulins include both antibodies and the blood proteins that transport lipids, iron, and copper. The plasma protein fibrinogen is one of several molecules involved in a series of chemical reactions that achieves blood clotting. If blood is allowed to stand, the series of reactions in the plasma, called coagulation, produces (1) a clot that entangles the formed elements and (2) a clear fluid called serum. Thus, serum is plasma from which the clotting factors have been removed.

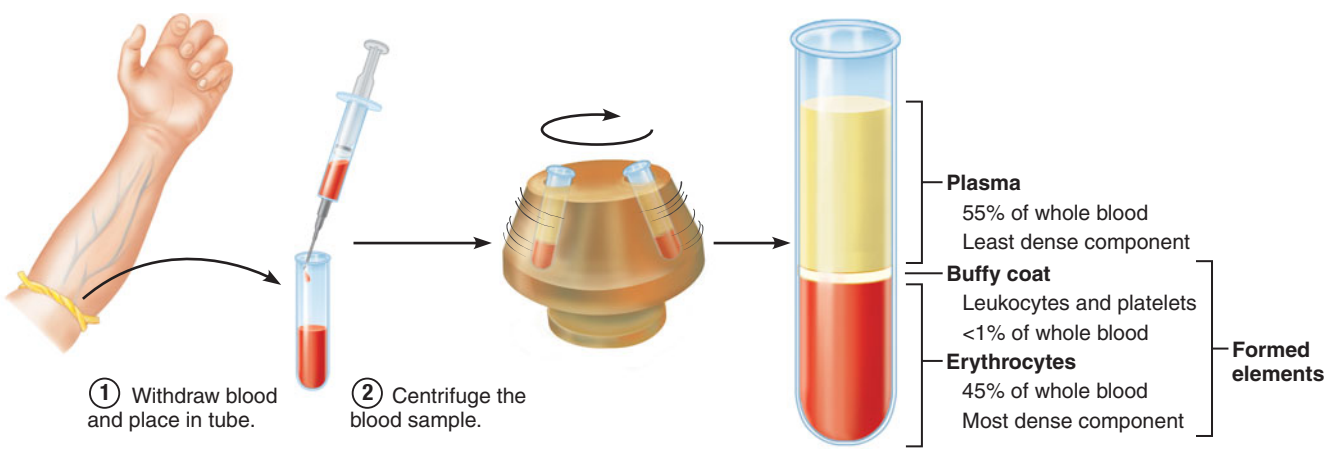


FIGURE 18.1 Major components of whole blood.

HEMOCHROMATOSIS An inherited condition in which the digestive tube absorbs too much iron from the diet is called **hemochromatosis** (he″mo-kro″mah-to′sis). The iron-carrying globulin proteins in blood plasma become saturated, and iron gradually builds up in the body's tissues, where it oxidizes and poisons many organs, especially the joints, liver, and pancreas. If detected before serious damage is done, it is easily treated by weekly sessions of blood removal (of half a liter of blood) to remove the excess iron. Hemochromatosis was recently found to be surprisingly common, affecting 1 of every 200 people in the United States.

check your understanding

1. What is the hematocrit? What is its normal value?
2. What are the three main types of plasma proteins, and what are their functions?

For answers, see Appendix B.

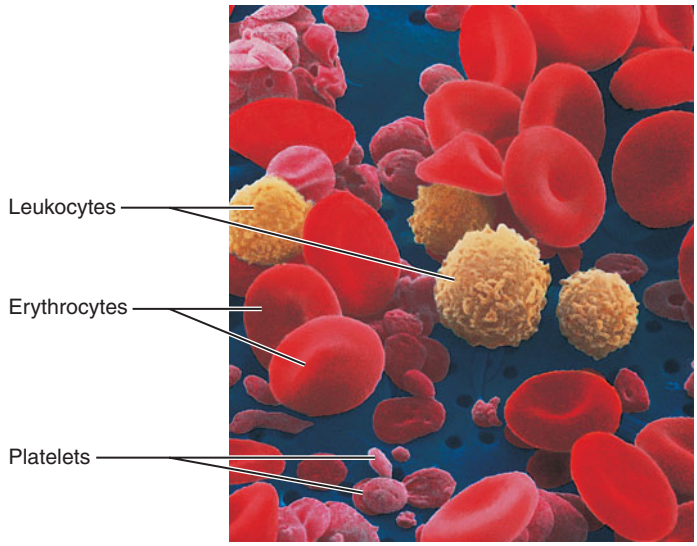
Formed Elements

- Describe the special structural features and functions of erythrocytes.
- List the five classes of leukocytes, along with the structural characteristics and functions of each.
- Describe the structure of platelets and their role in blood clotting.

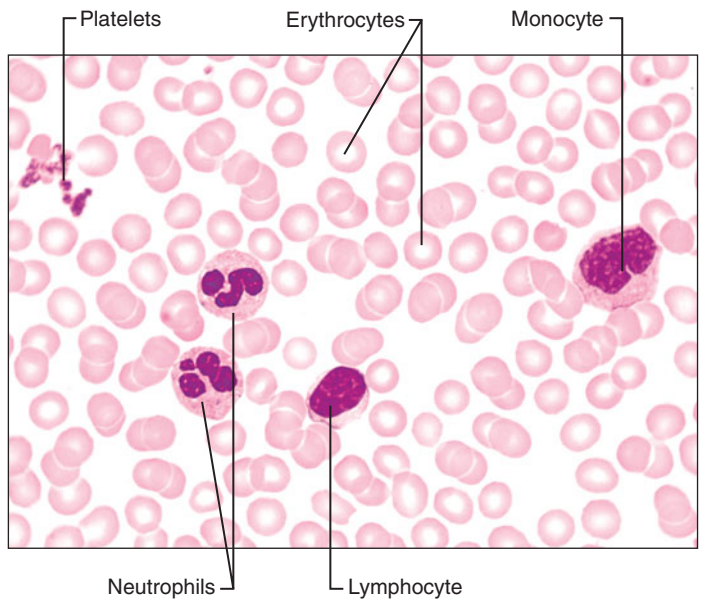
The **formed elements of blood,** or **blood cells,** have some unusual features. First, neither erythrocytes nor platelets are true cells: Erythrocytes lack nuclei and organelles, and platelets are merely cell fragments. Second, most of the formed elements cannot divide; they survive in the bloodstream for only a short time (a few hours to a few months) before being replaced by new cells produced in the bone marrow. The short-lived formed elements are broken down and their components recycled.

Examination of human blood under the microscope reveals numerous disc-shaped erythrocytes, a variety of spherical leukocytes, and a few tiny platelets, which might be mistaken for particles of debris **(Figure 18.2)**. Erythrocytes vastly outnumber the other types of formed elements. The types of blood cells are described below and summarized in **Table 18.1** on p. 544.

To view the blood cells, clinicians prepare blood smears such as that in Figure 18.2b for microscopic viewing. A technician first puts a drop of fresh blood on a clean glass slide and then, using the edge of another slide, spreads the drop into a thin film. The film is then air dried, preserved in methanol (wood alcohol), and stained. Blood smears are typically stained with Wright's stain, a mixture of an acidic dye called *eosin* (e′o-sin), which is pink, and a basic dye called *methylene* (meth′ĭ-lēn) *blue,* which yields blue and purple colors. Cellular structures stain differentially according to their chemical makeup; thus, staining is used to distinguish different cell types.



(a) SEM of blood (1660×, artificially colored)



(b) Photomicrograph of a human blood smear, Wright's stain (715×)

FIGURE 18.2 Blood cells.

Erythrocytes

Erythrocytes, or red blood cells (RBCs), are small, oxygen-transporting cells that are about 7.5 μm in diameter **(Figure 18.3)**. Erythrocytes are by far the most numerous formed element—4.3 to 5.2 million cells in a cubic millimeter of blood in women, and 5.1 to 5.8 million in men. Thus, a total of 25 trillion erythrocytes are present in the bloodstream of a healthy adult! Because normal red blood cells are relatively uniform in size (7–8 μm in diameter), they are ideal "measuring tools" for estimating the sizes of nearby structures in histological sections.

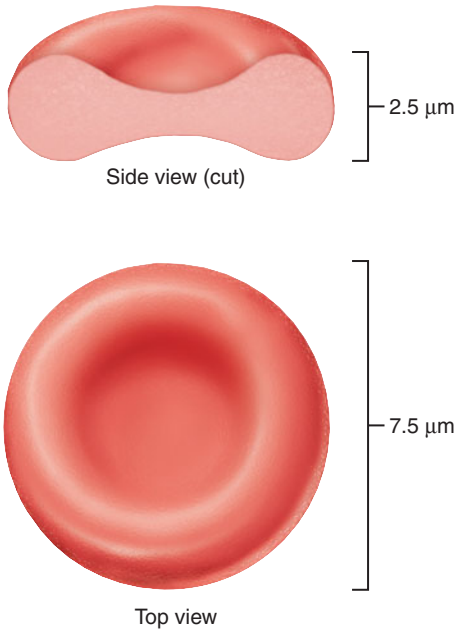


FIGURE 18.3 Structure of erythrocyes. Notice the distinctive biconcave shape.

Erythrocytes are shaped as biconcave discs—discs with depressed centers. In blood smears their thin centers appear lighter in color than their edges (Figure 18.2b). The biconcave shape of erythrocytes is maintained by a net of peripheral proteins on the inner surface of the plasma membrane. This deformable net both resists tearing forces and provides enough flexibility that erythrocytes are able to undergo moderate changes in shape—to twist or become cup-shaped in their journey through the narrow capillaries and then to resume their biconcave shape.

Erythrocytes are surrounded by a plasma membrane but have no nuclei or organelles. Their cytoplasm is packed with molecules of *hemoglobin,* an oxygen-carrying protein. Each hemoglobin molecule consists of four chains of amino acids (four polypeptides), each of which bears an iron atom that is the binding site for oxygen molecules. The oxidation of the iron atoms of hemoglobin gives blood its red color. Hemoglobin also attracts the eosin dye used in blood staining, so erythrocytes stain pink or orange-pink in blood smears.

Erythrocytes pick up oxygen at the lung capillaries and release it across other tissue capillaries throughout the body. Each of their special structural characteristics contributes to their respiratory function:

1. Their biconcave shape provides 30% more surface area than that of spherical cells of the same volume, allowing rapid diffusion of oxygen into and out of erythrocytes.
2. Discounting the water that is present in all cells, erythrocytes are over 97% hemoglobin. Without a nucleus or organelles, they are little more than bags of oxygen-carrying molecules.
3. Erythrocytes lack mitochondria and generate the energy they need by anaerobic mechanisms; therefore, they do not consume any of the oxygen they pick up and are very efficient oxygen transporters.

Along with the oxygen it carries, the hemoglobin in erythrocytes also carries 20% of the carbon dioxide that is transported by the blood. For more details of gas transport by the circulatory system, consult a physiology text.

Erythrocytes live for 100–120 days, much longer than most other types of blood cells. They originate from cells in red bone marrow, where they expel their nucleus and organelles before entering the bloodstream.

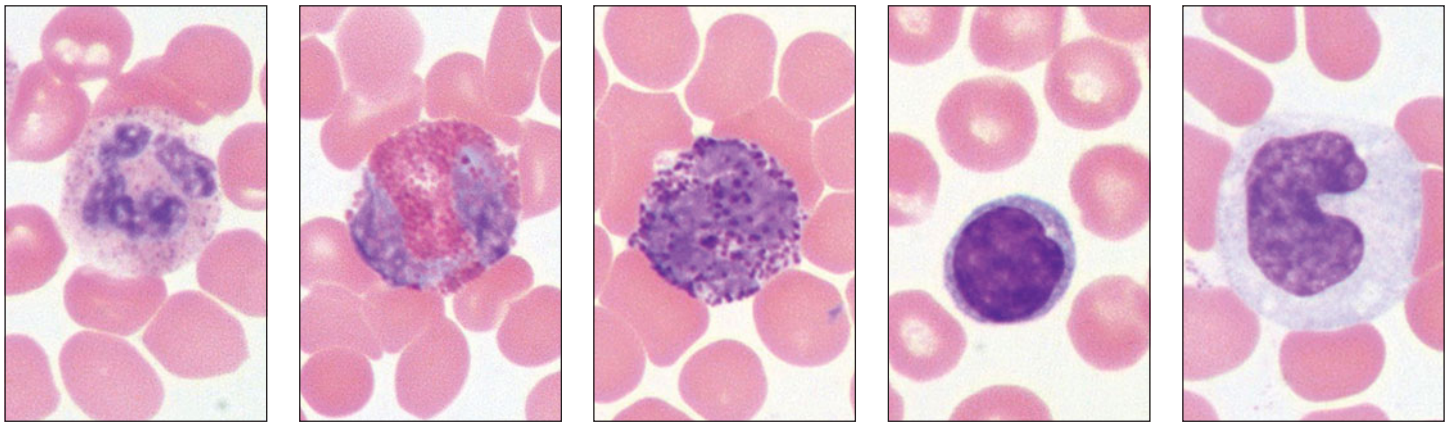
THALASSEMIA A group of inherited anemias called **thalassemia** (thal″ah-se′me-ah; "sea blood") is characterized by an insufficient production of one polypeptide chain of hemoglobin. It occurs most often in people of Mediterranean descent, such as Greeks and Italians. In the most common type, called beta-thalassemia, the erythrocytes are small, pale, and easily ruptured, so RBC counts are low. Symptoms include fatigue, enlargement of the spleen, and abnormal enlargement of the bone marrow and bones. Treatments include blood transfusions every month for life and the infusion of substances that absorb the excessive iron released from ruptured erythrocytes.

Leukocytes

Leukocytes, or white blood cells (WBCs), are far less numerous than erythrocytes—4800 to 11,000 leukocytes per cubic millimeter of blood—but they are crucial to the body's defense against disease. Roughly spherical in shape, leukocytes are the only formed elements that are complete cells, with the usual organelles and prominent nuclei (Figure 18.2a).

Leukocytes in effect constitute a mobile army that continuously protects the body from infectious microorganisms such as bacteria, viruses, and parasites. Unlike erythrocytes, which are confined to and perform their functions within blood vessels, leukocytes function outside the bloodstream in the loose connective tissues, where infections occur. Various chemicals produced or released at infection sites attract circulating leukocytes. In response, leukocytes leave the capillaries by actively squeezing between the endothelial cells that form the capillary walls, a process called **diapedesis** (di″ah-pĕ-de′sis; "leaping through"). Once outside the capillaries, leukocytes travel to the infection sites by amoeboid motion—that is, by forming flowing cytoplasmic extensions that move them along.

Like other blood cells, leukocytes originate in the bone marrow and are released continuously into the blood. The bone marrow also stores leukocytes and releases them into the blood in large quantities during serious infections. Clinicians count the leukocytes in a sample of a patient's blood when searching for evidence of an infectious disease. A leukocyte count exceeding 11,000 per cubic millimeter indicates infection or inflammation. The patient is said to have **leukocytosis.**



(a) Neutrophil; multilobed nucleus

(b) Eosinophil; bilobed nucleus, red cytoplasmic granules

(c) Basophil; bilobed nucleus, purplish black cytoplasmic granules

(d) Small lymphocyte; large spherical nucleus

(e) Monocyte; kidney-shaped nucleus

FIGURE 18.4 Leukocytes. In each case, the leukocytes are surrounded by erythrocytes. (All 1700×, Wright's stain.) (See *A Brief Atlas of the Human Body,* Second Edition, Plates 23–27.)

There are five types of leukocytes, divided into two groups based on the presence or absence of membrane-bound cytoplasmic granules. **Granulocytes** (*neutrophils, eosinophils,* and *basophils*) contain many obvious granules **(Figure 18.4a–c)**. Granulocytes are larger and much shorter lived than erythrocytes. In addition to their distinctive cytoplasmic granules, they have nonspherical nuclei with purple-staining lobes (rounded masses) joined by bandlike constrictions. Functionally, all granulocytes are phagocytic; that is, they engulf and digest foreign cells or molecules. **Agranulocytes** (lymphocytes and monocytes) lack obvious granules (Figure 18.4d and e). Although the two agranulocytes resemble each other structurally, they are distinct and unrelated cell lines.

This classification scheme is visually convenient but artificial. Modern developmental evidence indicates that all five types of leukocytes arise from largely independent cell lines (discussed on pp. 547–549). The relative percentages of the five types of leukocytes in the blood of an average, healthy person are shown in **Figure 18.5**. A simple mnemonic can help you remember the relative abundance of leukocytes, from the most abundant to the least abundant type: "**N**ever **L**et **M**onkeys **E**at **B**ananas" (neutrophils, lymphocytes, monocytes, eosinophils, basophils).

Neutrophils Bacteria-destroying **neutrophils** (nu′trofĭlz) are the most abundant class of leukocyte, constituting about 60% of all white blood cells in healthy people. Their nucleus consists of two to six lobes interconnected by very thin threads of chromatin (Figure 18.4a).

Neutrophils contain two kinds of cytoplasmic granules, both of which are so small that they can barely be seen with the light microscope. The more abundant granules stain a light pink; the other granules stain reddish purple. The name *neutrophil,* which means "neutral-loving," indicates that the cytoplasm takes up the red (acidic) and blue (basic) stains about equally, giving the cytoplasm a light purple color.

Neutrophils function to consume and destroy bacteria. Both types of granules in neutrophils are membrane-walled sacs of digestive enzymes that resemble lysosomes but contain greater quantities of the enzymes that specifically destroy the cell walls of bacteria. Attracted by bacterial products, these granulocytes quickly migrate to sites of infection, where they constitute the first line of defense in an inflammatory response (described on p. 93). Neutrophils destroy bacteria by phagocytosis and also by releasing bacteria-destroying substances into the surrounding extracellular matrix of the infected tissue. If the inflammation is severe or prolonged, these neutrophil secretions can cause serious tissue damage. **Pus,** which forms in areas of bacterial infection, is composed

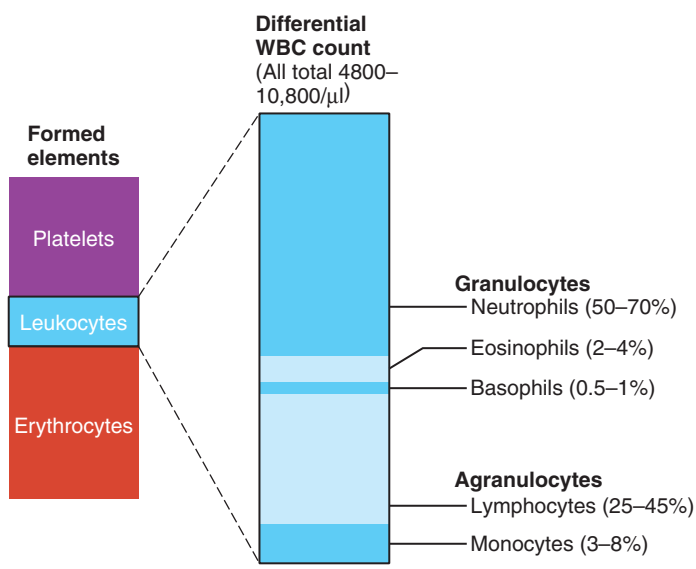
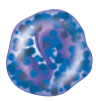
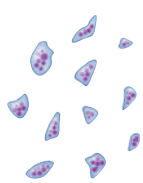


FIGURE 18.5 Relative percentages of the different types of leukocytes. These values are ranges for healthy individuals.

TABLE 18.1 Summary of Formed Elements of the Blood

Cell Type	Illustration	Description*	Number of Cell per mm^3 (μl) of Blood	Duration of Development (D) and Life Span (LS)	Function
ERYTHROCYTES (red blood cells; RBCs)		Biconcave, anucleate disc; salmon-colored; diameter 7–8 μm	4–6 million	D: 5–9 days LS: 100–120 days	Transport oxygen and carbon dioxide
LEUKOCYTES (white blood cells, WBCs)		Spherical, nucleated cells	4800–11,000		
Granulocytes		Nucleus multilobed; inconspicuous cytoplasmic granules; diameter 12–14 μm	3000–7000	D: 7–11 days LS: 6 hours to a few days	Destroy bacteria by phagocytosis
• Neutrophils					
• Eosinophils		Nucleus bilobed; red cytoplasmic granules; diameter 12–15 μm	100–400	D: 7–11 days LS: about 5 days	Turn off allergic responses and kill parasites
• Basophils		Nucleus bilobed; large blue-purple cytoplasmic granules; diameter 10–14 μm	20–50	D: 3–7 days LS: a few hours to a few days	Release histamine and other mediators of inflammation
Agranulocytes		Nucleus spherical or indented; pale blue cytoplasm; diameter 5–17 μm	1500–3000	D: days to weeks LS: hours to years	Mount immune response by direct cell attack (T cells) or via antibodies (B cells)
• Lymphocytes					
• Monocytes		Nucleus U- or kidney-shaped; gray-blue cytoplasm; diameter 14–24 μm	100–700	D: 2–3 days LS: months	Phagocytosis; develop into macrophages in tissues
PLATELETS		Discoid cytoplasmic fragments containing granules; stain deep purple; diameter 2–4 μm	150,000–500,000	D: 4–5 days LS: 5–10 days	Seal small tears in blood vessels; instrumental in blood clotting

*Appearance when stained with Wright's stain.

of dead neutrophils and other leukocytes, plus tissue debris and dead bacteria.

Eosinophils The relatively rare **eosinophils** (e″o-sin′o-filz) account for 1% to 4% of all leukocytes. Their nucleus usually has two lobes interconnected by a broad band and thus somewhat resembles an older cradle-style telephone receiver (Figure 18.4b). The granules in the cytoplasm are large and stain red with the acidic dye eosin (*eosinophil* = eosin-loving). These granules contain a variety of digestive enzymes that function during allergic reactions and parasitic infections.

Eosinophils play a role in ending allergic reactions by phagocytizing allergens (substances that induce allergy) after the allergens are bound to antibodies. The eosinophils then secrete substances that degrade histamine and other chemical mediators of inflammation that are released in the allergic reaction.

In response to a parasitic infection, eosinophils attach to parasites, and their granules release enzymes that digest and destroy the invaders. Fighting parasites is the most important function of eosinophils, and these cells gather in the wall of the digestive tube, where parasites are most likely to be encountered.

Basophils The rarest white blood cells are **basophils** (ba′so-filz) (Figure 18.4c), which on average account for only 0.5% of all leukocytes, or 1 in 200. The nucleus usually has two lobes and may be bent into the shape of a U or an S. The cytoplasm contains large granules that stain dark purple with basic dyes (*basophil* = base-loving). These granules contain histamine and other molecules that are secreted to mediate inflammation during allergic responses and parasitic infections (Table 18.1). Basophils are weakly phagocytic, but what they phagocytize is not known.

The inflammation-mediating function of basophils is almost identical to that of *mast cells,* granulated cells in connective tissue that also secrete histamine. However, mast cells direct the early stages of inflammation in allergies and parasitic infections, whereas basophils direct the later stages. Despite the functional similarities between these cells, they develop from distinct lines of immature cells in the bone marrow and thus are different cell types.

Lymphocytes The most important cells of the immune system are **lymphocytes** (lim′fo-sīts) (Figure 18.4d). Relatively common, they represent 20% to 45% of all leukocytes in the blood. The nucleus of a typical lymphocyte occupies most of the cell volume, is filled with condensed chromatin (which stains dark purple), is usually spherical (but may be slightly indented), and is surrounded by a thin rim of pale blue cytoplasm. Lymphocytes are often classified according to size as small (5–8 μm), medium (10–12 μm), or large (14–17 μm). Most lymphocytes in the blood are small. Like other leukocytes, they function not in the bloodstream, but instead in the connective tissues. In fact, most lymphocytes are firmly enmeshed in *lymphoid connective tissues,* where they play a crucial role in immunity.

Lymphocytes are effective in fighting infectious organisms because each lymphocyte recognizes and acts against a *specific* foreign molecule. Any such molecule that induces a response from a lymphocyte is called an **antigen** (an′tĭ-jen; "induce against"). The two main classes of lymphocytes—**T cells** and **B cells**—attack antigens in different ways. T cells attack foreign cells directly and B cells differentiate and produce **antibodies,** proteins that bind to the antigen and thus mark the foreign cell for destruction by macrophages. A full discussion of lymphocyte activity and the immune response is found in Chapter 21.

Monocytes The largest leukocytes are **monocytes** (mon′o-sīts) (see Figure 18.4e), which make up 4% to 8% of white blood cells. In blood smears, they resemble large lymphocytes in that both cell types have a blue cytoplasm and a purple nucleus. However, the nucleus of a monocyte is often bent into a distinctive kidney or horseshoe, and the nuclear chromatin is not as condensed (dark) as that in lymphocytes. Also, monocytes contain a larger proportion of cytoplasm than lymphocytes do. The cytoplasm of monocytes can contain some tiny granules (typical lysosomes), but they are so small and sparse that monocytes are not considered granulocytes.

Monocytes, like all leukocytes, use the bloodstream to reach the connective tissues. There, they transform into **macrophages,** phagocytic cells that move by amoeboid motion through connective tissue and ingest a wide variety of foreign cells, molecules, and tiny particles of debris (illustrated in Figure 4.9, p. 78).

COMPLETE BLOOD COUNT A common clinical procedure called a **complete blood count (CBC)** quantifies the various blood cells and measures some basic aspects of blood chemistry, providing a preliminary assessment of a patient's health. Blood is drawn, and the following quantities are measured in the blood sample: the hematocrit, the hemoglobin content, and the overall concentrations of erythrocytes, leukocytes, and platelets (number per cubic millimeter). A **CBC with differential (CBC with diff)** includes examination of living white and red cells under a microscope for structural abnormalities. For this test, a blood smear is prepared, and the technician identifies and determines the percentage and absolute concentration of each class of leukocytes. The whole process is becoming increasingly automated; sophisticated image-analysis machines can now recognize and count most individual types of leukocytes.

A CBC with diff provides important clinical information. Low hematocrit and erythrocyte levels may indicate that a patient is anemic (the blood has a diminished oxygen-carrying capacity; see p. 549). High numbers of neutrophils may suggest the presence of a major bacterial infection in the body; high numbers of eosinophils may indicate infection by parasitic worms or an allergy to ragweed during hay fever season.

Platelets

Platelets, also called *thrombocytes* (throm′bo-sīts; "clotting cells"), are not cells in the strict sense. They are disc-shaped, plasma membrane–enclosed fragments of cytoplasm that form by breaking off of larger cells called megakaryocytes. In blood smears, each platelet exhibits a blue-staining outer region and an inner region that contains purple-staining secretory granules (Figure 18.2, Table 18.1). Platelets are only one-tenth to one-twentieth as abundant as erythrocytes.

Platelets plug small tears in the walls of blood vessels to limit bleeding. Immediately after a vessel is damaged, platelets adhere in large numbers to exposed collagen at the edges of the tear and then secrete several types of products. Some products from their secretory granules signal more platelets to arrive, others cause the vessel to constrict so that bleeding slows, and still others initiate inflammation at the injury site. In addition, platelets release a molecule (thromboplastin, or PF_3) that helps initiate **clotting,** a sequence of chemical reactions in blood plasma that ultimately generates a network of tough fibrin strands among the accumulated platelets. This fibrin derives from the plasma protein fibrinogen. The mass consisting of the fibrin strands, the platelets,

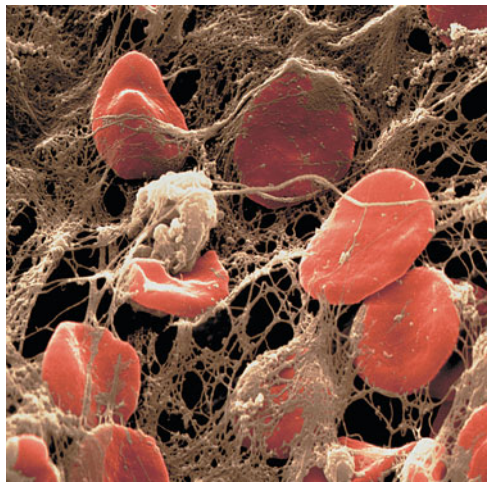


FIGURE 18.6 Blood clot. Scanning electron micrograph of a blood clot: a platelet (the light, spherical object in the center) and several erythrocytes trapped in a fibrin mesh (artificially colored; 2200×).

and any blood cells that are trapped by the strands is called a **clot** (Figure 18.6), which provides a strong seal across the tear. After the clot forms, the platelets within it contract in a muscle-like way, pulling the edges of the tear together.

Platelets do not adhere to the interior of healthy vessels. However, if the lining of an intact vessel is roughened by scarring, inflammation, or atherosclerosis (p. 610), platelets will adhere and initiate undesirable clotting within that vessel.

THROMBUS A clot that develops and persists in an intact blood vessel is called a **thrombus.** If a thrombus becomes large enough, it can block the flow of blood and cause the death of the tissues supplied by the affected vessels. If such a blockage occurs in the coronary arteries that supply the heart, the consequence may be the death of heart muscle and a fatal heart attack. If a thrombus or a piece of a thrombus breaks off of a vessel wall and floats freely in the bloodstream, it is considered an **embolus** ("wedge"; plural: **emboli**). An embolus becomes dangerous when it obstructs a vessel that is too narrow to permit its passage. For example, an embolus in the brain can cause a stroke by blocking the blood supply to oxygen-sensitive brain cells. (For more information on emboli, see the Related Clinical Terms on p. 552.)

check your understanding

3. Which of the formed elements (blood cells) do not contain nuclei?
4. Distinguish between the following terms: leukocyte and lymphocyte.
5. What are the two components of Wright's stain, and how does it differentially stain granulocytes?

For answers, see Appendix B.

BLOOD CELL FORMATION

- Distinguish red bone marrow from yellow bone marrow.
- Describe the basic histologic structure of red bone marrow.
- Define hematopoiesis and blood stem cell.
- Explain the differentiation of the various types of blood cells.

The process by which blood cells are formed, called **hematopoiesis** (hem″ah-to-poi-e′sis) or **hemopoiesis** (*hemo, hemato* = blood; *poiesis* = to make), begins in the early embryo and continues throughout life. After birth, all blood cells originate in the bone marrow, at the rate of 100 billion new cells a day! The various types of blood cells differentiate from a single cell type.

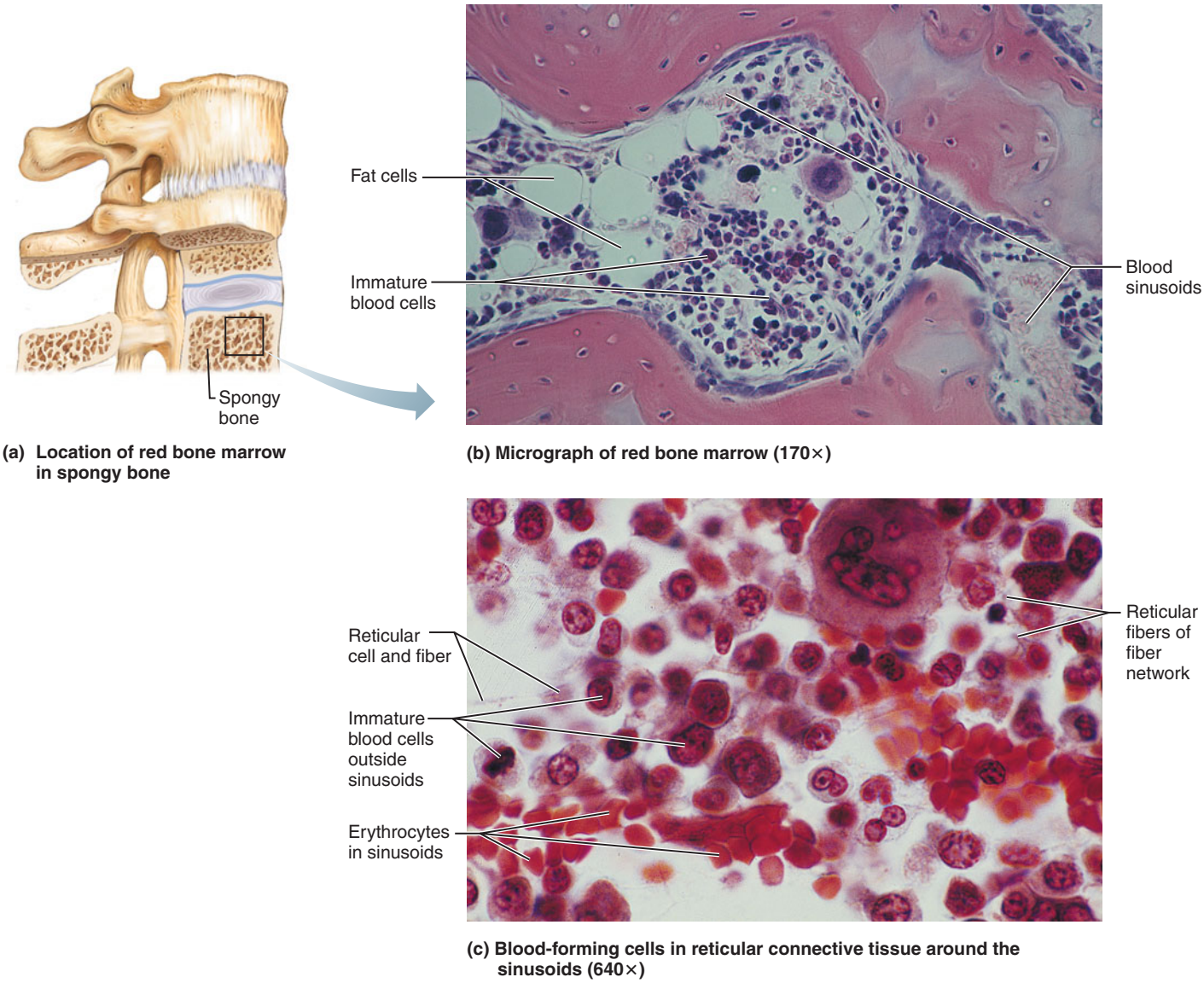
Bone Marrow as the Site of Hematopoiesis

Bone marrow occupies the interior of all the bones. If all of the bone marrow in the skeleton were combined, it would form the largest organ in the human body except for the skin.

There are two types of bone marrow, red and yellow. Only **red marrow** actively generates blood cells. In fact, its red hue derives from the immature erythrocytes it contains. **Yellow marrow** is dormant; it makes blood cells only in emergencies that demand increased hematopoiesis. The color of yellow marrow reflects the many fat cells it contains. At birth, all marrow in the skeleton is red. In adults, red marrow remains between the trabeculae of spongy bone throughout the axial skeleton and girdles and in the proximal epiphysis of each humerus and femur; yellow marrow occupies all other regions of the long bones of the limbs. The replacement of red marrow with yellow marrow in the limbs occurs between the ages of 8 and 18 years.

The microscopic structure of bone marrow is shown in Figure 18.7. The basic tissue framework is a reticular connective tissue (p. 83) in which reticular fibers form a complex network, much like a branching series of caves. The fibroblasts that cover and secrete this fiber network are called *reticular cells.* Within the fiber network (in the "caves") are both fat cells and the forming blood cells in all stages of maturation. Finally, running throughout the reticular tissue are many wide capillaries called *blood sinusoids.* As the forming blood cells reach maturity, they continuously enter the bloodstream by migrating into the nearby sinusoids through the endothelial cells that form the walls of these vessels.

The reticular tissue of the bone marrow also contains macrophages that extend pseudopods into the sinusoids to



(a) **Location of red bone marrow in spongy bone**

(b) **Micrograph of red bone marrow (170×)**

(c) **Blood-forming cells in reticular connective tissue around the sinusoids (640×)**

FIGURE 18.7 Red bone marrow.

capture antigens in the blood. Such a "blood-cleaning" function is also performed by macrophages in the spleen and liver.

Recently, it was found that some of the cells on the reticular-fiber network of the red bone marrow of adults are mesenchymal stem cells. That is, these cells can give rise to fat cells, osteoblasts, chondrocytes, fibroblasts, and muscle cells. This raises the exciting possibility that such cells can be extracted and used to regenerate all types of connective tissue and muscle for tissue and organ replacement.

Cell Lines in Blood Cell Formation

As mentioned above, immature blood cells divide and differentiate within the cavelike spaces of the reticular connective tissue in bone marrow, producing the various lines of blood cells. The formation of blood cells occurs in stages (Figure 18.8).

All blood cells arise from one cell type, the **blood stem cell.** In response to growth signals from the nearby reticular cells, they divide continuously, both to renew themselves and to produce lines of *progenitor cells* that lead to the various blood cells. The two types of progenitor cells that arise directly from blood stem cells are **lymphoid stem cells,** which give rise to lymphocytes, and **myeloid** (mi′ĕ-loid) **stem cells,** which give rise to all other blood cells. As myeloid stem cells divide, they progressively lose the ability to become certain cell types until they are *committed cells,* meaning that each can become just one type of blood cell. After a cell line reaches the committed stage, structural differentiation occurs (Figure 18.8) as the cells experience several final rounds of division. The structural changes that occur in each blood cell line are discussed next, beginning with the line that generates erythrocytes.

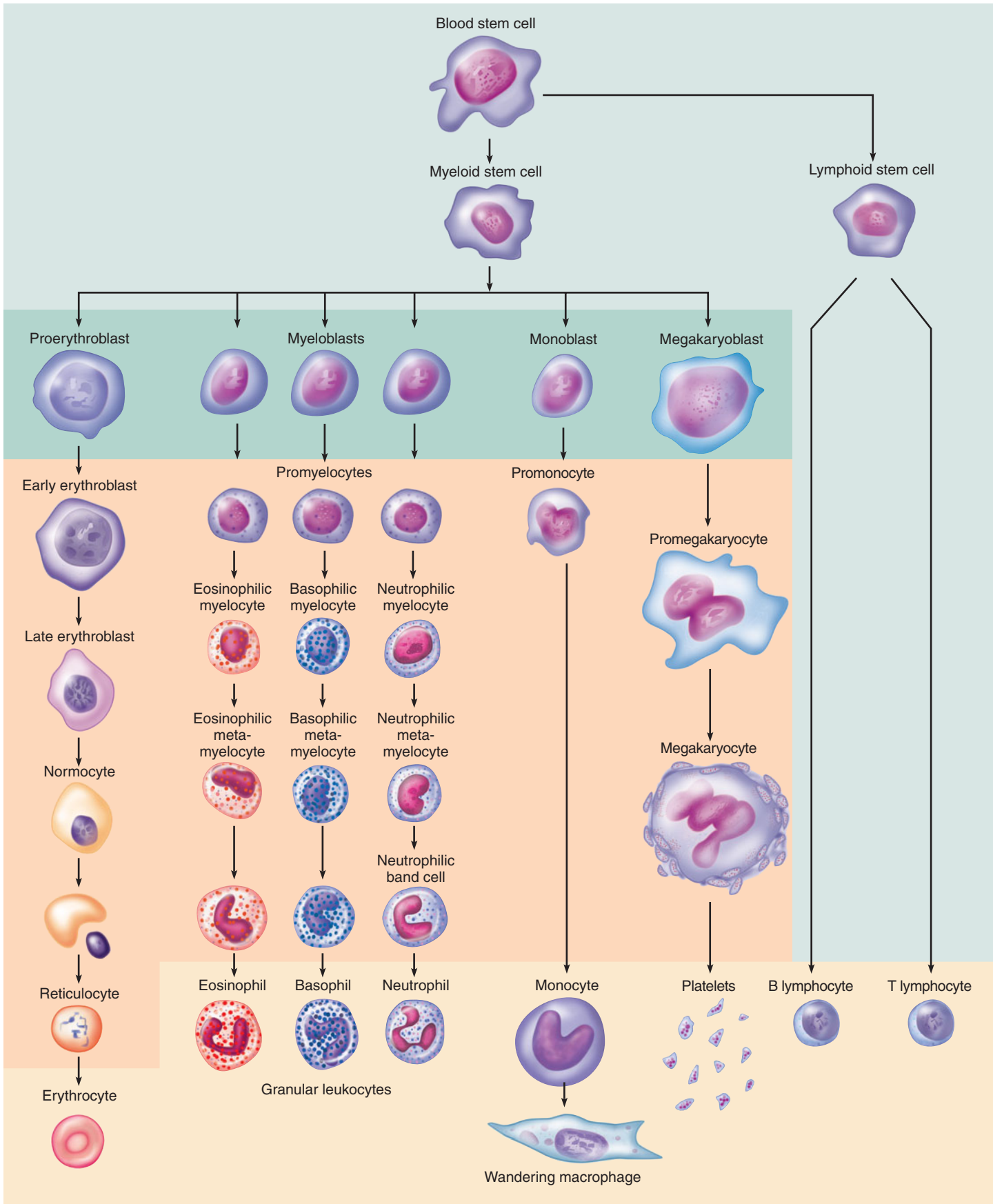


FIGURE 18.8 Stages of differentiation of blood cells in the bone marrow. The blast cells within the dark green region are committed cells—each of which can generate only one type of blood cell. The durations of these developmental sequences are listed in Table 18.1. The myeloid stem cells also give rise to mast cells, osteoclasts, and antigen-presenting cells (not illustrated).

Genesis of Erythrocytes

In the line that forms erythrocytes, the committed cells are **proerythroblasts** (pro″ĕ-rith′ro-blasts; "earliest red-formers"), which avidly accumulate iron for future production of hemoglobin. Proerythroblasts give rise to **early erythroblasts,** which act as ribosome-producing factories. Hemoglobin is made on these ribosomes and accumulates during the next two stages: the **late erythroblast** and the **normocyte.** The staining properties of the cytoplasm change during these stages, as blue-staining ribosomes become masked by pink-staining hemoglobin. When the normocyte stage is reached, cell division stops. When the cytoplasm of the normocyte is almost filled with hemoglobin, the nucleus stops directing the cell's activities and shrinks. Then, the nucleus and almost all organelles are ejected, and the cell collapses and assumes its biconcave shape. The cell is now a **reticulocyte,** a young erythrocyte that contains a network of blue-staining material (*reticulum* = network) representing clumps of ribosomes that remain after the other organelles are extruded. Reticulocytes enter the bloodstream and begin their task of transporting oxygen. Erythrocytes remain in the reticulocyte stage for their first day or two in the circulation, after which their ribosomes are degraded by intracellular enzymes and lost.

Formation of Leukocytes and Platelets

The committed cells in each *granulocyte* line are called **myeloblasts** (mi′ĕ-lo-blasts). They accumulate lysosomes and become **promyelocytes** (pro-mi′ĕ-lo-sīts″). The distinctive granules of each granulocyte appear next, in the **myelocyte** stage. When this stage is reached, cell division ceases. In the ensuing **metamyelocyte** stage, the nucleus stops functioning and bends into a thick "horseshoe." Neutrophils with such horseshoe nuclei are called **band cells.** The granulocytes then complete their differentiation and enter the bloodstream.

Not much structural differentiation occurs in the cell lines leading to monocytes and lymphocytes, as these cells look much like the stem cells from which they arise (Figure 18.8). In the line leading to monocytes, committed **monoblasts** enlarge and obtain more lysosomes as they become **promonocytes** and then monocytes. In the line leading to lymphocytes, the chromatin in the nucleus condenses and the amount of cytoplasm declines.

Other cells in the bone marrow become platelet-forming cells (Figure 18.8). In this line, immature **megakaryoblasts** (meg″ah-kar′e-o-blasts) undergo repeated mitoses; however, no cytoplasmic division occurs, and their nuclei never completely separate after mitosis. The result is a giant cell called a **megakaryocyte** (meg″ah-kar′e-o-sīt; "big nucleus cell") that has a large, multilobed nucleus containing many times the normal number of chromosomes. From their sites within the reticular connective tissue of red bone marrow just outside the blood sinusoids (Figure 18.7c), megakaryocytes send cytoplasmic extensions through the walls of the sinusoids and into the bloodstream. These extensions then break apart into platelets like postage stamps torn from a perforated sheet.

ABNORMAL NUMBERS OF IMMATURE BLOOD CELLS Reticulocytes (immature erythrocytes) make up 1% to 2% of all circulating erythrocytes in most healthy people. Percentages of reticulocytes outside this range indicate that a person is producing erythrocytes at an accelerated or decreased rate. Reticulocyte numbers greater than 2% might indicate that the person is adapting to life at high altitudes (where low oxygen levels stimulate erythrocyte production), whereas numbers less than 1% might indicate a degenerative disease of the bone marrow. To detect disorders of erythrocyte production, clinicians routinely obtain a **reticuloctye count** in blood workups.

Band cells (immature neutrophils) normally make up 1% to 2% of the neutrophils in the blood. This percentage increases dramatically during acute bacterial infections, when the bone marrow releases more immature neutrophils. Thus, detection of **elevated numbers of band cells** in differential WBC counts is considered an indicator of infection.

check your understanding

6. Which bones contain blood stem cells in adults?
7. What type of tissue forms the fibrous network within red bone marrow?
8. Which leukocytes do not form from myeloid stem cells?

For answers, see Appendix B.

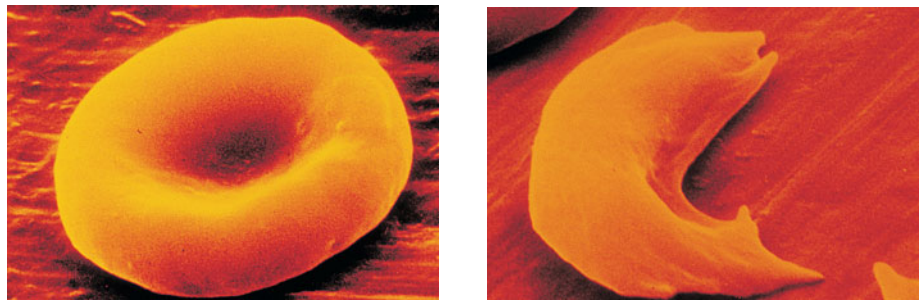
DISORDERS OF THE BLOOD

➤ Consider some common disorders of erythrocytes, leukocytes, and platelets.

Disorders of Erythrocytes

Polycythemia (pol″e-si-the′me-ah; "many blood cells") is an abnormal excess of erythrocytes in the blood. One variety, *polycythemia vera,* results from a cancer of the bone marrow that generates too many erythrocytes. Severe polycythemia causes an increase in the viscosity of the blood, which slows or blocks the flow of blood through the smallest vessels. It is treated by dilution—by removing some blood and replacing it with sterile physiological saline.

Anemia (ah-ne′me-ah; "lacking blood") is any condition in which erythrocyte levels or hemoglobin concentrations are low, such that the blood's capacity for carrying oxygen is diminished. Anemia can be caused by blood loss, iron deficiency, destruction of erythrocytes at a rate that exceeds their replacement, vitamin B_{12} or folic acid deficiency, or a genetic defect of hemoglobin. Anemic individuals are constantly tired and often pale, short of breath, and chilly because their tissues are receiving low amounts of oxygen.



(a) Normal erythrocyte (b) Sickled erythrocyte

FIGURE 18.9 Comparison of a normal erythrocyte with a sickled erythrocyte.
(Scanning electron micrographs, artificially colored, 4285×.)

Sickle cell disease, formerly called sickle cell anemia, is a common inherited condition exhibited primarily in people of central African descent; this disease occurs in approximately 1 of every 400 African Americans. Sickle cell disease results from a defect in the hemoglobin molecule that causes the abnormal hemoglobin to crystallize when the concentration of oxygen in the blood is low or the erythrocytes become dehydrated, as during exercise or anxiety. This causes the circulating erythrocytes to distort into the shape of a crescent, thus the name "sickle cell" **(Figure 18.9)**. These deformed erythrocytes are rigid, fragile, and easily destroyed. Because they do not pass through capillaries easily, the sickled erythrocytes block these vessels, causing painful attacks of ischemia. Sickle cell patients experience severe bone and chest pain, infections, and strokes. The disease used to be inevitably fatal during childhood, but current treatments allow many patients to survive into adulthood. A new drug, hydroxyurea, greatly reduces the frequency of attacks and eases the symptoms by increasing the proportion of erythrocytes that contain a normal, fetal form of hemoglobin, which prevents these cells from sickling. Other treatments include drugs that keep the erythrocytes hydrated and repeated blood transfusions. Bone marrow transplants offer a complete cure but their risks—a 10% death rate and a 20% rejection rate—are too great for them to be performed routinely.

Disorders of Leukocytes

Leukemia is a form of cancer resulting from the uncontrolled proliferation of a leukocyte-forming cell line in the bone marrow. Leukemias are classified according to (1) the cell line involved, as either *lymphoblastic* (from immature lymphocytes) or *myeloblastic* (from immature cells of the myeloid line) (see Figure 18.8); and (2) the rate of progression, as either *acute* (rapidly advancing) or *chronic* (slowly advancing). In all forms of leukemia, immature and cancerous leukocytes flood into the bloodstream. More significantly, however, the cancer cells take over the bone marrow, crowding out the normal blood cell lines and slowing the production of normal blood cells. Therefore, patients in late stages of leukemia suffer from anemia and devastating infections and from internal hemorrhaging due to clotting defects. Infections and hemorrhaging are the usual causes of death in people who succumb to leukemia. For information concerning new treatments for leukemia, see **A Closer Look**.

Disorders of Platelets

Thrombocytopenia (throm″bo-si″to-pe′ne-ah; "lack of platelets") is an abnormally low concentration of platelets in the blood. Characterized by diminished clot formation and by internal bleeding from small vessels, thrombocytopenia may result from damage to the bone marrow, chemotherapy, vitamin B_{12} deficiency, leukemia, autoimmune destruction of the platelets, or overactivity of the spleen (an organ that functions to remove and destroy platelets as well as other blood cells).

THE BLOOD THROUGHOUT LIFE

- Describe the embryonic origin of blood cells.
- List four different organs that form blood cells in the fetus.
- Name some blood disorders that become more common as the body ages.

The first blood cells develop with the earliest blood vessels in the mesoderm around the yolk sac of the 3-week-old embryo. After mesenchymal cells cluster into groups called *blood islands,* the outer cells in these clusters flatten and become the endothelial cells that form the walls of the earliest vessels; the inner cells become the earliest blood cells. Soon vessels form within the embryo itself, providing a route for blood cells to travel throughout the body.

Throughout the first 2 months of development, all blood cells form in the blood islands of the yolk sac, with some contribution from the floor of the aorta. These sources form not only the blood stem cells that will last a lifetime but also the primitive nucleated erythrocytes that carry oxygen in the embryo. Late in the second month, circulating stem cells from the yolk sac become established in the liver and spleen, which take over the blood-forming function and are the major hematopoietic organs until month 7. These stem cells in the liver and spleen produce the first leukocytes and the first platelet-forming cells, plus nucleated and non-nucleated erythrocytes. The bone marrow receives stem cells and begins

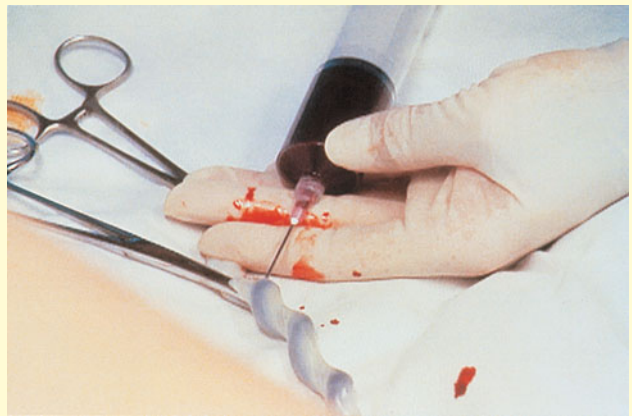
a closer look

Transplants of Bone Marrow and Cord Blood

Typically, treatment for leukemia patients involves transplanting healthy blood stem cells so that these patients can produce normal blood cells. First, however, the patient must undergo chemotherapy or radiation to kill both the cancer cells and blood-forming cells and to destroy the patient's immune system (to reduce the chances of transplant rejection).

In the most common procedure—a **bone marrow transplant**—marrow cells are aspirated from the iliac crest or sternum of a donor and transferred into the bloodstream of the recipient, where they circulate to and repopulate the recipient's marrow. An autologous transplant, in which the patient's own marrow is harvested while the leukemia is in remission, is the least risky approach, especially for older patients. However, in most transplant procedures bone marrow obtained from another person (an allogeneic transplant) must be used.

Allogeneic marrow transplants offer a hope of survival, but they have drawbacks. Perhaps paramount is the difficulty of finding a compatible donor to prevent rejection. Marrow transplants have the smallest margin of error in this respect: Not only can any of the recipient's surviving T cells attack the donor cells, but T cells in the donated marrow can attack the recipient's tissues—a reaction called **graft-versus-host disease.** Potential transplant recipients seeking donors have a 25% chance of finding a suitable match in a parent or sibling, and an even smaller chance among unrelated donors. Patients forced to wait for suitable donors often deteriorate in the meantime, and even those who receive a compatible transplant must take immunosuppressive drugs for life to lessen the risk of rejection. Furthermore, graft-versus-host disease afflicts more than half of all recipients and kills up to a third shortly after the procedure. The overall cure rate for leukemia patients who receive marrow from an unrelated donor is less than 25%.



A clinician uses a syringe to extract blood from an umbilical cord (the twisted gray structure at lower center).

A newer source of blood stem cells for transplants is blood from the placenta, a pancake-shaped organ through which the fetus obtains oxygen and nutrients from the mother. The placenta contains stem cells until the very end of pregnancy, and a few tablespoons of placental blood are easily obtainable from the umbilical cord shortly after birth (see photo). Properly stored in liquid nitrogen, stem cells last indefinitely and are alive when thawed. So-called **cord-blood (**or **placental-blood) transplants,** first performed in 1988, may soon render marrow transplants obsolete, for the following reasons:

- *Ready availability.* Obtaining cord blood only requires permission from the newborn's parents to harvest blood from a source that is otherwise disposed of as medical waste.
- *Safety.* Cord blood is less likely than adult donor marrow to contain microbes that could infect the recipient.
- *Long shelf life.* Unlike marrow, which must be obtained from the donor immediately before transplantation, cord blood can be stored indefinitely in one of many cord-blood banks worldwide.
- *Reduced risk of rejection.* Because the T cells in cord blood are immature, they are less likely to trigger graft-versus-host disease. Studies document that cord-blood recipients experience lower rates of rejection, regardless of whether they are related to their donors. As a result, the tissue match between donor and recipient need not be so close, which increases the pool of potential donors.

Medical researchers are currently developing new strategies for increasing the success rates of both bone marrow and cord-blood transplants. One approach is to stimulate stem cells in cord blood to multiply before being transplanted, and another is to remove all T cells from donor tissue before the procedure. Ultimately, researchers hope to grow large quantities of nonantigenic blood stem cells in the laboratory for subsequent transplantation.

low-level hematopoiesis during month 3. Bone marrow becomes the major hematopoietic organ in month 7 of development and is the only hematopoietic organ postnatally. Should a severe need for blood cell production arise, however, the liver and spleen may resume their blood-cell-forming roles, even in adults.

The most common diseases of the blood that appear with aging are chronic leukemias, anemias, and clotting disorders. However, these and most other age-related blood disorders are usually precipitated by disorders of the heart, blood vessels, or immune system. For example, the increased incidence of leukemias in old age is believed to result from the waning ability of the immune system to destroy cancer cells, and the formation of abnormal thrombi and emboli reflects the progression of atherosclerosis, which roughens the linings of arterial walls.

check your understanding

9. List the symptoms of anemia. What component of blood is affected by this disorder?
10. What are the major hematopoietic organs in the fetus before month 7?
11. Why do cord-blood transplant recipients experience lower rates of tissue rejection?

For answers, see Appendix B.

RELATED CLINICAL TERMS

BONE MARROW BIOPSY Procedure for obtaining a sample of bone marrow, usually using a needle to aspirate marrow from the sternum or the iliac bone. The marrow is examined to diagnose disorders of blood cell formation, leukemia, infections, and types of anemia resulting from damage to, or failure of, the marrow.

EMBOLUS Any abnormal mass carried freely in the bloodstream; may be a blood clot, air bubbles, fat masses, clumps of cells, or pieces of tissue. Blood clots are the most common kind of emboli, but *fat emboli,* which enter the blood from the bone marrow following a bone fracture, are also common. *Bacterial emboli* (clusters of bacteria) can occur during blood poisoning. Air bubbles can enter the bloodstream when a central intravenous line is accidentally disconnected, producing an air embolism.

HEMOPHILIA An inherited disease caused by the lack of, or a reduced amount of, a clotting factor, resulting in blood that does not clot normally. People with hemophilia bleed longer and thus can suffer from excessive blood loss when injured. Replacement clotting factor may be administered intravenously following an injury or as a preventive treatment.

HEMORRHAGE (hem′ŏ-rij; "blood bursting forth") Any abnormal discharge of blood out of a vessel; bleeding.

CHAPTER SUMMARY

1. The circulatory system is subdivided into the cardiovascular system (heart, blood vessels, and blood) and the lymphatic system (lymphatic vessels and lymph).
2. Blood carries respiratory gases and nutrients to body tissues and picks up waste products from body tissues. Blood also transports hormones and defense cells to target tissues and regulates body temperature.

Composition of Blood (pp. 540–546)

3. Blood consists of plasma and formed elements (erythrocytes, leukocytes, and platelets). Erythrocytes make up about 45% of blood volume, plasma about 55%, and leukocytes and platelets under 1%.
4. The volume percentage of erythrocytes is the hematocrit.

Blood Plasma (pp. 540–541)

5. Plasma is a fluid that is 90% water. The remaining 10% consists of nutrients, respiratory gases, salts, hormones, and plasma proteins. Serum is plasma from which the clotting factors have been removed.

Formed Elements (pp. 541–546)

6. Blood cells are short-lived and are replenished continuously by new cells from the bone marrow.
7. A blood smear is prepared by putting a drop of blood on a glass slide; spreading it to form a film; then drying, preserving, and staining the film. Blood smears are stained with mixtures of two dyes, one acidic, such as eosin, and one basic, such as methylene blue.
8. Erythrocytes, the most abundant blood cells, are anucleate, biconcave discs with a diameter of 7–8 μm. Essentially, they are bags of hemoglobin, the oxygen-transporting protein. The main function of erythrocytes is to transport oxygen between the lungs and the body tissues. Erythrocytes live about 120 days in the circulation.
9. Leukocytes fight infections in the loose connective tissues outside capillaries, using the bloodstream only as a transport system. They leave capillaries by diapedesis and crawl through the connective tissues to the infection sites. There are only 4800–11,000 leukocytes, compared to about 5 million erythrocytes, in a cubic millimeter of blood.
10. The five distinct types of leukocytes are grouped into granulocytes and agranulocytes, according to whether they have distinctive cytoplasmic granules. Granulocytes, which include neutrophils, eosinophils, and basophils, are short-lived cells with distinctive cytoplasmic granules and lobed nuclei. All are phagocytic cells. The agranulocytes are lymphocytes and monocytes.
11. Neutrophils, the most abundant leukocytes, have multilobed nuclei. Two types of small granules give their cytoplasm a light purple color in stained blood smears. The function of neutrophils is phagocytosis of bacteria.
12. Eosinophils have bilobed nuclei and large, red-staining granules that contain digestive enzymes. They destroy and digest parasites and stop allergic reactions.

13. Basophils are rare leukocytes with bilobed nuclei and large, purple-staining granules full of chemical mediators of inflammation. They mediate the late stages of allergic reactions. Although a distinct cell type, they are functionally similar to mast cells.

14. Lymphocytes or their products attack antigens in the specific immune response. These cells have a sparse, blue-staining cytoplasm and a dense, purple-staining, spherical nucleus. T lymphocytes destroy foreign cells directly, whereas B lymphocytes secrete antibodies that mark foreign cells for phagocytosis.

15. Monocytes, the largest leukocytes, resemble large lymphocytes but have a lighter-staining nucleus that may be kidney-shaped. They transform into macrophages in connective tissues.

16. Platelets are disc-shaped, membrane-enclosed fragments of megakaryocyte cytoplasm that contain several kinds of secretory granules. They plug tears in blood vessels, signal vasoconstriction, help initiate clotting, and then retract the clot and close the tear.

Blood Cell Formation (pp. 546–549)

Bone Marrow as the Site of Hematopoiesis (pp. 546–547)

17. Collectively, bone marrow is the body's second largest organ. Red marrow, located between the trabeculae of spongy bone in the axial skeleton, girdles, and proximal epiphysis of each humerus and femur of adults, actively makes blood cells. Yellow marrow, in the other regions of limb bones of adults, is dormant.

18. Microscopically, bone marrow consists of wide capillaries (sinusoids) snaking through reticular connective tissue. The latter contains reticular fibers, fibroblasts (reticular cells), macrophages, fat cells, and immature blood cells in all stages of maturation. New blood cells enter the blood through the sinusoid walls.

Cell Lines in Blood Cell Formation (pp. 547–549)

19. All blood cells continuously arise from blood stem cells. As these cells divide, there is an early separation into lymphoid stem cells (future lymphocytes) and myeloid stem cells (precursors to all other blood cell classes). These stem cells commit to the specific blood cell lines and structural differentiation begins.

20. Erythrocytes start as proerythroblasts and proceed through various stages, during which hemoglobin accumulates and the organelles and nucleus are extruded. For their first 1 or 2 days in the circulation, erythrocytes are reticulocytes.

21. The three distinct classes of granular leukocytes begin as myeloblasts, then proceed through various stages in which they gain specific granules and their nucleus shuts down, distorting into a horseshoe shape. The cells then mature and enter the bloodstream. Some neutrophils enter the circulation as immature band cells.

22. Monocytes and lymphocytes look somewhat like stem cells. Structural changes are minimal in the developmental pathways of these cells.

23. In the platelet line, immature megakaryoblasts become giant megakaryocytes with multilobed nuclei. The cytoplasm of megakaryocytes breaks up to form platelets in the blood.

Disorders of the Blood (pp. 549–550)

24. Polycythemia is an excess of erythrocytes in the blood, and anemia is any condition in which the blood's capacity for carrying oxygen is diminished. Sickle cell disease is an inherited condition in which the erythrocytes distort into a sickle shape and block the capillaries. Leukemia is cancer of leukocyte-forming cells in bone marrow, and thrombocytopenia is abnormally low concentration of platelets in the blood.

The Blood Throughout Life (pp. 550–552)

25. The blood stem cells develop in blood islands of the yolk sac in the 3-week-old embryo and then travel to the hematopoietic organs.

26. The hematopoietic organs in the fetus are the liver, spleen, and bone marrow.

27. The incidence of leukemia, anemia, and clotting disorders increases with age.

REVIEW QUESTIONS

Multiple Choice/Matching Questions

For answers, see Appendix B.

1. Which of the following descriptions of erythrocytes is *false*? Erythrocytes (a) are shaped like biconcave discs, (b) have a life span of about 120 days, (c) contain hemoglobin, (d) have lobed nuclei.

2. Rank the following leukocytes in order of their relative abundance in the blood of a normal, healthy person, from 1 (most abundant) to 5 (least abundant).

____ **(a)** lymphocytes

____ **(b)** basophils

____ **(c)** neutrophils

____ **(d)** eosinophils

____ **(e)** monocytes

3. The white blood cell that releases histamine and other mediators of inflammation is the (a) basophil, (b) neutrophil, (c) monocyte, (d) eosinophil.

4. Which of the following blood cells are phagocytic? (a) lymphocytes, (b) erythrocytes, (c) neutrophils, (d) lymphocytes and neutrophils.

5. The blood cell that can attack a specific antigen is (a) a lymphocyte, (b) a monocyte, (c) a neutrophil, (d) a basophil, (e) an erythrocyte.

6. Match the names of the blood cells in column B with their descriptions in column A. Some names are used more than once.

Column A	**Column B**
____ **(1)** destroys parasites	**(a)** erythrocyte
____ **(2)** has two types of granules	**(b)** neutrophil
____ **(3)** does not use diapedesis	**(c)** eosinophil
____ **(4)** stops the allergic response	**(d)** basophil
____ **(5)** the only cell that is not spherical	**(e)** lymphocyte
____ **(6)** granulocyte that phagocytizes bacteria	**(f)** monocyte
____ **(7)** the largest blood cell	

—— **(8)** granulocyte with the smallest granules

—— **(9)** a young one is a reticulocyte

—— **(10)** lives for about 4 months

—— **(11)** most abundant blood cell

—— **(12)** includes T cells and B cells

7. In typically stained monocytes, the blue cytoplasm and the purple nuclei are colored by this dye: (a) eosin, (b) brilliant cresyl blue, (c) basin (as in basophilic), (d) methylene blue, (e) none of the above—you need two dyes for two colors.

Short Answer Essay Questions

8. Which class or classes of formed elements form the buffy coat in a centrifuged blood sample?

9. (a) What is the basic functional difference between red bone marrow and yellow bone marrow? (b) Where is yellow marrow located?

10. (a) Describe the steps of erythrocyte formation in the bone marrow. (b) What name is given to the immature type of red blood cell that is newly released into the circulation?

11. Describe the structure of platelets, and explain their functions.

12. What is the difference between a blood stem cell and a committed cell in the bone marrow?

13. What is the relationship between megakaryocytes and platelets?

14. Looking at a blood smear under the microscope, Tina became confused by the unusual nuclei of granulocytes. She kept asking why each eosinophil had two nuclei and why neutrophils had four or five nuclei. How would you answer her?

15. Compare and contrast each of the following pairs of terms: (a) circulatory system and cardiovascular system, (b) complete blood count and complete blood count with differential.

16. On her test, Floris wrote that the function of platelets was "clotting." The instructor, however, demanded a more complete answer. Indicate what the instructor had in mind.

17. When leukocytes are examined in a blood count, is it possible to tell B lymphocytes from T lymphocytes? Explain your answer.

18. Compare an eosinophil to a basophil, both in structure and in function.

19. What are the advantages of placental-blood transplants over bone marrow transplants?

20. What are the functions of the following plasma proteins: globulins, albumin, fibrinogen?

21. How does serum differ from plasma?

CRITICAL REASONING & CLINICAL APPLICATION QUESTIONS

1. After young Janie was diagnosed as having acute lymphocytic leukemia, her parents could not understand why infection was a major problem for Janie when her WBC count was so high. Provide an explanation for Janie's parents.

2. Freddy could tell that a neuron cell body on his slide was as wide as ten erythrocytes. How wide was the neuron cell body (in micrometers)?

3. The Jones family, who raise sheep on their ranch, let their sheepdog Rooter lick their faces, and they would sometimes kiss him on the mouth. The same day that the veterinarian diagnosed Rooter as having tapeworms, a blood test indicated that both the family's daughters had blood eosinophil levels of over 3000 per cubic millimeter. What is the connection?

4. A reticulocyte count indicated that 5% of Tyler's red blood cells were reticulocytes. His blood test also indicated he had polycythemia and a hematocrit of 65%. Explain the connections among these three facts.

5. Cancer patients being treated with chemotherapy drugs, which are designed to destroy rapidly mitotic cells, are monitored closely for changes in their RBC and WBC counts. Why?

6. Your child has had a moderate fever for 2 days. On the third day, you take her to the pediatrician. After an examination, blood is drawn and a CBC with diff is performed. How does this information aid the pediatrician in determining whether the cause of the infection is viral or bacterial?