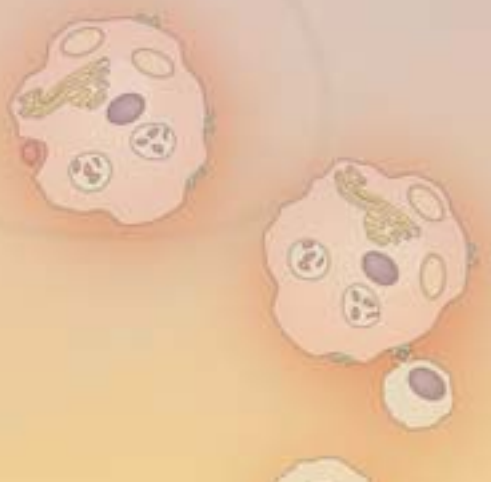
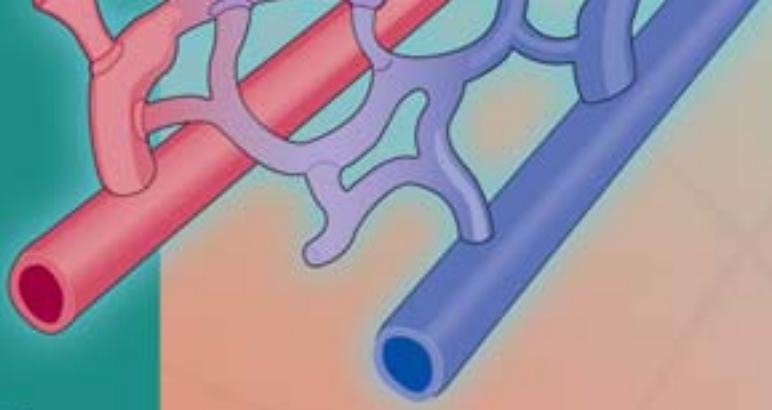
unit V

Circulation and Body Defense

The chapters in this unit discuss the systems that move materials through the body. The blood is the main transport medium. It circulates through the cardiovascular system, consisting of the heart and the blood vessels. The lymphatic system, in addition to other functions, help to balance body fluids by bringing substances from the tissues back to the heart. Components of the blood and the lymphatic system are involved in body defenses against infection as part of the immune system.





Selected Key Terms

The following terms and other boldface terms in the chapter are defined in the Glossary

agglutination
anemia
antigen
antiserum
centrifuge
coagulation
cryoprecipitate
erythrocyte
fibrin
hematocrit
hemoglobin
hemolysis
hemorrhage
hemostasis
leukemia
leukocyte
megakaryocyte
plasma
platelet (thrombocyte)
serum
thrombocytopenia
transfusion

Learning Outcomes

After careful study of this chapter, you should be able to:

1. List the functions of the blood
2. List the main ingredients in plasma
3. Describe the formation of blood cells
4. Name and describe the three types of formed elements in the blood and give the function of each
5. Characterize the five types of leukocytes
6. Define *hemostasis* and cite three steps in hemostasis
7. Briefly describe the steps in blood clotting
8. Define *blood type* and explain the relation between blood type and transfusions
9. List the possible reasons for transfusions of whole blood and blood components
10. Define *anemia* and list the causes of anemia
11. Define *leukemia* and name the two types of leukemia
12. Describe several forms of clotting disorders
13. Specify the tests used to study blood
14. Show how word parts are used to build words related to the blood (see Word Anatomy at the end of the chapter)

chapter 13

The Blood

The circulating blood is of fundamental importance in maintaining homeostasis. This life-giving fluid brings nutrients and oxygen to the cells and carries away waste. The heart pumps blood continuously through a closed system of vessels. The heart and blood vessels are described in Chapters 14 and 15.

Blood is classified as a connective tissue because it consists of cells suspended in an intercellular background material, or matrix. Blood cells share many characteristics of origination and development with other connective tissues. However, blood differs from other connective tissues in that its cells are not fixed in position; instead, they move freely in the plasma, the liquid portion of the blood.

Whole blood is a viscous (thick) fluid that varies in color from bright scarlet to dark red, depending on how much oxygen it is carrying. (It is customary in drawings to color blood high in oxygen as red and blood low in oxygen as blue.) The blood volume accounts for approximately 8% of total body weight. The actual quantity of circulating blood differs with a person's size; the average adult male, weighing 70 kg (154 pounds), has about 5 liters (5.2 quarts) of blood.

Functions of the Blood

The circulating blood serves the body in three ways: transportation, regulation, and protection.

Transportation

- Oxygen from inhaled air diffuses into the blood through thin membranes in the lungs and is carried by the circulation to all body tissues. Carbon dioxide, a waste product of cell metabolism, is carried from the tissues to the lungs, where it is breathed out.
- The blood transports nutrients and other needed substances, such as electrolytes (salts) and vitamins, to the cells. These materials enter the blood from the digestive system or are released into the blood from body reserves.
- The blood transports the waste products from the cells to sites where they are removed. For example, the kidney removes excess water, acid, electrolytes, and urea (a nitrogen-containing waste). The liver removes blood pigments, hormones, and drugs, and the lungs eliminate carbon dioxide.
- The blood carries hormones from their sites of origin to the organs they affect.

Regulation

- Buffers in the blood help keep the pH of body fluids steady at about 7.4. (The actual range of blood pH is 7.35 to 7.45.) Recall that pH is a measure of the acidity or alkalinity of a solution. At an average pH of 7.4, blood is slightly alkaline (basic).
- The blood regulates the amount of fluid in the tissues by means of substances (mainly proteins) that maintain the proper osmotic pressure. Recall that osmotic pressure is related to the concentration of dissolved and suspended materials in a solution. Proper osmotic pressure is needed for fluid balance, as described in Chapter 15.
- The blood transports heat that is generated in the muscles to other parts of the body, thus aiding in the regulation of body temperature.

Protection

- The blood is important in defense against disease. It carries the cells and antibodies of the immune system that protect against pathogens.
- The blood contains factors that protect against blood loss from the site of an injury. The process of blood coagulation, needed to prevent blood loss, is described later in this chapter.

Checkpoint 13-1 What are some substances transported in the blood?

Checkpoint 13-2 What is the pH range of the blood?

Blood Constituents

The blood is divided into two main components (Fig. 13-1). The liquid portion is the **plasma.** The **formed elements,** which include cells and cell fragments, fall into three categories, as follows:

- **Erythrocytes** (eh-RITH-ro-sites), from *erythro,* meaning "red," are the red blood cells, which transport oxygen.
- **Leukocytes** (LU-ko-sites), from *leuko,* meaning "white," are the several types of white blood cells, which protect against infection.
- **Platelets,** also called **thrombocytes** (THROM-bo-sites), are cell fragments that participate in blood clotting.

Table 13-1 summarizes information on the different types of formed elements. Figure 13-2 shows all the categories of formed elements in a blood smear, that is, a blood sample spread thinly over the surface of a glass slide, as viewed under a microscope.

Checkpoint 13-3 What are the two main components of blood?

Blood Plasma

About 55% of the total blood volume is plasma. The plasma itself is 91% water. Many different substances, dissolved or suspended in the water, make up the other 9% by weight (see Fig. 13-1). The plasma content may vary somewhat because substances are removed and added as the blood cir-

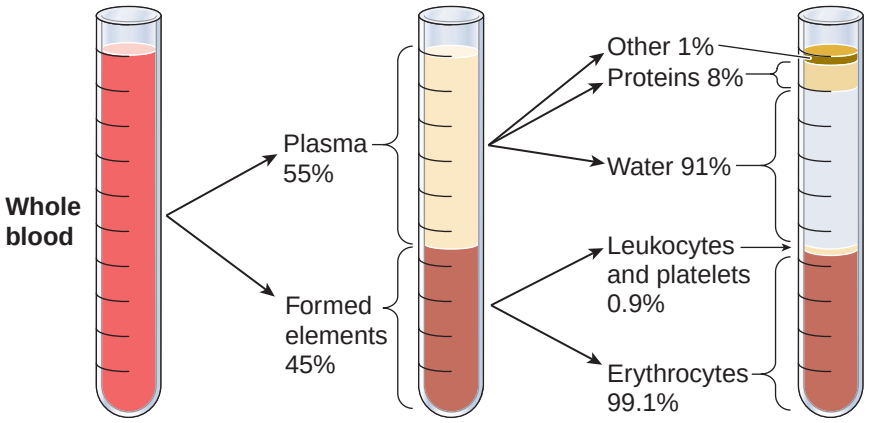


Figure 13-1 Composition of whole blood. Percentages show the relative proportions of the different components of plasma and formed elements.

culates to and from the tissues. However, the body tends to maintain a fairly constant level of most substances. For example, the level of glucose, a simple sugar, is maintained at a remarkably constant level of about one tenth of one percent (0.1%) in solution.

After water, the next largest percentage (about 8%) of material in the plasma is **protein**. The plasma proteins include the following:

- **Albumin** (al-BU-min), the most abundant protein in plasma, is important for maintaining the osmotic pressure of the blood. This protein is manufactured in the liver.
- **Clotting factors,** necessary for blood coagulation, are also manufactured in the liver.
- **Antibodies** combat infection. Antibodies are made by certain white blood cells.
- **Complement** consists of a group of enzymes that helps antibodies in their fight against pathogens (see Chap. 17).

The remaining 1% of the plasma consists of nutrients, electrolytes, and other materials that must be transported. With regard to the nutrients, the principal carbohydrate found in the plasma is glucose. This simple sugar is absorbed from digested foods in the intestine. It is also stored as glycogen, mainly in the liver, and released as needed into the blood to supply energy to the cells. Amino acids, the products of protein digestion, also circulate in the plasma. Lipids constitute a small percentage of blood plasma. Lipid components include fats, cholesterol, and lipoproteins, which are proteins bound to cholesterol.

The electrolytes in the plasma appear primarily as chloride, carbonate, or phosphate salts of sodium, potassium, calcium, and magnesium. These salts have a variety of functions, including the formation of bone (calcium and phosphorus), the production of certain hormones (such as iodine for the production of thyroid hormones), and the maintenance of the acid–base balance (such as sodium and potassium carbonates and phosphates present in buffers).

Other materials transported in plasma include vitamins, hormones, waste products, drugs, and dissolved gases, primarily oxygen and carbon dioxide.

Checkpoint 13-4 Next to water, what is the most abundant type of substance in plasma?

13

The Formed Elements

All of the blood's formed elements are produced in red bone marrow, which is located in the ends of long bones and in the inner mass of all other bones. The ancestors of all the blood cells are called **hematopoietic** (blood-forming) **stem cells**. These cells have the potential to develop

Table 13•1 Formed Elements of Blood

FORMED ELEMENT	NUMBER PER μL OF BLOOD	DESCRIPTION	FUNCTION
Erythrocyte (red blood cell)	5 million	Tiny (7 μM diameter), biconcave disk without nucleus (anuclear)	Carries oxygen bound to hemoglobin; also carries some carbon dioxide and buffers blood
Leukocyte (white blood cell)	5,000 to 10,000	Larger than red cell with prominent nucleus that may be segmented (granulocyte) or unsegmented (agranulocyte); vary in staining properties	Protects against pathogens; destroys foreign matter and debris; some are active in the immune system; located in blood, tissues, and lymphatic system
Platelet	150,000 to 450,000	Fragment of large cell (megakaryocyte)	Hemostasis; forms a platelet plug and starts blood clotting (coagulation)

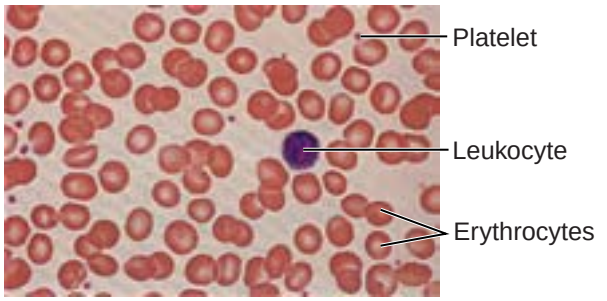


Figure 13-2 Blood cells as viewed under the microscope. All three types of formed elements are visible. *ZOOMING IN ✦ Which cells are the most numerous in the blood?*

into any of the blood cell types produced within the red marrow.

In comparison with other cells, most of those in the blood are short lived. The need for constant blood cell replacement means that normal activity of the red bone marrow is absolutely essential to life.

Checkpoint 13-5 Where do blood cells form?

Checkpoint 13-6 What type of cell gives rise to all blood cells?

Erythrocytes

Erythrocytes, the red blood cells (RBCs, or red cells), measure about 7 μm in diameter. They are disk-shaped bodies with a depression on both sides. This biconcave shape creates a central area that is thinner than the edges (Fig. 13-3). Erythrocytes are different from other cells in that the mature form found in the circulating blood lacks a nucleus (is anuclear) and also lacks most of the other organelles commonly found in cells. As red cells mature, these components are lost, providing more space for the cells to carry oxygen. This vital gas is bound in the red cells to **hemoglobin** (he-mo-GLO-bin), a protein that contains iron (see Box 13-1, Hemoglobin: Door to Door Oxygen Delivery). Hemoglobin, combined with oxygen, gives the blood its characteristic red color. The more oxygen carried by the hemoglobin, the brighter is the red color of the blood. Therefore, the blood that goes from the lungs to the tissues is a bright red because it carries a great supply of oxygen; in contrast, the blood that returns to the lungs is a much darker red because it has given up much of its oxygen to the tissues.

Hemoglobin has two lesser functions in addition to the transport of oxygen. Hemoglobin that has given up its oxygen is able to carry hydrogen ions. In this way, hemoglobin acts as a buffer and plays an important role in acid–base balance (see Chap. 21). Hemoglobin also carries some carbon dioxide from the tissues to the lungs for elimination. The carbon dioxide is bound to a different part of the molecule than the part that holds oxygen, so that it does not interfere with oxygen transport.

Hemoglobin's ability to carry oxygen can be blocked by carbon monoxide. This odorless and colorless but harmful gas combines with hemoglobin to form a stable compound that can severely restrict the erythrocytes' ability to carry oxygen. Carbon monoxide is a byproduct of the incomplete burning of fuels, such as gasoline and other petroleum products and coal, wood, and other carbon-containing materials. It also occurs in cigarette smoke and automobile exhaust.

Erythrocytes are by far the most numerous of the blood cells, averaging from 4.5 to 5 million per microliter (μL) of blood. (A microliter is one millionth of a liter. It is equal to a cubic millimeter or mm^3). Because mature red cells have no nucleus and cannot divide, they must be replaced constantly. After leaving the bone marrow, they circulate in the bloodstream for about 120 days before their membranes deteriorate and they are destroyed by the liver and spleen. Red cell production is stimulated by the hormone **erythropoietin** (eh-rith-ro-POY-eh-tin) (**EPO**), which is released from the kidney in response to a decrease in its oxygen supply. The constant production of red cells requires an adequate supply of nutrients, particularly protein, the B vitamins B_{12} and folic acid, required for the production of DNA, and the minerals iron and copper for the production of hemoglobin. Vitamin C is also important for the proper absorption of iron from the small intestine.

Checkpoint 13-7 Red cells are modified to carry a maximum amount of hemoglobin. What is the main function of hemoglobin?

Leukocytes

The **leukocytes,** or white blood cells (WBCs, or white cells), are different from the erythrocytes in appearance, quantity, and function. The cells themselves are round, but they contain prominent nuclei of varying shapes and sizes. Occurring at a concentration of 5,000 to 10,000 per cubic millimeter of blood, leukocytes are outnumbered by red cells by about 700 to 1. Al-

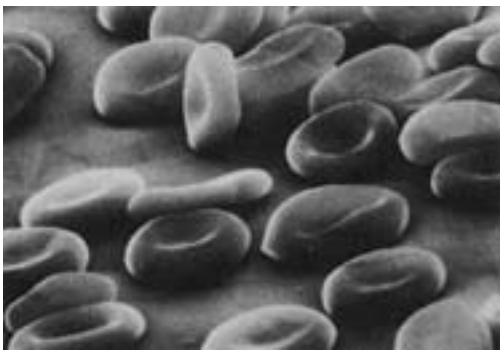
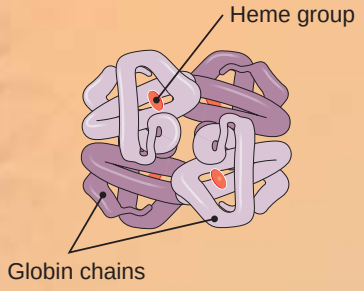


Figure 13-3 Red blood cells as seen under a scanning electron microscope. This type of microscope provides a three-dimensional view of the cells. *ZOOMING IN ✦ Why are these cells described as biconcave?*

Box 13-1 A Closer Look

Hemoglobin: Door to Door Oxygen Delivery

The hemoglobin molecule is a protein made of four chains of amino acids (the globin pzmolecule), each of which holds an iron-containing heme group. Each of the four hemes can bind one molecule of oxygen.



Hemoglobin. This protein in red blood cells consists of four amino acid chains (globins), each with an oxygen-binding heme group.

Hemoglobin allows the blood to carry much more oxygen than it could were the oxygen simply dissolved in the plasma. A red blood cell contains about 250 million hemoglobins, each capable of binding four molecules of oxygen. So, a single red blood cell can carry about one billion oxygen molecules! Hemoglobin reversibly binds oxygen, picking it up in the lungs and releasing it in the body tissues. Active cells need more oxygen and also generate heat and acidity. These changing conditions promote the release of oxygen from hemoglobin into metabolically active tissues.

Immature red blood cells (erythroblasts) produce hemoglobin as they mature into erythrocytes in the red bone marrow. When the liver and spleen destroy old erythrocytes they break down the released hemoglobin. Some of its components are recycled, and the remainder leaves the body as a brown fecal pigment called stercobilin. In spite of some conservation, dietary protein and iron are still essential to maintain hemoglobin supplies.

though the red cells have a definite color, the leukocytes tend to be colorless.

The different types of white cells are identified by their size, the shape of the nucleus, and the appearance of granules in the cytoplasm when the cells are stained. The stain commonly used for blood is Wright stain, which is a mixture of dyes that differentiates the various blood cells. The "granules" in the white cells are actually lysosomes and other secretory vesicles. They are present in all white blood cells, but they are more easily stained and more visible in some cells than in others. The relative percentage of the different types of leukocytes is a valuable clue in arriving at a medical diagnosis (Table 13-2).

The granular leukocytes, or **granulocytes** (GRAN-u-lo-sites), are so named because they show visible granules in the cytoplasm when stained (see Fig. 13-4 A-C). Each has a very distinctive, highly segmented nucleus. The different types of granulocytes are named for the type of dyes they take up when stained. They include the following:

- **Neutrophils** (NU-tro-fils) stain with either acidic or basic dyes and show lavender granules
- **Eosinophils** (e-o-SIN-o-fils) stain with acidic dyes (eosin is one) and have beadlike, bright pink granules
- **Basophils** (BA-so-fils) stain with basic dyes and have large, dark blue granules that often obscure the nucleus

The neutrophils are the most numerous of the white cells, constituting approximately 60% of all leukocytes (see Table 13-2). Because the nuclei of the neutrophils have various shapes, these cells are also called **polymorphs** (meaning "many forms") or simply *polys*. Other nicknames are *segs*, referring to the segmented nucleus, and *PMNs*, an abbreviation of **p**oly**m**orphonuclear **n**eutrophils. Before reaching full maturity and becoming segmented, the nucleus of the neutrophil looks like a thick, curved band (Fig. 13-5). An increase in the number of these **band cells** (also called *stab* or *staff cells*) is a sign of infection and the active production of neutrophils.

Table 13•2 Leukocytes (White Blood Cells)

CELL TYPE	RELATIVE PERCENTAGE (ADULT)	FUNCTION
Granulocytes	54%–62%	Phagocytosis
Neutrophils	1%–3%	Allergic reactions; defense against parasites
Eosinophils	< 1%	Allergic reactions; inflammatory reactions
Basophils		
Agranulocytes	25%–38%	Immunity (T cells and B cells)
Lymphocytes	3%–7%	Phagocytosis
Monocytes		

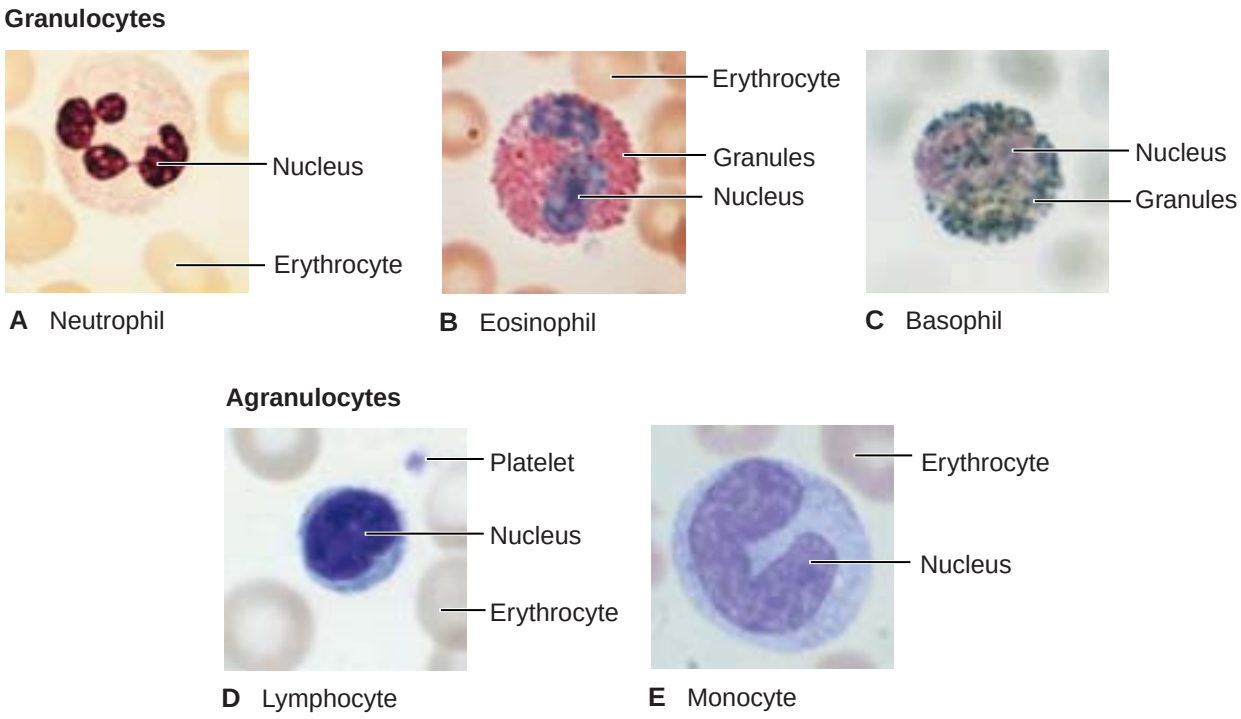


Figure 13-4 **Granulocytes (A-C) and agranulocytes (D, E). (A)** The neutrophil has a large, segmented nucleus. **(B)** The eosinophil has many bright pink-staining granules. **(C)** The basophil has large dark blue-staining granules. **(D)** The lymphocyte has a large undivided nucleus. **(E)** The monocyte is the largest of the leukocytes. *ZOOMING IN ✦ Which group of leukocytes has segmented nuclei? Which specific type of leukocyte is largest in size? Smallest in size?*

The eosinophils and basophils make up a small percentage of the white cells but increase in number during allergic reactions.

The agranular leukocytes, or **agranulocytes,** are so named because they lack easily visible granules (see Fig. 13-4 D, E). Their nuclei are round or curved and are not segmented. There are two types of agranular leukocytes:

- **Lymphocytes** (LIM-fo-sites) are the second most numerous of the white cells. Although lymphocytes originate in the red bone marrow, they develop to maturity in lymphoid tissue and can multiply in this tissue as well (see Chapter 16). They circulate in the lymphatic system and are active in immunity.
- **Monocytes** (MON-o-sites) are the largest in size. They average about 5% of the leukocytes.

Function of Leukocytes Leukocytes clear the body of foreign material and cellular debris. Most importantly, they destroy pathogens that may invade the body. Neutrophils and monocytes engage in **phagocytosis** (fag-o-si-TO-sis), the engulfing of foreign matter (Fig. 13-6). Whenever pathogens enter the tissues, as through a wound, they are attracted to the area. They squeeze between the cells of the capillary walls and proceed by ameboid (ah-ME-boyd), or amebalike, motion to the area of infection where they engulf the invaders. Lysosomes in the cytoplasm then digest the foreign organisms and the cells eliminate the waste products.

When foreign organisms invade, the bone marrow and lymphoid tissue go into emergency production of white cells, and their number increases enormously as a result. Detection of an abnormally large number of white cells in the blood is an indication of infection. In battling pathogens, leukocytes themselves may be destroyed. A mixture of dead and living

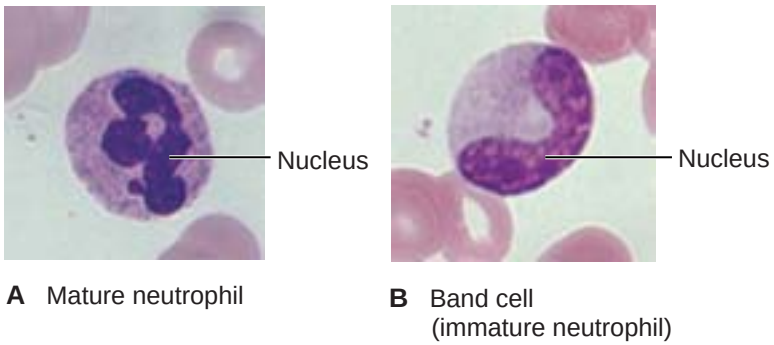


Figure 13-5 **Stages in neutrophil development. (A)** A mature neutrophil has a segmented nucleus. **(B)** An immature neutrophil is called a band cell because the nucleus is shaped like a thick, curved band. (×1325) (Reprinted with permission from Gartner LP, Hiatt JL. Color Atlas of Histology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

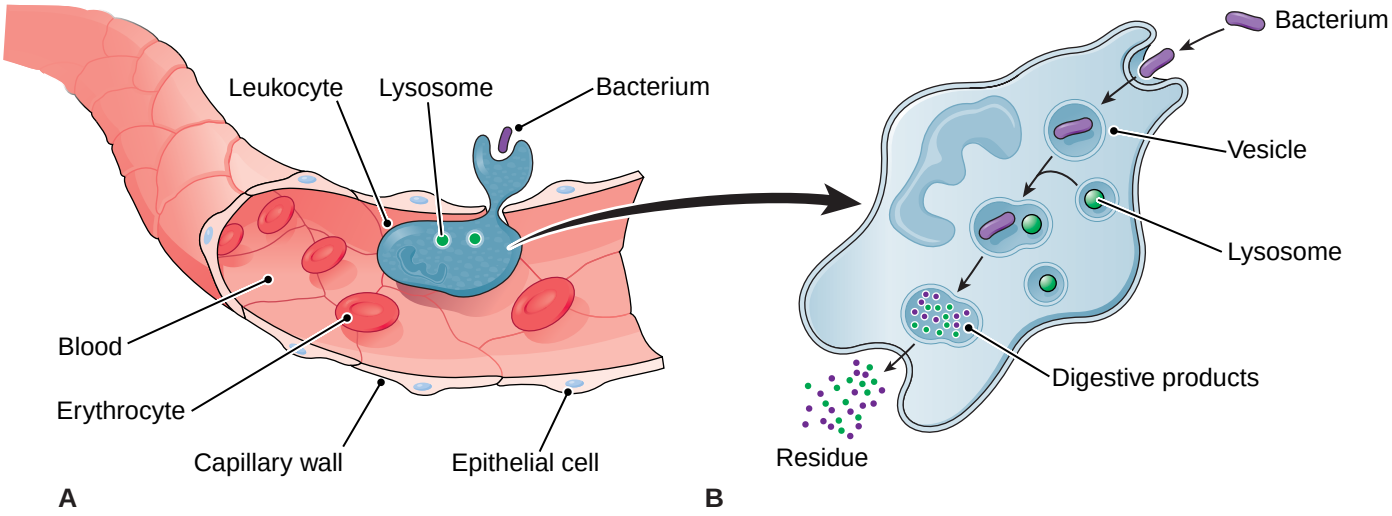


Figure 13-6 **Phagocytosis. (A)** A phagocytic leukocyte (white blood cell) squeezes through a capillary wall in the region of an infection and engulfs a bacterium. **(B)** The bacterium is enclosed in a vesicle and digested by a lysosome. *ZOOMING IN ✦ What type of epithelium makes up the capillary wall?*

bacteria, together with dead and living leukocytes, forms **pus**. A collection of pus localized in one area is known as an **abscess**.

Some monocytes enter the tissues, enlarge, and mature into **macrophages** (MAK-ro-faj-ez), which are highly active in disposing of invaders and foreign material. Although most circulating lymphocytes live only 6 to 8 hours, those that enter the tissues may survive for longer periods—days, months, or even years.

Some lymphocytes become **plasma cells,** active in the production of circulating antibodies needed for immunity. The activities of the various white cells are further discussed in Chapter 17.

Checkpoint 13-8 What are the types of granular leukocytes? Of agranular leukocytes?

Checkpoint 13-9 What is the most important function of leukocytes?

Platelets The blood **platelets** (thrombocytes) are the smallest of all the formed elements (Fig. 13-7 A). These tiny structures are not cells in themselves but rather fragments constantly released from giant bone marrow cells called **megakaryocytes** (meg-ah-KAR-e-o-sites) (Fig. 13-7 B). Platelets do not have nuclei or DNA, but they do contain active enzymes and mitochondria. The number of platelets in the circulating blood has been estimated to range from 150,000 to 450,000 per μL (mm^3). They have a life-span of about 10 days.

Platelets are essential to blood **coagulation** (clotting). When blood comes in contact with any tissue other than the smooth lining of the blood vessels, as in the case of injury, the platelets stick together and form a plug that seals the wound. The platelets then release chemicals that participate in the formation of a clot to stop blood loss. More details on these reactions follow.

Checkpoint 13-10 What is the function of blood platelets?

Hemostasis

Hemostasis (he-mo-STA-sis) is the process that prevents blood loss from the circulation when a blood vessel is ruptured by an injury. Events in hemostasis include the following:

1. **Contraction** of the smooth muscles in the blood vessel wall. This reduces the flow of blood and loss from the defect in the vessel wall. The term for this reduction in the diameter of a vessel is *vasoconstriction*.
2. Formation of a **platelet plug**. Activated platelets be-

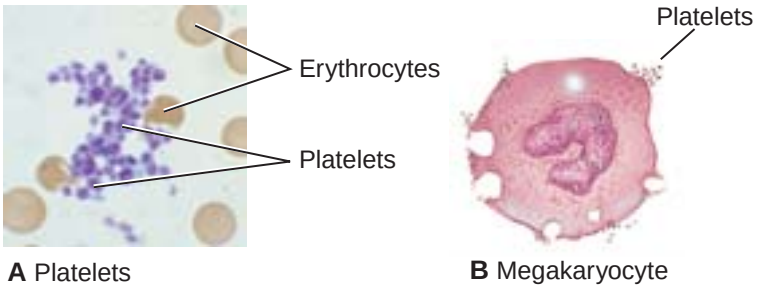


Figure 13-7 **Platelets (thrombocytes). (A)** Platelets in a blood smear. **(B)** A megakaryocyte releases platelets. (B, Reprinted with permission from Gartner LP, Hiatt JL. Color Atlas of Histology. 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2000.)

13

come sticky and adhere to the defect to form a temporary plug.
3. Formation of a **blood clot**.

Blood Clotting

The many substances necessary for blood clotting, or coagulation, are normally inactive in the bloodstream. A balance is maintained between compounds that promote clotting, known as **procoagulants,** and those that prevent clotting, known as **anticoagulants.** In addition, there are chemicals in the circulation that act to dissolve any unnecessary and potentially harmful clots that may form. Under normal conditions, the substances that prevent clotting prevail. When an injury occurs, however, the procoagulants are activated, and a clot is formed.

The clotting process is a well-controlled series of separate events involving 12 different factors, each designated by a Roman numeral. The final step in these reactions is the conversion of a plasma protein called **fibrinogen** (fi-BRIN-o-jen) into solid threads of **fibrin,** which form the clot.

A few of the final steps involved in blood clot formation are described below and diagrammed in Figure 13-8:

- Substances released from damaged tissues result in the formation of **prothrombinase** (pro-THROM-bih-nase), a substance that triggers the final clotting mechanism.
- Prothrombinase converts prothrombin in the blood to **thrombin.** Calcium is needed for this step.
- Thrombin, in turn, converts soluble fibrinogen into insoluble fibrin. **Fibrin** forms a network of threads that entraps plasma and blood cells to form a clot.

Blood clotting occurs in response to injury. Blood also clots when it comes into contact with some surface other than the lining of a blood vessel, for example, a glass or plastic tube used for a blood specimen. In this case, the preliminary steps of clotting are somewhat different and require more time, but the final steps are the same as those described above.

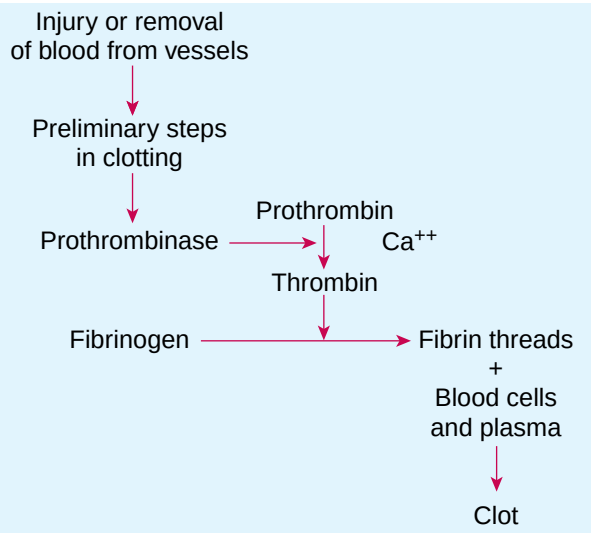


Figure 13-8 Final steps in blood clot formation. *ZOOMING IN ✦ What material in the blood forms a clot?*

The fluid that remains after clotting has occurred is called **serum** (plural, *sera*). Serum contains all the components of blood plasma *except* the clotting factors, as expressed in the formula:

$$\text{Plasma} = \text{serum} + \text{clotting factors}$$

Several methods used to measure the body's ability to coagulate blood are described later in this chapter.

Checkpoint 13-11 What happens when fibrinogen converts to fibrin?

Blood Types

If for some reason the amount of blood in the body is severely reduced, through **hemorrhage** (HEM-eh-rij) (excessive bleeding) or disease, the body cells suffer from lack of oxygen and nutrients. One possible measure to take in such an emergency is to administer blood from another person into the veins of the patient, a procedure called **transfusion.** Care must be taken in transferring blood from one person to another, however, because the patient's plasma may contain substances, called *antibodies* or *agglutinins*, that can cause the red cells of the donor's blood to rupture and release their hemoglobin. Such cells are said to be **hemolyzed** (HE-mo-lized), and the resulting condition can be dangerous.

Certain proteins, called **antigens** (AN-ti-jens) or *agglutinogens,* on the surface of the red cells cause these incompatibility reactions. There are many types of such proteins, but only two groups are particularly likely to cause a transfusion reaction, the so-called A and B antigens and the Rh factor.

The ABO Blood Type Group

There are four blood types involving the A and B antigens: A, B, AB, and O (Table 13-3). These letters indicate the type of antigen present on the red cells. If only the A antigen is present, the person has type A blood; if only the B antigen is present, he or she has type B blood. Type AB red cells have both antigens, and type O have neither. Of course no one has antibodies to his or her own blood type antigens, or their plasma would destroy their own cells. Each person does, however, develop antibodies that react with the AB antigens he or she is lacking. (The reason for the development of these antibodies is not totally understood, because people usually develop antibodies only when they have been exposed to an antigen.) It is these antibodies in the patient's plasma that can react with antigens on the donor's red cells to cause a transfusion reaction.

Table 13•3 The ABO Blood Group System

BLOOD TYPE	RED BLOOD CELL ANTIGEN	REACTS WITH ANTISERUM	PLASMA ANTIBODIES	CAN TAKE FROM	CAN DONATE TO
A	A	Anti-A	Anti-B	A, O	A, AB
B	B	Anti-B	Anti-A	B, O	B, AB
AB	A, B	Anti-A, Anti-B	None	AB, A, B, O	AB
O	None	None	Anti-A, Anti-B	O	O, A, B, AB

Testing for Blood Type Blood sera containing antibodies to the A or B antigens are used to test for blood type. These antisera are prepared in animals using either the A or the B antigens to induce a response. Blood serum containing antibodies that can agglutinate and destroy red cells with A antigen is called **anti-A serum;** blood serum containing antibodies that can destroy red cells with B antigen is called **anti-B serum.** When combined with a blood sample in the laboratory, each antiserum causes the corresponding red cells to clump together in a process known as **agglutination** (ah-glu-tih-NA-shun). The blood's agglutination pattern when mixed *separately* with these two sera reveals its blood type (Fig. 13-9). Type A reacts with anti-A serum only; type B reacts with anti-B serum only. Type AB agglutinates with both, and type O agglutinates with neither A nor B.

A blood specimen from any person who has had a prior blood transfusion or a pregnancy is tested further for the presence of any less common antibodies. Both the red cells and the serum are tested separately for any possible cross-reactions with donor blood.

Checkpoint 13-12 What are the four ABO blood type groups?

Blood Compatibility Heredity determines a person's blood type, and the percentage of people with each of the different blood types varies in different populations. For example, about 45% of the white population of the United States have type O blood, 40% have A, 11% have B and only 4% have AB. The percentages vary within other population groups.

In an emergency, type O blood can be given to any ABO type because the cells lack both A and B antigens and will not react with either A or B antibodies (see Table 13-3). People with type O blood are called *universal donors*. Conversely, type AB blood contains no antibodies to agglutinate red cells, and people with this blood type can therefore receive blood from any ABO type donor. Those with AB blood are described as *universal recipients*. Whenever possible, it is safest to give the same blood type as the recipient's blood.

The Rh Factor

More than 85% of the United States' population has another red cell antigen group called the **Rh factor,** named for *Rhe-*

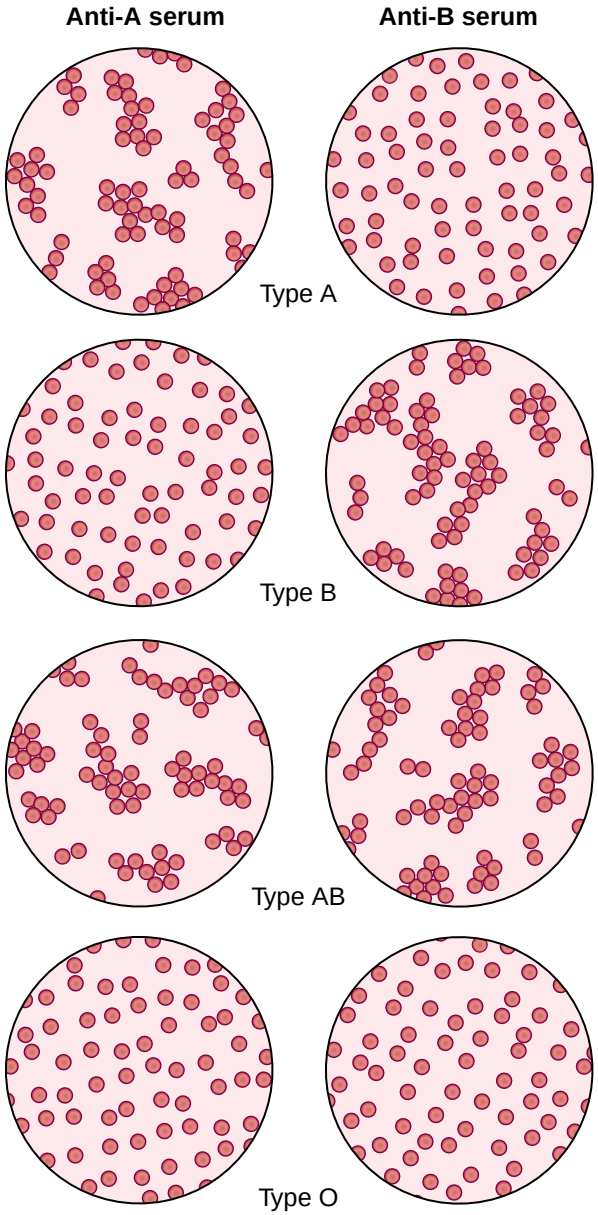


Figure 13-9 Blood typing. Labels at the top of each column denote the kind of antiserum added to the blood samples. Anti-A serum agglutinates (causes to clump) red cells in type A blood, but anti-B serum does not. Anti-B serum agglutinates red cells in type B blood, but anti-A serum does not. Both sera agglutinate type AB blood cells, and neither serum agglutinates type O blood. *ZOOMING IN ✦ Can you tell from these reactions whether these cells are Rh positive or Rh negative?*

sus monkeys, in which it was first found. Rh is also known as the *D antigen*. People with this antigen are said to be **Rh positive;** those who lack this protein are said to be **Rh negative.** If Rh-positive blood is given to an Rh-negative person, he or she may produce antibodies to the "foreign" Rh antigens. The blood of this "Rh-sensitized" person will then destroy any Rh-positive cells received in a later transfusion.

Rh incompatibility is a potential problem in certain pregnancies. A mother who is Rh negative may develop antibodies to the Rh protein of an Rh-positive fetus (the fetus having inherited this factor from the father). Red cells from the fetus that enter the mother's circulation during pregnancy and childbirth evoke the response. In a subsequent pregnancy with an Rh-positive fetus, some of the anti-Rh antibodies may pass from the mother's blood into the blood of her fetus and destroy the fetus's red cells. This condition is called **hemolytic disease of the newborn** (HDN). An older name is *erythroblastosis fetalis*). HDN is now prevented by administration of immune globulin $Rh_o(D)$, trade name Rho-GAM, to the mother during pregnancy and shortly after delivery. These preformed antibodies clear the mother's circulation of Rh antigens and prevent stimulation of an immune response. In many cases, a baby born with HDN could be saved by a transfusion that replaces much of the baby's blood with Rh-negative blood.

Checkpoint 13-13 What are the blood antigens most often involved in incompatibility reactions?

Uses of Blood and Blood Components

Blood can be packaged and kept in blood banks for emergencies. To keep the blood from clotting, a solution such as citrate-phosphate-dextrose-adenine (CPDA-1) is added. The blood may then be stored for up to 35 days. The blood supplies in the bank are dated with an expiration date to prevent the use of blood in which red cells may have disintegrated. Blood banks usually have all types of blood and blood products available. It is important that there be an extra supply of type O, Rh-negative blood because in an emergency this type can be used for any patient. It is normal procedure to test the recipient and give blood of the same type.

A person can donate his or her own blood before undergoing elective (planned) surgery to be used during surgery if needed. This practice eliminates the possibility of incompatibility and of disease transfer as well. Such **autologous** (aw-TOL-o-gus) (self-originating) blood is stored in a blood bank only until the surgery is completed.

Whole Blood Transfusions

The transfer of whole human blood from a healthy person to a patient is often a life-saving process. Whole blood transfusions may be used for any condition in which there is loss of a large volume of blood, for example:

- In the treatment of massive hemorrhage from serious mechanical injuries
- For blood loss during internal bleeding, as from bleeding ulcers
- During or after an operation that causes considerable blood loss
- For blood replacement in the treatment of hemolytic disease of the newborn

Caution and careful evaluation of the need for a blood transfusion is the rule, however, because of the risk for transfusion reactions and the transmission of viral diseases, particularly hepatitis.

Use of Blood Components

Most often, when some blood ingredient is needed, it is not whole blood but a blood component that is given. Blood can be broken down into its various parts, which may be used for different purposes.

A common method for separating the blood plasma from the formed elements is by use of a **centrifuge** (SEN-trih-fuje), a machine that spins in a circle at high speed to separate components of a mixture according to density. When a container of blood is spun rapidly, all the formed elements of the blood are pulled into a clump at the bottom of the container. They are thus separated from the plasma, which is less dense. The formed elements may be further separated and used for specific purposes, for example, packed red cells alone or platelets alone.

Blood losses to the donor can be minimized by removal of the blood, separation of the desired components, and return of the remainder to the donor. The general term for this procedure is **hemapheresis** (hem-ah-fer-E-sis) (from the Greek word *apheresis* meaning "removal") If the plasma is removed and the formed elements returned to the donor, the procedure is called **plasmapheresis** (plas-mah-fer-E-sis).

Use of Plasma Blood plasma alone may be given in an emergency to replace blood volume and prevent circulatory failure (shock). Plasma is especially useful when blood typing and the use of whole blood are not possible, such as in natural disasters or in emergency rescues. Because the red cells have been removed from the plasma, there are no incompatibility problems; plasma can be given to anyone. Plasma separated from the cellular elements is usually further separated by chemical means into various components, such as plasma protein fraction, serum albumin, immune serum, and clotting factors.

The packaged plasma that is currently available is actually plasma protein fraction. Further separation yields serum albumin that is available in solutions of 5% or 25% concentration. In addition to its use in treatment of circulatory shock, these solutions are given when plasma

proteins are deficient. They increase the osmotic pressure of the blood and thus draw fluids back into circulation. The use of plasma proteins and serum albumin has increased because these blood components can be treated with heat to prevent transmission of viral diseases.

In emergency situations healthcare workers may administer fluids known as *plasma expanders*. These are cell-free isotonic solutions used to maintain blood fluid volume to prevent circulatory shock.

Fresh plasma may be frozen and saved. When frozen plasma is thawed, a white precipitate called **cryoprecipitate** (kri-o-pre-SIP-ih-tate) forms in the bottom of the container. Plasma frozen when it is less than 6 hours old contains all the factors needed for clotting. Cryoprecipitate is especially rich in clotting factor VIII and fibrinogen. These components may be given when there is a special need for these factors.

The gamma globulin fraction of the plasma contains antibodies produced by lymphocytes when they come in contact with foreign agents, such as bacteria and viruses. Antibodies play an important role in the immune system (see Chap. 17). Commercially prepared immune sera are available for administration to patients in immediate need of antibodies, such as infants born to mothers with active hepatitis.

Checkpoint 13-14 How is blood commonly separated into its component parts?

Blood Disorders

Abnormalities involving the blood may be divided into three groups:

- **Anemia** (ah-NE-me-ah), a disorder in which there is an abnormally low level of hemoglobin or red cells in the blood and thus impaired delivery of oxygen to the tissues.
- **Leukemia** (lu-KE-me-ah), a neoplastic blood disease characterized by an increase in the number of white cells.
- **Clotting disorders.** These disorders are characterized by an abnormal tendency to bleed due to a breakdown in the body's clotting mechanism.

Anemia

Anemia may result from loss of red cells, as through excessive bleeding (hemorrhage), or from conditions that cause the cells to hemolyze (rupture). In other cases, bone marrow failure or nutritional deficiences impede the production of red cells or hemoglobin.

Excessive Loss or Destruction of Red Cells Hemorrhagic loss of red cells may be sudden and acute or gradual and chronic. The average adult has about 5 liters of blood. If a person loses as much as 2 liters suddenly, death usually results. If the loss is gradual, however, over a period of weeks, or months, the body can compensate and withstand the loss of as much as 4 or 5 liters. Possible causes of chronic blood loss include bleeding ulcers, excessive menstrual flow, and bleeding hemorrhoids (piles). If the cause of the blood loss can be corrected, the body is usually able to restore the blood to normal. This process can take as long as 6 months, and until the blood returns to normal, the affected person may have anemia.

Hemolytic anemia Anemia caused by the excessive destruction of red cells is called **hemolytic** (he-mo-LIH-tik) **anemia.** The spleen, along with the liver, normally destroys old red cells. Occasionally, an overactive spleen destroys the cells too rapidly, causing anemia. Infections may also cause red cell loss. For example, the malarial parasite multiplies in red cells and destroys them, and certain bacteria, particularly streptococci, produce a toxin that causes hemolysis.

Certain inherited diseases that cause the production of abnormal hemoglobin may also result in hemolytic anemia. The hemoglobin in normal adult cells is of the A type and is designated *HbA*. In the inherited disease **sickle cell anemia,** the hemoglobin in many of the red cells is abnormal (HbS). When these cells give up their oxygen to the tissues, they are transformed from the normal disk shape into a sickle shape (Fig. 13-10). These sickle cells are fragile and tend to break easily. Because of their odd shape, they also tend to become tangled in masses that can block smaller blood vessels. When obstruction occurs, there may be severe joint swelling and pain, especially in the fingers and toes, as well as abdominal pain. This aspect of sickle cell anemia is referred to as *sickle cell crisis.*

Sickle cell anemia occurs almost exclusively in black people. About 8% of African Americans have one of the genes for the abnormal hemoglobin and are said to have

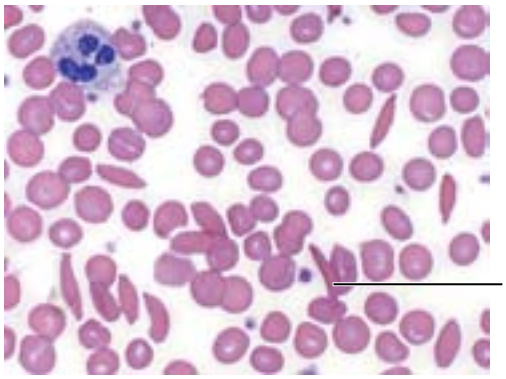


Figure 13-10 A blood smear in sickle cell anemia. Abnormal cells take on a crescent (sickle) shape when they give up oxygen. (Reprinted with permission from Ross MH, Kaye GI, Pawlina W. Histology. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.) *ZOOMING IN ✦ What kind of cell is in the upper left corner of this picture? What are the small dark bodies between the cells?*

the **sickle cell trait.** It is only when the involved gene is transmitted from both parents that the clinical disease appears. About 1% of African Americans have two of these genes and thus have **sickle cell disease.** One drug has been found to reduce the frequency of painful crisis in certain adults. Hydroxyurea causes the body to make some hemoglobin of an alternate form (fetal hemoglobin) so that the red cells are not as susceptible to sickling. People taking hydroxyurea require blood tests every 2 weeks to assess for drug-induced bone marrow suppression.

Impaired Production of Red Cells or Hemoglobin Many factors can interfere with normal red cell production. Anemia that results from a deficiency of some nutrient is referred to as *nutritional anemia.* These conditions may arise from a deficiency of the specific nutrient in the diet, from an inability to absorb the nutrient, or from drugs that interfere with the body's use of the nutrient.

Deficiency Anemia The most common nutritional anemia is **iron-deficiency anemia.** Iron is an essential constituent of hemoglobin. The average diet usually provides enough iron to meet the needs of the adult male, but this diet often is inadequate to meet the needs of growing children and women of childbearing age.

A diet deficient in proteins or vitamins can also result in anemia. Folic acid, one of the B complex vitamins, is necessary for the production of blood cells. Folic acid deficiency anemia occurs in people with alcoholism, in elderly people on poor diets, and in infants or others suffering from intestinal disorders that interfere with the absorption of this water-soluble vitamin.

Pernicious (per-NISH-us) **anemia** is characterized by a deficiency of vitamin B_{12}, a substance essential for proper red cell formation. The cause is a permanent deficiency of **intrinsic factor,** a gastric juice secretion that is responsible for vitamin B_{12} absorption from the intestine. Neglected pernicious anemia can bring about deterioration in the nervous system, causing difficulty in walking, weakness and stiffness in the extremities, mental changes, and permanent damage to the spinal cord. Early treatment, including the intramuscular injection of vitamin B_{12} and attention to a prescribed diet, ensures an excellent outlook. This treatment must be kept up for the rest of the patient's life to maintain good health.

Bone Marrow Suppression Bone marrow suppression or failure also leads to decreased red cell production. One type of bone marrow failure, **aplastic** (a-PLAS-tik) **anemia,** may be caused by a variety of physical and chemical agents. Chemical substances that injure the bone marrow include certain prescribed drugs and toxic agents such as gold compounds, arsenic, and benzene. Physical agents that may injure the marrow include x-rays, atomic radiation, radium, and radioactive phosphorus.

The damaged bone marrow fails to produce either red or white cells, so that the anemia is accompanied by **leukopenia** (lu-ko-PE-ne-ah), a drop in the number of white cells. Removal of the toxic agent, followed by blood transfusions until the marrow is able to resume its activity, may result in recovery. Bone marrow transplantations have also been successful.

Bone marrow suppression also may develop in patients with certain chronic diseases, such as cancer, kidney or liver disorders, and rheumatoid arthritis. Some medications are now available to stimulate bone marrow production of specific types of blood cells. The hormone EPO made by recombinant methods (genetic engineering) can be given in cases of severe anemia to stimulate red cell production.

Checkpoint 13-15 What is anemia?

Leukemia

Leukemia is a neoplastic disease of blood-forming tissue. It is characterized by an enormous increase in the number of white cells. Although the cells are high in number, they are incompetent and cannot perform their normal jobs. They also crowd out the other blood cells.

As noted earlier, the white cells have two main sources: red marrow, also called *myeloid tissue,* and lymphoid tissue. If this wild proliferation of white cells stems from cancer of the bone marrow, the condition is called **myelogenous** (mi-eh-LOJ-en-us) **leukemia.** When the cancer arises in the lymphoid tissue, so that most of the abnormal cells are lymphocytes, the condition is called **lymphocytic** (lim-fo-SIT-ik) **leukemia.** Both types of leukemia appear in acute and chronic forms.

The cause of leukemia is unknown. Both inborn factors and various environmental agents have been implicated. Among the latter are chemicals (such as benzene), x-rays, radioactive substances, and viruses.

Patients with leukemia exhibit the general symptoms of anemia because the white cells overwhelm the red cells. In addition, they have a tendency to bleed easily, owing to a lack of platelets. White cell failure lowers immunity, resulting in frequent infections. The spleen is greatly enlarged, and several other organs may be increased in size because of internal accumulation of white cells. Treatment consists of x-ray therapy and chemotherapy (drug treatment), but the disease is malignant and thus may be fatal. With new chemotherapeutic methods, the outlook is improving, and many patients survive for years. (See Box 13-2, Bone Marrow Transplants: Getting the Gift of Life.)

Checkpoint 13-16 What is leukemia?

Box 13-2 Hot Topics

Bone Marrow Transplants: Getting the Gift of Life

Large doses of chemotherapy or radiation are sometimes used to destroy abnormal hematopoietic stem cells in the bone marrow of patients with leukemia. Unfortunately, these therapies also destroy normal stem cells in the marrow, hampering the production of new blood cells. A **bone marrow transplant** replaces the hematopoietic cells after aggressive treatment for leukemia. The procedure is also used to treat sickle cell anemia, aplastic anemia, and some immune diseases.

Most patients receive *allogeneic transplants*, stem cells harvested from the bone marrow of a close relative or occasionally from an unrelated donor. It is important that the donor marrow matches the recipient's marrow as closely as possible. For this reason, potential donors undergo blood tests to determine if their marrow antigens are compatible with the recipient's. A poorly matched transplant increases the risk of marrow rejection and graft-versus-host disease (GVHD), a life-threatening complication that occurs when immune cells from the transplanted marrow attack and destroy the patient's organs. In certain circumstances, the patient's own bone marrow can be harvested, and replaced after treatment. This type of bone marrow transplant is called an *autologous transplant* and is not associated with tissue rejection or GVHD.

When bone marrow is to be harvested, the donor is given general or local anesthesia, a large needle is inserted into the pelvic bone, and the marrow is extracted. Then, it is filtered to remove bone fragments and unwanted blood cells, and either used immediately or stored frozen for later use. The recipient receives the bone marrow transplant intravenously. After entering the bloodstream, the transplanted hematopoietic stem cells travel to the bone marrow, where they begin to produce new blood cells. Complete recovery may take up to several months for an autologous transplant and one to two years for an allogeneic transplant. During this time, the patient is very susceptible to infectious diseases. Despite the risks, bone marrow transplants give patients with life-threatening blood diseases like leukemia a better chance of survival.

Clotting Disorders

A characteristic common to all clotting disorders is a disruption of the coagulation process, which brings about abnormal bleeding.

Hemophilia (he-mo-FIL-e-ah) is a rare hereditary bleeding disorder, a disease that influenced history by its occurrence in some Russian and Western European royal families. All forms of hemophilia are characterized by a deficiency of a specific clotting factor, most commonly factor VIII. In those with hemophilia, any cut or bruise may cause serious abnormal bleeding. The needed clotting factors are now available in purified concentrated form for treatment in cases of injury, preparation for surgery, or painful bleeding into the joints, a frequent occurrence in hemophilia. Cryoprecipitate contains factor VIII, and clotting factors are also produced by recombinant (genetic engineering) methods.

Von Willebrand disease is another hereditary clotting disorder. It involves a shortage of von Willebrand factor, a plasma component that helps platelets to adhere (stick) to damaged tissue and also carries clotting factor VIII. This disorder is treated by administration of the appropriate clotting factor. In mild cases, a drug similar to the hormone ADH may work to prevent bleeding by raising the level of von Willebrand factor in the blood.

The most common clotting disorder is a deficient number of circulating platelets (thrombocytes). The condition, called **thrombocytopenia** (throm-bo-si-to-PE-ne-ah), results in hemorrhage in the skin or mucous membranes. The decrease in platelets may be due to their decreased production or increased destruction. There are several possible causes of thrombocytopenia, including diseases of the red bone marrow, liver disorders, and various drug toxicities. When a drug causes the disorder, its withdrawal leads to immediate recovery.

Disseminated intravascular coagulation (DIC) is a serious clotting disorder involving excessive coagulation. This disease occurs in cases of tissue damage due to massive burns, trauma, certain acute infections, cancer, and some disorders of childbirth. During the progress of DIC, platelets and various clotting factors are used up faster than they can be produced, and serious hemorrhaging may result.

Checkpoint 13-17 What blood components are low in cases of thrombocytopenia?

Blood Studies

Many kinds of studies can be done on blood, and some of these have become a standard part of a routine physical examination. Machines that are able to perform several tests at the same time have largely replaced manual procedures, particularly in large institutions. Standard blood tests are listed in Tables 2 and 3 of Appendix 4.

The Hematocrit

The **hematocrit** (he-MAT-o-krit), the volume percentage of red cells in whole blood, is determined by spinning a blood sample in a high-speed centrifuge for 3 to 5 minutes to separate the cellular elements from the plasma (Fig. 13-11).

The hematocrit is expressed as the volume of packed red cells per unit volume of whole blood. For example,

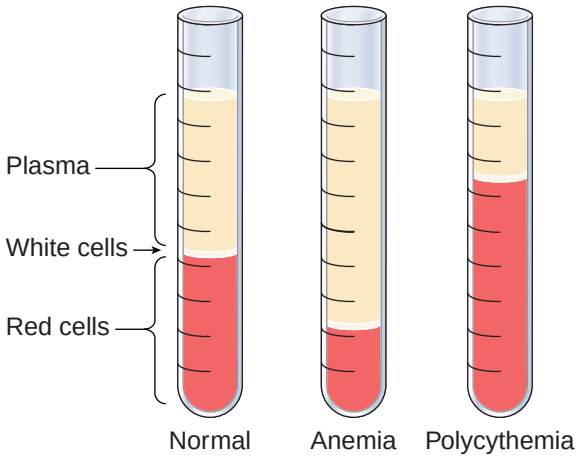


Figure 13-11 **Hematocrit.** The tube on the left shows a normal hematocrit. The middle tube shows that the percentage of red blood cells is low, indicating anemia. The tube on the right shows an excessively high percentage of red cells, as seen in polycythemia. (Reprinted with permission from Cohen BJ. Medical Terminology. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

"hematocrit, 38%" in a laboratory report means that the patient has 38 mL red cells per 100 mL (dL) of blood; red cells comprise 38% of the total blood volume. For adult men, the normal range is 42% to 54%, whereas for adult women the range is slightly lower, 36% to 46%. These normal ranges, like all normal ranges for humans, may vary depending on the method used and the interpretation of the results by an individual laboratory. Hematocrit values much below or much above these figures point to an abnormality requiring further study.

Hemoglobin Tests

A sufficient amount of hemoglobin in red cells is required for adequate oxygen delivery to the tissues. To measure its level, the hemoglobin is released from the red cells, and the color of the blood is compared with a known color scale. Hemoglobin is expressed in grams per 100 mL whole blood. Normal hemoglobin concentrations for adult males range from 14 to 17 g per 100 mL blood. Values for adult women are in a somewhat lower range, at 12 to 15 g per 100 mL blood. A decrease in hemoglobin to below normal levels signifies anemia.

Normal and abnormal types of hemoglobin can be separated and measured by the process of **electrophoresis** (e-lek-tro-fo-RE-sis). In this procedure, an electric current is passed through the liquid that contains the hemoglobin to separate different components based on their electrical charge. This test is useful in the diagnosis of sickle cell anemia and other disorders caused by abnormal types of hemoglobin.

Blood Cell Counts

Most laboratories use automated methods for obtaining the data for blood counts. Visual counts are sometimes done using a **hemocytometer** (he-mo-si-TOM-eh-ter), a ruled slide used to count the cells in a given volume of blood under the microscope.

Red Cell Counts The normal red cell count varies from 4.5 to 5.5 million cells per μL (mm^3) of blood. An increase in the red cell count is called **polycythemia** (pol-e-si-THE-me-ah). People who live at high altitudes develop polycythemia, as do patients with the disease **polycythemia** (pol-e-si-THE-me-ah) **vera**, a disorder of the bone marrow.

White Cell Counts The leukocyte count varies from 5000 to 10,000 cells per μL of blood. In **leukopenia**, the white count is below 5000 cells per mL. This condition indicates depressed bone marrow or a bone marrow neoplasm. In **leukocytosis** (lu-ko-si-TO-sis), the white cell count exceeds 10,000 cells per mL. This condition is characteristic of most bacterial infections. It may also occur after hemorrhage, in cases of gout (a type of arthritis), and in uremia, the presence of nitrogenous waste in the blood as a result of kidney disease.

Platelet Counts It is difficult to count platelets visually because they are so small. More accurate counts can be obtained with automated methods. These counts are necessary for the evaluation of platelet loss (thrombocytopenia) such as occurs after radiation therapy or cancer chemotherapy. The normal platelet count ranges from 150,000 to 450,000 per μL of blood, but counts may fall to 100,000 or less without causing serious bleeding problems. If a count is very low, a platelet transfusion may be given.

The Blood Slide (Smear)

In addition to the above tests, the **complete blood count** (CBC) includes the examination of a stained blood slide (see Fig. 13-2). In this procedure, a drop of blood is spread thinly and evenly over a glass slide, and a special stain (Wright) is applied to differentiate the otherwise colorless white cells. The slide is then studied under the microscope. The red cells are examined for abnormalities in size, color, or shape and for variations in the percentage of immature forms, known as reticulocytes (See Box 13-3 to learn about reticulocytes and how their counts are used to diagnose disease). The number of platelets is estimated. Parasites, such as the malarial organism and others, may be found. In addition, a **differential white count** is done. This is an estimation of the percentage of each white cell type in the smear. Because each type has a specific function, changes in their proportions can be a valuable diagnostic aid (see Table 13-2).

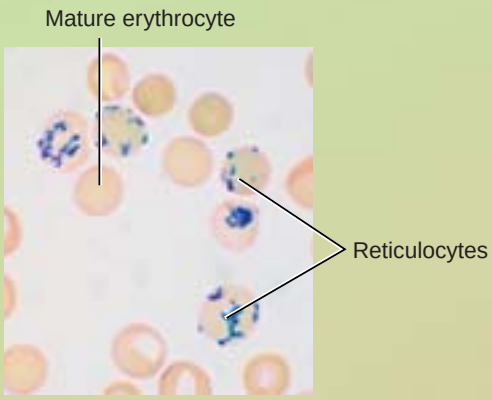
Checkpoint 13-18 The hematocrit is a common blood test. What is a hematocrit?

Box 13-3 Clinical Perspectives

Counting Reticulocytes to Diagnose Disease

As erythrocytes mature in the red bone marrow, they go through a series of stages in which they lose their nucleus and most other organelles, maximizing the space available to hold hemoglobin. In one of the last stages of development, small numbers of ribosomes and some rough endoplasmic reticulum remain in the cell and appear as a network, or reticulum, when stained. Cells at this stage are called **reticulocytes**. Reticulocytes leave the red bone marrow and enter the bloodstream where they become fully mature erythrocytes in about 24 to 48 hours. The average number of red cells maturing through the reticulocyte stage at any given time is about 1-2%. Changes in these numbers can be used in diagnosing certain blood disorders.

When erythrocytes are lost or destroyed, as from chronic bleeding or some form of hemolytic anemia, red blood cell production is "stepped up" to compensate for the loss. Greater numbers of reticulocytes are then released into the blood before reaching full maturity, and counts increase above normal. On the other hand, a decrease in the number of circulating reticulocytes suggests a problem with red blood cell production, as in cases of deficiency anemias or suppression of bone marrow activity.



Reticulocytes. Some ribosomes and rough ER appear as a network in a late stage of erythrocyte development. (Reprinted with permission from Cormack DH. Essential Histology. 2nd ed. Philadelphia: Lippincott Williams & Wilkins, 2001.)

Blood Chemistry Tests

Batteries of tests on blood serum are often done by machine. One machine, the Sequential Multiple Analyzer (SMA), can run some 20 tests per minute. Tests for electrolytes, such as sodium, potassium, chloride, and bicarbonate, may be performed at the same time along with tests for blood glucose, and nitrogenous waste products, such as blood urea nitrogen (BUN), and **creatinine** (kre-AT-in-in).

Other tests check for enzymes. Increased levels of **CPK** (creatine phosphokinase), **LDH** (lactic dehydrogenase), and other enzymes indicate tissue damage, such as damage that may occur in heart disease. An excess of **alkaline phosphatase** (FOS-fah-tase) could indicate a liver disorder or metastatic cancer involving bone (see Table 3 in Appendix 4).

Blood can be tested for amounts of lipids, such as cholesterol, triglycerides (fats), and lipoproteins, or for amounts of plasma proteins. Many of these tests help in evaluating disorders that may involve various vital organs. For example, the presence of more than the normal amount of glucose (sugar) dissolved in the blood, a condition called **hyperglycemia** (hi-per-gli-SE-me-ah), is found most frequently in patients with unregulated diabetes. Sometimes, several sugar evaluations are done after the administration of a known amount of glucose. This procedure is called the **glucose tolerance test** and is usually given along with another test that determines the amount of sugar in the urine. This combination of tests can indicate faulty cell metabolism. The list of blood chemistry tests is extensive and is constantly increasing. We may now obtain values for various hormones, vitamins, antibodies, and toxic or therapeutic drug levels.

Coagulation Studies

Before surgery and during treatment of certain diseases, hemophilia for example, it is important to know that coagulation will take place within normal time limits. Because clotting is a complex process involving many reactants, a delay may result from a number of different causes, including lack of certain hormonelike substances, calcium salts, or vitamin K. The amounts of the various clotting factors are evaluated by percentage to aid in the diagnosis and treatment of bleeding disorders.

Additional tests for coagulation include tests for bleeding time, clotting time, capillary strength, and platelet function.

Bone Marrow Biopsy

A special needle is used to obtain a small sample of red marrow from the sternum, sacrum, or iliac crest in a procedure called a **bone marrow biopsy**. If marrow is taken from the sternum, the procedure may be referred to as a **sternal puncture**. Examination of the cells gives valuable information that can aid in the diagnosis of bone marrow disorders, including leukemia and certain kinds of anemia.

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
Blood Constituents		
erythr/o	red, red blood cell	An *erythrocyte* is a red blood cell.
leuk/o	white, colorless	A *leukocyte* is a white blood cell.
thromb/o	blood clot	A *thrombocyte* is a cell fragment that is active in blood clotting.
hemat/o	blood	*Hematopoietic* stem cells form (-poiesis) all of the blood cells.
hemo	blood	*Hemoglobin* is a protein the carries oxygen in the blood.
morph/o	shape	The nuclei of *polymorphs* have many shapes.
lymph/o	lymph, lymphatic system	*Lymphocytes* are white blood cells that circulate in the lymphatic system.
mon/o	single, one	A *monocyte* has a single, unsegmented nucleus.
phag/o	eat, ingest	Certain leukocytes take in foreign matter by the process of *phagocytosis*.
macr/o	large	A *macrophage* takes in large amounts of foreign matter by phagocytosis .
kary/o	nucleus	A *megakaryocyte* has a very large nucleus.
Hemostasis		
-gen	producing, originating	*Fibrinogen* converts to fibrin in the formation of a blood clot.
pro-	before, in front of	Prothrombinase is an enzyme (-ase) that converts *prothrombin* to thrombin.
Blood Types		
-lysis	loosening, dissolving, separating	A recipient's antibodies to donated red cells can cause *hemolysis* of the cells.
Uses of Blood and Blood Components		
cry/o	cold	*Cryoprecipitate* forms when blood plasma is frozen and then thawed.
Blood Disorders		
–emia (from –hemia)	blood	*Anemia* is a lack (an-) of red cells or hemoglobin.
–penia	lack of	*Leukopenia* is a lack of white cells.

Summary

I. Functions of the blood

A. Transportation—of oxygen, carbon dioxide, nutrients, minerals, vitamins, hormones, waste
B. Regulation—of pH, fluid balance, body temperature
C. Protection—against foreign organisms, blood loss

II. Blood constituents

A. Plasma—liquid component
   1. Water—main ingredient
   2. Proteins—albumin, clotting factors, antibodies, complement
   3. Nutrients—carbohydrates, lipids, amino acids
   4. Electrolytes (minerals)
   5. Waste products
   6. Gases—oxygen and carbon dioxide
   7. Hormones and other materials
B. The formed elements—produced in red bone marrow from hematopoietic stem cells
   1. Erythrocytes (red cells)—carry oxygen bound to hemoglobin
   2. Leukocytes (white cells)—destroy invading organisms and remove waste
      a. Granulocytes—neutrophils (polymorphs, segs, PMNs), eosinophils, basophils
      b. Agranulocytes—lymphocytes, monocytes
   3. Platelets (thrombocytes)
      a. Fragments of megakaryocytes
      b. Participate in blood clotting

III. Hemostasis—prevention of blood loss

A. Contraction of blood vessels
B. Formation of platelet plug
C. Formation of blood clot
   1. Blood clotting

a. Regulators
   (1) Procoagulants—promote clotting
   (2) Anticoagulants—prevent clotting
b. 12 clotting factors
c. Final steps in blood clotting
   (1) Prothrombinase converts prothrombin to thrombin
   (2) Thrombin converts fibrinogen to solid threads of fibrin
   (3) Threads form clot
d. Serum—fluid that remains after blood has clotted

IV. Blood types

A. ABO blood type group—types A, B, AB, and O
   1. Tested by mixing blood sample with antisera to different antigens
   2. Incompatible transfusions cause destruction of donor red cells
B. Rh factor—positive or negative

V. Uses of blood and blood components

A. Blood banks—store blood
   1. Autologous blood—donated for a person's own use
B. Whole blood transfusions—used only to replace large blood losses
C. Use of blood components—formed elements separated by centrifugation
D. Use of plasma
   1. Protein fractions
   2. Cryoprecipitate—obtained by freezing; contains clotting factors
   3. Gamma globulin—contains antibodies

VI. Blood disorders

A. Anemia—lack of hemoglobin or red cells
   1. Loss or destruction of cells
   2. Impaired production of cells
      a. Deficiency anemia
      b. Pernicious anemia
      c. Bone marrow suppression
B. Leukemia—excess production of white cells
   1. Myelogenous leukemia—cancer of bone marrow
   2. Lymphocytic leukemia—cancer of lymphoid tissue
C. Clotting disorders
   1. Hemophilia—lack of clotting factors
   2. Thrombocytopenia—lack of platelets
   3. Disseminated intravascular coagulation (DIC)

VII. Blood studies

A. Hematocrit—measures percentage of packed red cells in whole blood
B. Hemoglobin tests—color test, electrophoresis
C. Blood cell counts
D. Blood slide (smear)
E. Blood chemistry tests—electrolytes, waste products, enzymes, glucose, hormones
F. Coagulation studies—clotting factor assays, bleeding time, clotting time, capillary strength, platelet function
G. Bone marrow biopsy

Questions for Study and Review

Building Understanding

Fill in the blanks

1. The liquid portion of blood is called _____.
2. The ancestors of all blood cells are called _____cells.
3. Platelets are produced by certain giant cells called _____.
4. Some monocytes enter the tissues and mature into phagocytic cells called _____.
5. Erythrocytes have a lifespan of approximately _____ days.

Matching

Match each numbered item with the most closely related lettered item.

___ 6. an increased erythrocyte count
___ 7. a decreased erythrocyte count
___ 8. an increased leukocyte count
___ 9. a decreased leukocyte count
___ 10. a decreased platelet count

a. thrombocytopenia
b. anemia
c. leukopenia
d. leukocytosis
e. polycythemia

Multiple choice

___ 11. Red blood cells transport oxygen that is bound to
   a. erythropoietin
   b. complement
   c. hemoglobin
   d. thrombin

___ 12. All of the following are granulocytes except
   a. lymphocytes
   b. neutrophils
   c. eosinophils
   d. basophils

___ 13. Antibodies are produced by
   a. erythrocytes
   b. macrophages
   c. plasma cells
   d. band cells

___ 14. The correct sequence of hemostatic events is
   a. vessel contraction, plug formation, and blood clot
   b. blood clot, plug formation, vessel contraction
   c. plug formation, blood clot, vessel contraction
   d. vessel contraction, blood clot, plug formation

___ 15. If one wanted to measure the number of eosinophils in a blood sample, he or she would conduct the following test:
   a. hematocrit
   b. electrophoresis
   c. complete blood cell count
   d. differential white blood cell count

Understanding Concepts

16. List the three main functions of blood. What is the average volume of circulating blood in the body?
17. Compare and contrast the following:
   a. formed elements and plasma
   b. erythrocyte and leukocyte
   c. hemorrhage and transfusion
   d. hemapheresis and plasmapheresis
18. List four main types of proteins in blood plasma and state their functions. What are some other substances carried in blood plasma?
19. Describe the structure and function of erythrocytes. State the normal blood cell count for erythrocytes.
20. Construct a chart that compares the structure and function of the five types of leukocytes. State the normal blood cell count for leukocytes
21. Diagram the three final steps in blood clot formation.
22. Name the four blood types in the ABO system. What antigens and antibodies (if any) are found in each type?
23. Compare and contrast the following disease conditions:
   a. hemolytic anemia and aplastic anemia
   b. myelogenous leukemia and lymphocytic leukemia
   c. hemophilia and von Willebrand disease

Conceptual Thinking

24. J. Regan, a 40-year-old firefighter, has just had his annual physical. He is in excellent health, except for his red blood cell count, which is elevated. How might Mr. Regan's job explain his polycythemia?
25. If leukemia is associated with an elevated white blood cell count, why is it also associated with an increased risk of infection?