

CHAPTER

23

The Hematologic and Lymphatic Systems



LEARNING OBJECTIVES

1. Describe the principal functions of the blood and its mechanisms to maintain homeostasis.
2. Identify the four plasma proteins and their chief functions.
3. Outline the structure and function of the red blood cells, white blood cells, and platelets.
4. Discuss the importance of chemotaxis and phagocytosis in fighting invading organisms.
5. Describe the mechanism of blood clotting.
6. Identify the four blood groups and the Rh factors.
7. Describe the blood groups that are considered the universal donor and the universal recipient and state why this is so.
8. Describe lymphatic circulation and the filtration role of the lymph nodes.
9. Describe the circle of Willis and the blood–brain barrier, including the function of each.
10. Explain the process of hepatic–portal circulation.
11. Discuss at least three normal changes in the hematologic and lymphatic systems caused by aging.

NEW TERMINOLOGY

agglutination	lymph
albumin	lymph node
anastomose	lymphocyte
coagulation	monocyte
crossmatching	phagocytosis
embolus	pinocytosis
endocytosis	plasma
erythrocyte	platelet
fibrin	prothrombin
fibrinogen	Rh factor
globulin	spleen
hematopoiesis	thrombin
hemorrhage	thrombocyte
hemostasis	thrombus
leukocyte	tonsil

ACRONYMS

BBB	RBC
Hb	Rh+
Hgb	Rh–
MABP	WBC

The hematologic system consists of the components of the blood (ie, plasma and formed elements) and the bone marrow, the primary organ that manufactures blood cells. The lymphatic system consists of the lymphatic vessels and tissues. Other organs and structures, such as the spleen, liver, and kidneys, also perform specific functions related to these systems.

STRUCTURE AND FUNCTION

The *hematologic system* has three general functions: transportation, regulation, and protection. These functions involve removal of hematologic waste products, delivery of nutrients

and oxygen to cells, blood volume regulation, blood cell and antibody production, and blood coagulation. The *lymphatic system* transports dietary fats to the blood, drains interstitial fluid, helps protect the body from infection, and provides immunity. It also returns any excess proteins that may escape from the blood vessels to the systemic circulation. Box 23-1 lists the functions of the hematologic and lymphatic systems.



Key Concept *The hematologic and lymphatic systems have transportation and protective functions in the body. Also, blood functions in regulatory processes in the body, and lymph functions in the manufacture of formed elements and the absorption and storage of substances in the body.*

BLOOD

Blood is a versatile vascular fluid that is heavier, thicker, and more viscous than water. Although it is a liquid, it has a unique quality that contributes to its ability to form solid clots. The primary objective of blood is to maintain a constant environment for the rest of the body's tissues. It maintains this homeostasis via its viscosity (thickness), its ability to carry dissolved substances, and its ability to move to all body parts. Blood is responsible for the transportation of oxygen, carbon dioxide, nutrients, heat, waste products, and hormones to and from the cells. It also helps regulate pH, body temperature, and cellular water content. It contributes to protection from blood loss and foreign body invasion.

Blood is considered a connective tissue because almost all of it is made of cells that share many characteristics with other connective tissues in terms of origin and development (Cohen & Wood, 2005). It differs from other connective tissues, however, in that its cells are not fixed, but move freely in the liquid portion of the blood known as *plasma*.

BOX 23-1. Functions of the Hematologic and Lymphatic Systems

Blood

Transportation

- Transports oxygen to body cells and carbon dioxide away from body cells
- Exchanges oxygen for carbon dioxide at cellular level
- Transports water, nutrients, and other needed substances, such as salts (electrolytes) and vitamins, to body cells
- Aids in body heat transfer
- Transports waste products from cells to be removed from the circulation (eg, kidney removes excess water, electrolytes, and urea; liver removes bile pigments and drugs)
- Transports hormones from sites of origin to organs they affect
- Transports enzymes

Regulation

- Contributes to regulation of body temperature
- Assists in maintenance of acid–base balance
- Assists in maintenance of fluid–electrolyte balance

Protection

- Fights disease and infection (leukocytes)
- Promotes clotting of blood (platelets and specialized factors)

- Provides immunity due to antibodies and antitoxins (specialized cells)

Lymph

Transportation

- Carries fluid away from tissues
- Carries wastes away from tissues

Absorption

- Absorbs fats and transports fats to blood (lacteals)
- Stores blood (spleen)
- Destroys worn-out erythrocytes

Protection

- Filters waste products out of blood
- Filters foreign substances out of blood (including dead blood cells, bacteria, smoke by-products, cancer cells)
- Destroys bacteria
- Participates in antibody production to fight foreign invasion

Manufacture

- Manufactures lymphocytes and monocytes
- Manufactures erythrocytes (spleen in fetus)

Hematopoiesis (hemopoiesis) refers to the production and maturation of blood cells. The red bone marrow manufactures all blood cells, or “formed elements,” in blood. Other tissues, such as tissues of the lymph nodes, spleen, and thymus, contribute to additional production and maturation of agranular white blood cells. *Erythropoiesis* refers to the formation of red blood cells (erythrocytes). A glycoprotein-type hormone, erythropoietin is secreted by the kidneys in the adult. This hormone stimulates the stem cells of bone marrow to produce the red blood cells.



Key Concept A form of erythropoietin, derived in DNA technology, may be used to treat the type of anemia caused by insufficient or ineffective RBCs. This is called recombinant human erythropoietin or epoetin alfa.

Blood is composed of both plasma and formed elements. It is carried through a closed system of vessels pumped by the heart (see Chap. 22). The volume of circulating blood differs with individual body size; however, the average adult body contains approximately 4 to 6 L.



Key Concept Blood is composed of plasma and formed elements.

Plasma

Blood **plasma** is the fluid portion of circulating blood. It constitutes 55% of blood volume. Plasma is 90% water. Its remaining 10% consists primarily of plasma proteins, but it

also includes salts (electrolytes), nutrients, nitrogenous waste products, gases, hormones, and enzymes.

The salts contained in the plasma are sodium (Na^+), calcium (Ca^+), potassium (K^+), and magnesium (Mg^{++}). The plasma also contains ions of other elements in the form of bicarbonates, sulfates, chlorides, and phosphates (see Chap. 17). Plasma absorbs these salts from food for use by body cells. The maintenance of these salts within the plasma controls the chemical and acid–base balance of the blood and contributes to the entire body’s chemical and fluid balance.

Plasma Proteins

Four groups of plasma proteins are manufactured in the liver. **Albumin** is the largest group, accounting for 60% to 80% of plasma proteins. Its important function is to provide thickness to the circulating blood volume, thus providing osmotic pressure. (Osmotic pressure draws water from surrounding tissue fluid into capillaries. Therefore, osmotic pressure maintains fluid volume and blood pressure.) Loss of albumin can result in dramatic fluid shifts, edema, hypotension, and even death. (The basis for these concepts is explained in Chap. 17.) **Fibrinogen** and **prothrombin** are two other plasma proteins; both are essential for blood clotting.

Globulin is the fourth type of plasma protein. Two types of globulin (alpha and beta) are made in the liver and act as carriers for molecules, such as fats. Gamma globulins (immunoglobulins [Ig]) are antibodies. Antibodies are materials that are synthesized by the body in response to antigens (foreign invaders), thus providing us with immunity against infection and disease (see Chap. 24).



Key Concept Albumin, the largest group of plasma proteins, helps maintain blood pressure and circulating fluid volume. The three other circulatory plasma proteins are fibrinogen, prothrombin, and globulin.

Formed Elements

The remaining 45% of blood volume consists of formed elements. These elements are red blood cells (RBCs), white blood cells (WBCs), and platelets. Figure 23-1 illustrates the various types of WBCs and RBCs.

Red Blood Cells

RBCs, also called **erythrocytes** (erythro = red; cyte = cell), are flattened, biconcave disks. (*Biconcave* means that both sides of the element are thinner in the center than at the edges.) When RBCs mature, they have no nucleus and thus cannot reproduce.

Erythrocytes are the most numerous of the blood cells. About 25 trillion RBCs are found in the body. Approximately 3,000 RBCs could be placed side by side within a 1-inch space. They are made from stem cells in red bone marrow. The RBCs are fragile and wear out quickly. The liver and the spleen destroy old, used RBCs. The life of an individual RBC is about 120 days.

Each RBC contains molecules of the compound hemoglobin (**Hgb** or **Hb**). Hemoglobin is composed of the iron-containing pigment *heme* and a protein, *globin*. (Iron is the pigment that makes RBCs appear red.) As blood passes through the lungs, the iron in hemoglobin picks up oxygen in a loose chemical combination (not a compound). When hemoglobin is saturated with oxygen, the blood is bright red. As blood circulates through the capillaries, the hemoglobin gives its oxygen to various cells of the body and picks up their carbon dioxide. The deoxygenated blood is much darker (almost maroon) in color.



Key Concept Iron in the hemoglobin picks up oxygen in the lungs. This oxygen is exchanged for carbon dioxide at the cellular level and returned to the lungs to complete the cycle.

White Blood Cells

WBCs, also known as **leukocytes** (*leuko* means white; *cyte* means cell), defend the body against disease organisms, toxins, and irritants. They differ greatly from RBCs. WBCs contain nuclei and can move independently in an amoeboid fashion. WBCs also assist in repairing damaged tissues. Sometimes they die during this activity and collect with bacteria to form *pus*.

There are two types of WBCs: granular and agranular.

Granular Leukocytes (Granulocytes). These are divided into three subgroups: basophils, eosinophils, and neutrophils.

- **Basophils** are involved in allergic and inflammatory reactions. These cells contain heparin (an anticoagulant) and histamine. Histamine is a chemical that is released when there is a foreign invader in the body, along with other substances in the basophil. These substances cause an inflammatory or a hypersensitivity reaction in the body, resulting in vasodilation and edema, itching, and possibly bronchial constriction. These signs and symptoms are the result of an allergic or inflammatory response.
- **Eosinophils** are characterized by a speckled or grainy cytoplasm and survive only about 12 hours to 3 days. They

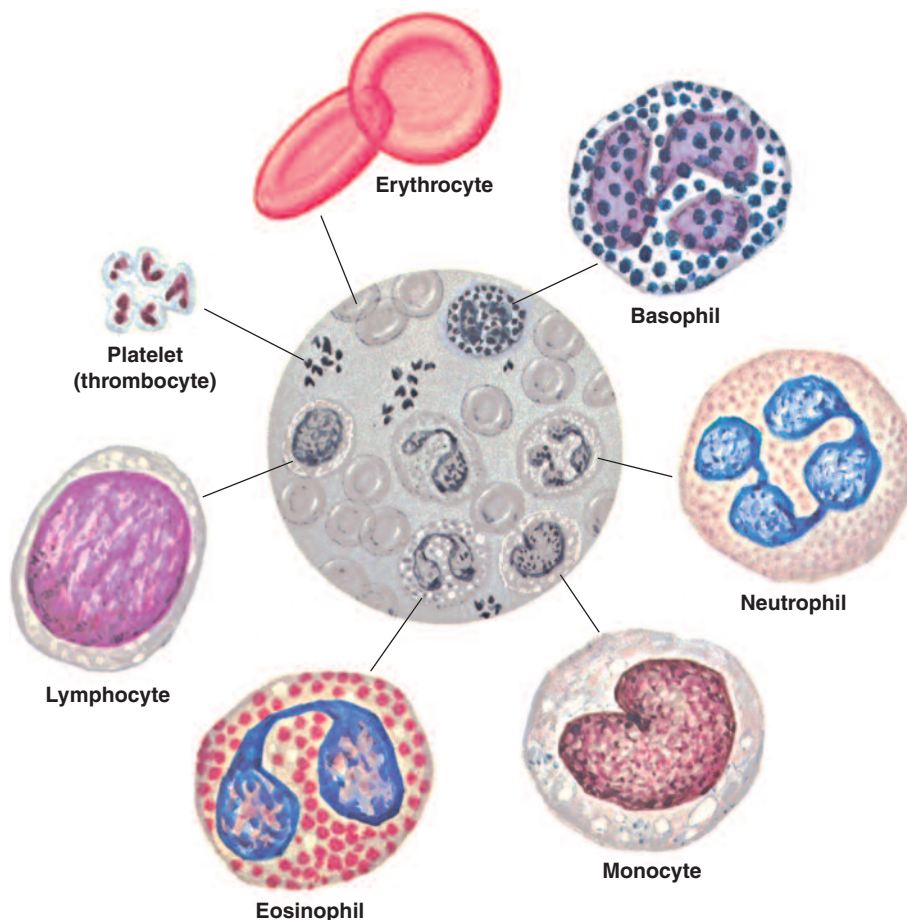


FIGURE 23-1. Normal types of blood cells. Erythrocytes are the red blood cells. Also shown are platelets (thrombocytes). All the other cells shown are types of white blood cells (leukocytes). Granulocytes (granular leukocytes) consist of the basophils, the neutrophils, and the eosinophils. Agranulocytes (agranular leukocytes) consist of the monocytes and lymphocytes.

increase in number during allergic reactions and parasitic infections and are believed to release chemicals to assist the body in detoxifying foreign proteins or engulfing and devouring invaders. The term **endocytosis** involves both **phagocytosis** (engulfing of particulate matter) and **pino-cytosis** (engulfing of extracellular *fluid* materials). Eosinophils may also have a role in decreasing the release of chemical mediators during allergic reactions.

- **Neutrophils** are the most numerous of WBCs. These can also be called *polymorphonuclear (PMNs)* or *segmented neutrophils (segs)*. Neutrophils are considered to be first in the line of defense against bacteria. Because of their ability to move away from blood vessels, neutrophils can move directly to sites of infection. They push or squeeze through the capillary wall and rush to the threatened spot. They find their way to foreign or damaged tissues by their attraction to certain chemical substances (*chemotaxis*). They are colorless unless they are stained to be visible under the microscope. The neutrophils increase in number and engulf and devour invaders (*phagocytosis* or *endocytosis*). Neutrophils increase in number during bacterial infections, burns, or inflammation. Because they have a short lifespan (approximately 10 hours), they need to be replaced frequently. When an infection occurs, more neutrophils are released from the bone marrow. When the demand for these granulocytes is very high, the bone marrow releases immature neutrophils called *bands*. When looking at WBC counts, *an increased number of bands signifies an infection*. This increase in bands may also be described as a “shift to the left.” Figure 23-2 illustrates phagocytosis.



Key Concept Blood cells have a short life-span and are constantly being manufactured in the body. The average lifespan for the different cells is:

- Red blood cells: 120 days
- Eosinophils: 12 hours to 3 days
- Neutrophils: 10 hours
- Monocytes and lymphocytes: 100 to 300 days

Agranular Leukocytes (Agranulocytes). These are divided into two subgroups: monocytes and lymphocytes. Under normal conditions, agranular lymphocytes are functional for about 100 to 300 days. They are produced in the lymphatic tissue of the spleen, lymph nodes, and thymus and in the hemopoietic tissues in red bone marrow.

- **Monocytes** are transformed into *macrophages*, which are phagocytic cells (as are the neutrophils). These WBCs play a role in acute and chronic inflammatory processes. A high monocyte count may be due to a viral or fungal infection, tuberculosis, or chronic diseases.
- **Lymphocytes** can be differentiated into various types. The most important of these are *B lymphocytes (B cells)* and *T lymphocytes (T cells)*. These lymphocytes play an important role in the immune response and are discussed in greater detail in Chapter 24. Lymphocytes increase in number during infectious processes that might be caused by viral infections or immune diseases.



Key Concept Granular leukocytes:

- **Basophils**—involved in the inflammatory process and allergic reactions
- **Eosinophils**—involved in allergic reactions and parasitic infections
- **Neutrophils**—involved in phagocytosis; defense against bacteria

Agranular leukocytes:

- **Monocytes**—transformed into macrophages; involved in phagocytosis
- **Lymphocytes**—involved in immune responses

Platelets

Platelets, also called **thrombocytes** (*thrombo* means clot; *cyte* means cell), are the smallest of blood's formed elements. They are not whole cells but rather are fragments of larger cells. They lack nuclei but are capable of amoeboid movement. They are formed in red bone marrow. Platelets

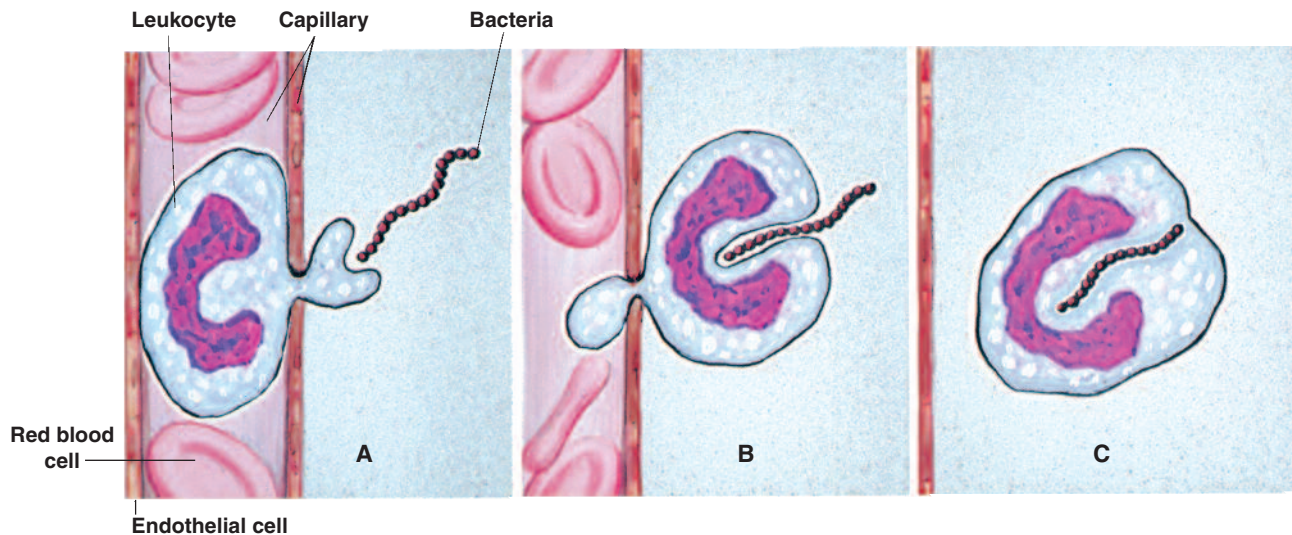


FIGURE 23-2. Phagocytosis. (A) Leukocytes squeeze out of blood vessels and rush to the site of an invading organism. (B) When foreign matter (such as bacteria or dead tissue [shown here as a streptococcus]) comes in contact with the cell membrane of the neutrophil, the cell membrane surrounds and pinches off the area, leaving the membrane intact. (C) Consequently, the engulfed material is enclosed in a membranous vesicle within the neutrophil, where enzymes within the cell destroy the foreign material.

are essential for blood clotting. Table 23-1 lists some normal laboratory values.

Blood Clotting and Hemorrhage

Hemostasis refers to the cessation of bleeding (*heme* = commonly used to denote blood; *stasi* = stopping). When damage or rupture occurs to blood vessels, the hemostatic response must be quick and carefully controlled to stop blood loss. This hemostatic initial response includes vascular spasm (vasoconstriction), platelet plug formation, and blood clotting (that is, the **coagulation** process that forms a fibrin clot) (Porth, 2004).

CONCEPTS in action **ANIMATION**

Clotting

Blood clotting protects the body from losing vital plasma fluid and blood cells by sealing off broken blood vessels. Without this action, individuals would not survive even minor cuts and wounds. The process of clot formation involves a number of complex activities within the blood, some of which are not totally understood. Figure 23-3 illustrates the clotting mechanism.

When a blood vessel is disrupted, platelets break down and cause the release of a chemical, *thromboplastin*, which interacts with certain protein factors and calcium ions to form *prothrombin activator*. This activator then reacts with additional calcium ions to convert the plasma protein *prothrombin* to **thrombin**. Thrombin then converts the soluble plasma protein *fibrinogen* into insoluble threads of **fibrin**. The threads of fibrin form a net to entrap RBCs and platelets to form a clot. This clot acts like a plug in a hole and tends to draw injured edges together. As the clot shrinks, a clear yellow liquid called *serum* is squeezed out. Serum is like plasma except that fibrinogen and other clotting elements needed in the coagulation process are now absent. Coagulation is a complicated mechanism that cannot occur if any necessary elements are missing. Vitamin K is necessary for the formation of prothrombin and other clotting factors. (Bacteria in the colon produce most vitamin K.)

A **thrombus** is a stationary clot. An **embolus** is a clot that circulates. Both of these clots can lead to death if they plug arteries to the heart, lungs, or brain. Several medications are available to treat blood clots and are discussed in Unit 9.



Key Concept The initial response to a disruption in a blood vessel includes vascular spasm (vasospasm), platelet plug formation, and the coagulation process that forms a fibrin clot. Platelets, calcium ions, and vitamin K are important elements in this complex coagulation process.

Hemorrhage

The literal definition of **hemorrhage** is escape of blood from blood vessels; however, hemorrhage is usually thought of as the loss of a considerable amount of blood. A cut or torn blood vessel allows blood to escape. Hemostatic mechanisms, such as clotting, are beneficial in preventing hemorrhage in smaller vessels, but extensive hemorrhage from larger vessels requires medical intervention (Tortora & Grabowski, 1996). Extensive or severe hemorrhage is serious because the body can lose so much fluid and oxygen-carrying RBCs that death may result. Inability to clot in extensive hemorrhage may be due to a variety of factors: force behind the flow of blood, size of the wound, volume of blood lost, or a deficiency in any of the coagulant substances. Severe hemorrhage is treated with blood replacement, using blood from another person. This replacement of blood is called a *transfusion*.



Key Concept Often, more blood is lost from a torn or nicked blood vessel than from a vessel that is cleanly cut through. The muscles in a blood vessel contract as a protective measure. If these muscles are cut unevenly, they cannot effectively close the blood vessel. Hemorrhage from an artery comes in spurts. Hemorrhage from a vein comes in a steady flow.

Blood Groups

Blood falls into one of four groups: A, B, AB, and O (Table 23-2). These blood types are inherited (genetic) combinations of antigens and antibodies found on the membranes of RBCs. **Crossmatching** is a laboratory test of donor and

Table 23-1. Selected Approximate Normal Laboratory Values*

	Male	Female	Newborn
Hemoglobin (Hgb)	14–18 g/dL	12–16 g/dL	16.5–19.5 g/dL Children vary by age.
Cell Counts			
Erythrocytes (RBCs)	4.6–6.2 million/mm ³	4.2–5.4 million/mm ³	Children vary by age.
Leukocytes (total) (WBCs)	(All adults) 5,000–9,000 million/mm ³		
Differential (Diff) in percentages			
Band neutrophils	3–5		
Segmented neutrophils	54–62		
Lymphocytes	25–33		
Monocytes	3–7		
Eosinophils	1–3		
Basophils	0–1		
Platelets	150,000–400,000/mm ³		

*Values vary slightly by laboratory.

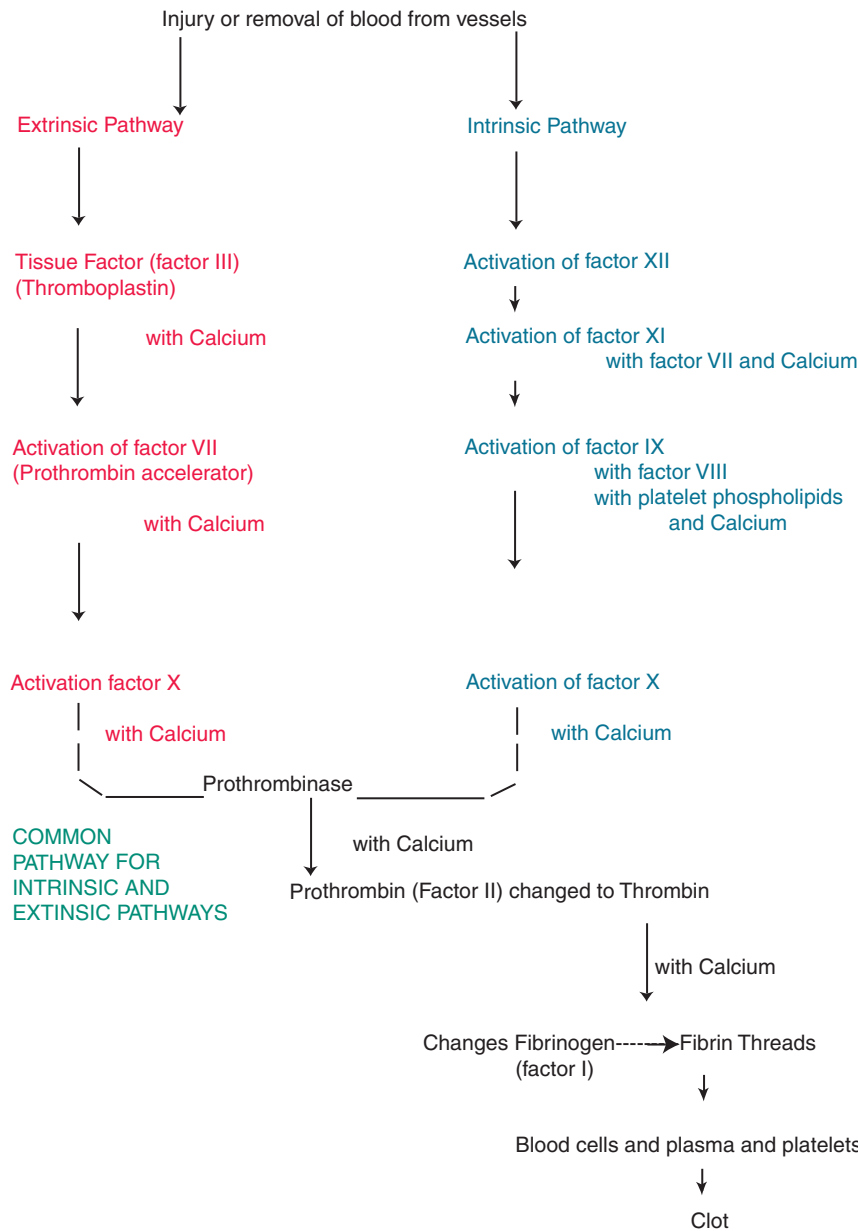


FIGURE 23-3. Final steps in the formation of a blood clot. (Cohen & Wood, 2005).

Table 23-2. Blood Groups and Compatibilities

Blood Group	Percent of Population	Antigen on Erythrocytes	Antibody in Plasma	Can Donate Red Blood Cells to	Can Receive Red Blood Cells From
A	41%	A	Anti-B (reacts against B antigen)	A or AB	A or O
B	10%	B	Anti-A (reacts against A antigen)	B or AB	B or O
AB	4%	A and B	None	AB	A, B, AB, or O*
O	45%	None	Anti-A and Anti-B (reacts against both A and B factors)	A, B, AB, or O†	O

*Blood group AB is known as the universal recipient because people of this group may receive red blood cells from donors of any ABO group in an extreme emergency.

†Blood group O is known as the universal donor because these red blood cells may be given to people of any ABO group in an extreme emergency.

recipient cells to check for **agglutination** (clumping of cells). If an incompatible type of blood is given to a person, a fatal transfusion reaction may result.

Except for blood types, no differences exist in the blood of healthy people of different races or genders. Blood does not carry or transmit mental, emotional, or physical characteristics.

Rh Factors

Just like a blood group, **Rh factors** are also inherited *antigens*. (The Rh system is named after the Rhesus monkey used in early experiments.) Of the several types of antigens that may be found on the surface of RBCs, more than 90 are loosely connected to the Rh system. The most commonly found Rh factor and the one most likely to cause a transfusion reaction is abbreviated D (Duffy). Blood is tested for the presence of D antigen.

If a person's blood contains D factor, the person is said to be Rh-positive (**Rh+** or D+); if this factor is absent, the person is Rh-negative (**Rh-**). The percentage of Rh-negative people is lower within some races; approximately 2% to 7% of African Americans and 1% of Asians and Native Americans are Rh-negative, while more than 10% of Caucasians are Rh-negative.

When an Rh-negative person receives Rh-positive blood, he or she develops antibodies that could cause a severe re-

action to subsequent blood transfusions. This can also occur in an Rh-positive pregnancy in an Rh-negative mother. (Unit 10 discusses in more detail the Rh factor and its effects on pregnancy.)

LYMPH

The lymphatic system is related to, yet separate from, the hematologic system. Body cells normally are bathed in tissue fluid. Some of this fluid drains into blood capillaries and flows directly to the veins. Another group of vessels, called *lymphatic vessels*, also drains this fluid. The lymphatic vessels begin as a network of tiny closed-ended lymphatic capillaries in spaces between cells. These capillaries are slightly larger than blood capillaries and have a unique structure that allows interstitial fluid to flow into them but not out. The excess fluid and certain other waste products that collect there form the thin, watery, colorless liquid known as **lymph**. Because lymph originally derives from plasma, its composition is much the same, except that lymph is lower in protein content. Specialized lymphatic capillaries called *lacteals* absorb digested fats and fat-soluble vitamins in the small intestine. Figure 23-4 depicts the lymphatic system.

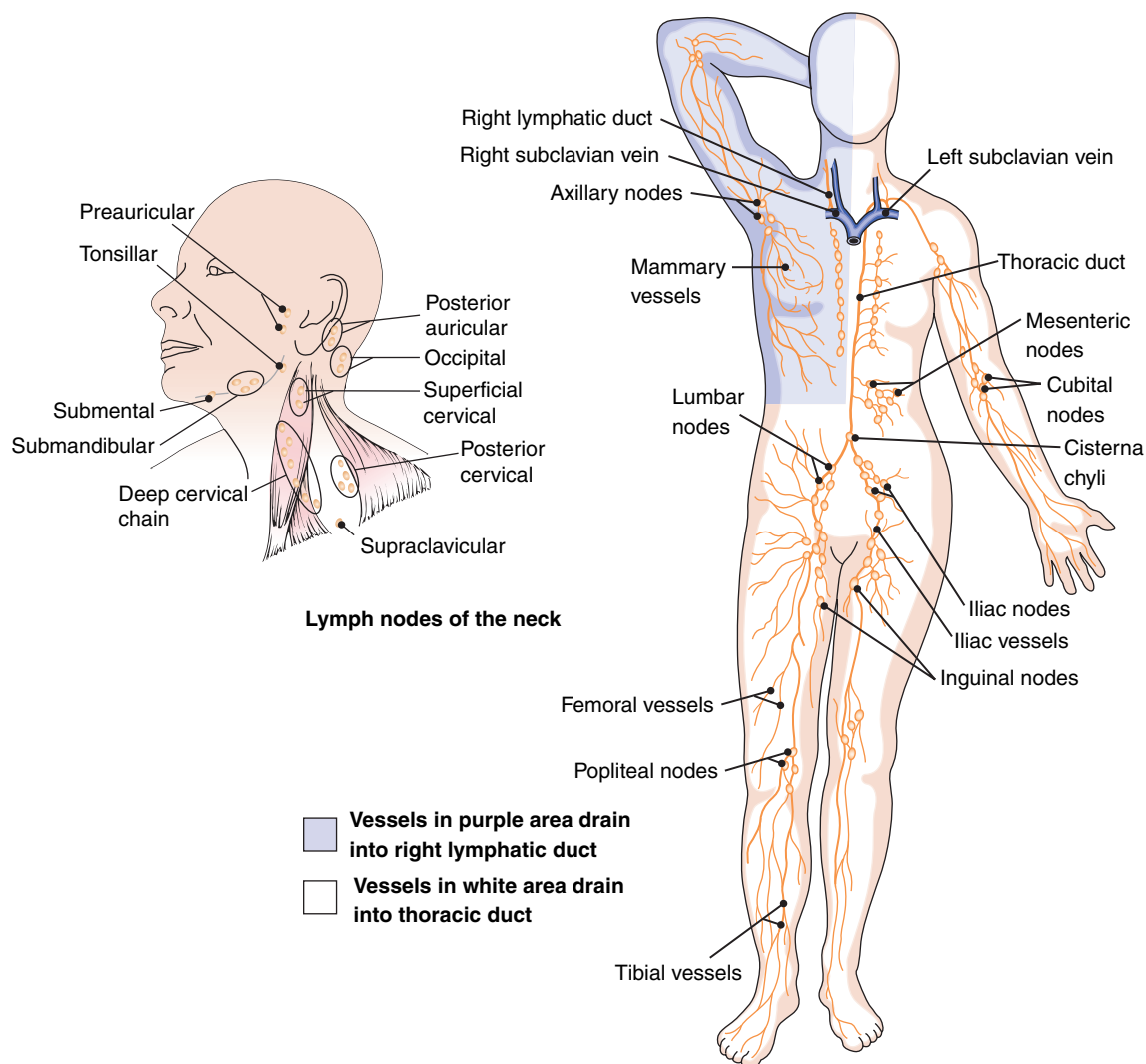


FIGURE 23-4. The lymphatic system. (Weber & Kelley, 2007.)

Movement of Lymph

Lymphatic vessels are thin-walled vessels with one-way valves that prevent backflow of lymphatic fluid. These vessels are located both superficially (near the skin surface) and deeper in the body. Most lymphatic vessels are located near the venous system and are named according to their body location. An example of this would be *femoral* lymphatic vessels that are located in the thighs. Lymphatic vessels carrying fluid eventually form a network of vessels in specific areas of the body. These areas are called *regional nodes*. After the fluid moves through the nodes, it is transported by other lymphatic vessels to either the right lymphatic duct or the thoracic duct.

Lymphatic fluid is propelled through the body by rhythmic contractions. These contractions occur due to changes in abdominal and thoracic pressure during breathing and also due to skeletal muscle contractions that promote the return of venous blood—and subsequently lymphatic fluid—to the heart.

Lymph Nodes and Nodules

Small bundles of special lymphoid tissue termed **lymph nodes** are situated in clusters along the lymphatic vessels. Many of these nodes appear in the neck (*cervical*), groin (*inguinal*), and armpits (*axillary*) (see Fig. 23-4). Before lymph reaches the veins, it passes through these nodes. A capsule of connective tissue covers each node. Each node is densely packed with lymphocytes.

Lymph nodes perform several vital functions. The most important is that of filtration. The “swollen glands” that may appear in a person’s cervical, inguinal, and axillary regions during illness are really lymph nodes at work. They are trying to filter and destroy pathogens. The nodes have enlarged as their macrophages (phagocytic cells) eat and destroy invaders. When palpated, these enlarged, nonmalignant nodes are soft and tender. They may become quite painful.

Lymph nodules are small masses of nonencapsulated lymphatic tissues that stand guard in all mucous membranes. Because membranes line cavities that open to the external environment, nodules are in strategic locations to filter substances that enter the body. Mucous membranes line the respiratory, gastrointestinal, urinary, and reproductive tracts. Some areas of lymph nodules or tissues have special names: for example, Peyer’s patches, which are found in the small intestine.

Lymph Nodes and Cancer

Cancer cells can travel from their primary site of invasion to distant sites by way of the lymph nodes. Lymph nodes may either function to filter out cancer cells or may inadvertently spread cancer to other body sites. For this reason, when cancer surgery is performed, the lymph nodes in the area are also tested. If no cancer cells are present in adjoining lymph nodes, the cancer was most likely localized to its original site. If the cancer is found in the lymph nodes, it is said to be *spreading* or *metastasizing*. In some cases, the adjoining lymph nodes are removed during surgery. Removal may be a precautionary measure or may be necessary because the nodes already contain cancer cells. Palpable cancerous lymph nodes may be enlarged and, unlike nodes fighting infection, feel firm and nontender.



Key Concept *Lymph nodes function to filter and destroy pathogens. Swollen glands are a sign of the lymph nodes trying to rid the body of these pathogens. Lymph nodes may also be invaded by cancer cells and may actually serve as reservoirs from which the cancer cells are spread throughout the body. This is why lymph nodes are tested for the presence of malignant cells and often removed along with a cancerous (malignant) tumor, whether or not they show malignancy.*

Lymphatic Organs

The lymphatic organs are the tonsils, spleen, and thymus. They are masses of lymphatic tissue with somewhat different functions than those of the lymph vessels or nodes. The tonsils and spleen are designed to filter tissue fluid, although not necessarily lymph. The thymus plays a more active role in the development of the immune system and is discussed in greater detail in Chapter 24.

Tonsils

Tonsils form a ring of lymphatic tissue around the pharynx (See Fig. 26-2.) This tissue forms a protective barrier for substances entering the oral and respiratory passages. The tonsils may become so loaded with bacteria that removal (tonsillectomy) is advisable. A slight enlargement, however, is not an indication for surgery.



Key Concept *In years past, many children had their tonsils removed. Today, tonsillectomy usually is performed only if absolutely necessary because of the tonsils’ filtration and protective functions.*

Spleen

The **spleen** is an organ containing lymphoid tissue designed to filter blood. It is a somewhat flattened, dark purple organ about 6 inches (15.24 cm) long and 3 inches (7.62 cm) wide. It is located directly below the diaphragm, above the left kidney, and behind the stomach.

The spleen has several functions. In the fetus, the spleen (along with the liver) has a role in blood cell formation (later this role is taken over by the red bone marrow). In an adult, the spleen destroys old RBCs and forms *bilirubin* from the hemoglobin in RBCs. It acts as a reservoir for blood, which can be released to the body quickly in an emergency such as a hemorrhage. The spleen also filters and destroys pathogens and other foreign materials in the blood. Specially treated B lymphocytes that produce antibodies against foreign antigens and T lymphocytes that attach to invading viruses or foreign entities are contained in the spleen. Both of these types of lymphocytes have an active role in the immune system of the body (see Chap. 24). The spleen also contains monocytes, which become macrophages in the spleen to fight infection by the mechanism of phagocytosis. All of these agranulocytes help the body fight infection in different ways.

Although its functions are important, the spleen can be removed without ill effects. An adult without a spleen, however, is more susceptible to some bacterial infections, such as

pneumonia and meningitis. After the spleen is removed, the liver, bone marrow, and lymph nodes assume some of the spleen's functions.



Key Concept *The spleen destroys old RBCs, filters and destroys pathogens, manufactures lymphocytes and monocytes, and is a reservoir for blood.*

SYSTEM PHYSIOLOGY

Blood Circulation

Blood flows in a circuitous route throughout the entire body. The blood vessels, subdivided into two *circuits* (pulmonary and systemic), together with the four chambers of the heart, form the closed system for the flow of blood (see Chap. 22).

Pulmonary Circulation

The phase of circulation in which blood is pumped through the lungs to get rid of waste products (particularly CO₂) and to pick

up a supply of oxygen (O₂) is called *pulmonary circulation*. Blood in the general (systemic) circulation returns to the *right atrium* of the heart. It passes into the *right ventricle* and then into the *pulmonary artery* (the only artery in the body that carries unoxygenated blood). The blood continues to capillaries in the lungs, where carbon dioxide, carried in hemoglobin, is exchanged for oxygen from the lungs. Small veins collect the blood from the lung capillaries. These veins combine eventually into four *pulmonary veins*, which pour oxygenated blood into the *left atrium* of the heart. (The pulmonary veins are the only veins that carry oxygenated blood.) Figure 23-5 illustrates pulmonary and systemic circulation.

Systemic Circulation

From the left atrium, the oxygenated blood enters the *left ventricle*. The left ventricle pumps the blood out of the left side of the heart into the general circulation or *systemic circulation*. As stated previously, the purpose of the blood circulation is to carry nutrients and oxygen to body cells and to return with accumulated waste products. As blood leaves the left ventricle, it surges into the largest artery of the body, the *aorta*. The aorta is further divided into the *ascending aorta*, *aortic arch*,

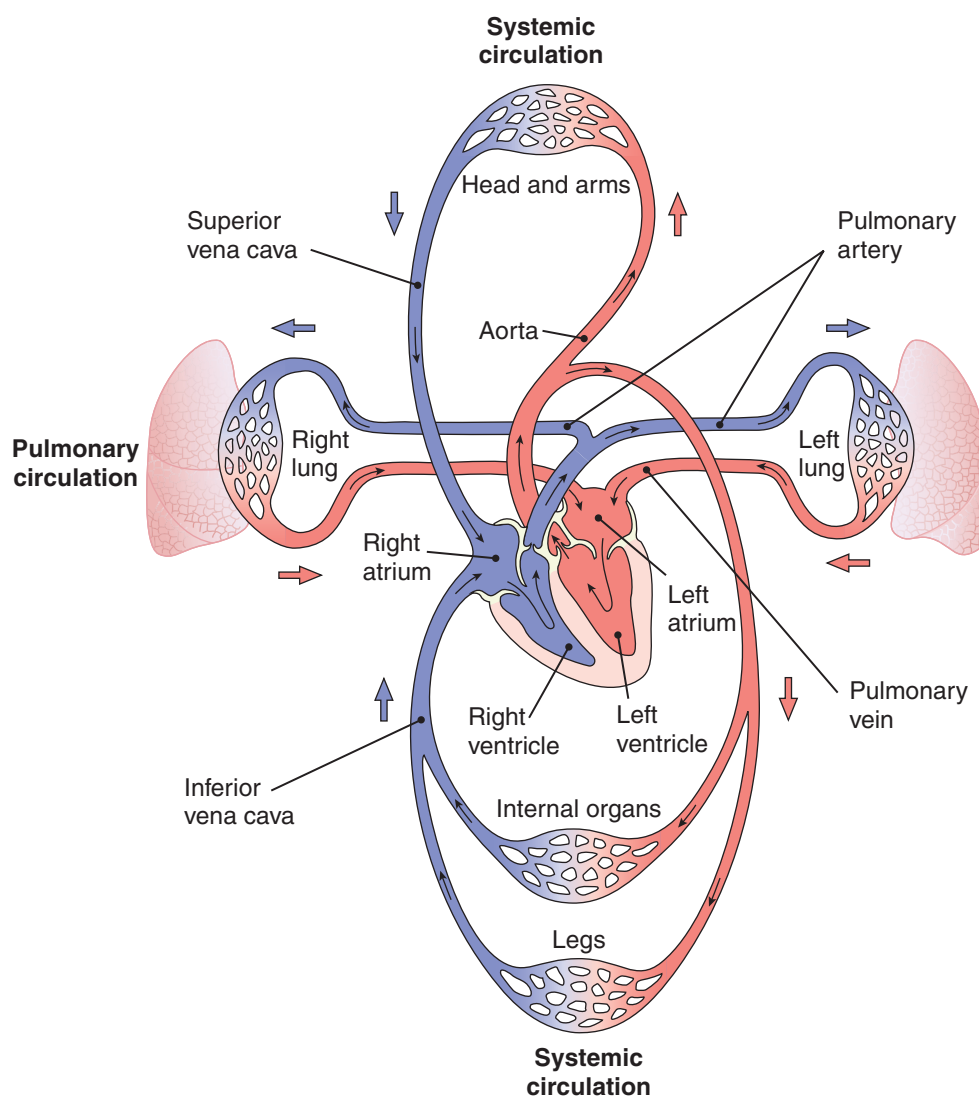


FIGURE 23-5. The heart is a double pump. The *pulmonary circuit* carries blood to the lungs to be oxygenated; the *systemic circuit* carries blood to all other parts of the body.

thoracic aorta, and *abdominal aorta*, which is divided into smaller arteries. The blood travels through smaller and smaller arterial branches. From the smallest arteries, the *arterioles*, the blood enters the capillaries, where oxygen and food are exchanged for waste products. Chapter 17 describes the processes by which these exchanges occur. The blood then begins its journey back to the heart from capillaries to *venules*, then to larger *veins*, and finally through the *inferior* and *superior vena cavae* to the right atrium, thereby completing the circuitous route.

Hepatic–Portal Circulation. The hepatic–portal circulation is a subdivision of systemic circulation. It is an efficient detour in the pathway of venous return, directed at transporting raw materials in the form of carbohydrates, fats, and proteins from the digestive organs and the spleen to the liver.

The hepatic–portal circulation is unique because it begins and ends with capillaries (Fig. 23-6). The capillaries from the stomach, intestine, spleen, and pancreas empty into veins. These veins drain into a common vessel, the *portal vein*, which leads into the liver.

In the liver, blood again enters capillaries, called *sinusoids*. Here, the liver extracts appropriate materials and chemically modifies them. The liver synthesizes, stores, detoxifies, regulates, and transforms these raw materials into useful substances that the entire body needs. The useful substances and the blood then empty into the *hepatic vein*. The hepatic vein leads to the *inferior vena cava*. Chapter 26 describes digestion and the functions of the liver in more detail.

Cerebral Circulation

Circulation to the brain is vital in maintaining life and the ability to function. Anteriorly, one branch of the *common carotid artery* is the *internal carotid artery*. The internal carotid **anastomoses** (connects) with the circle of Willis (see below), thus providing oxygenated blood to the brain.

Oxygenated blood also arrives at the brain by another route. The *right vertebral artery* and *left vertebral artery* branch off from the *subclavian artery* at the posterior aspect of the brain. These two vertebral arteries join at the brain stem and create the *basilar artery*. From here, blood is transported to the circle of Willis.

The *circle of Willis (cerebral arterial circle)* is formed by the *anterior communicating artery*, *posterior communicating artery*, *anterior cerebral artery*, *posterior cerebral artery*, and *internal carotid artery*. Figure 23-7 shows the arteries that supply the brain, including the arteries of the circle of Willis. All of these arteries supply different areas of the brain with blood. Blood returns to the heart via venous sinuses that transport blood to the internal jugular veins and back to the heart.

Cerebral blood flow is 10% to 15% of the total cardiac output. One factor that impacts blood flow is blood pressure. Adequate *cerebral perfusion* (blood flow to the brain) is required. The mean arterial blood pressure (**MABP**) is calculated based upon the relationship of the sBP and the dBP. The brain requires a continuous flow of blood because it requires a constant supply of oxygen and nutrients (specifically glucose) to survive. The brain does not have the ability to create a collateral circulation, as does the heart in some cases.

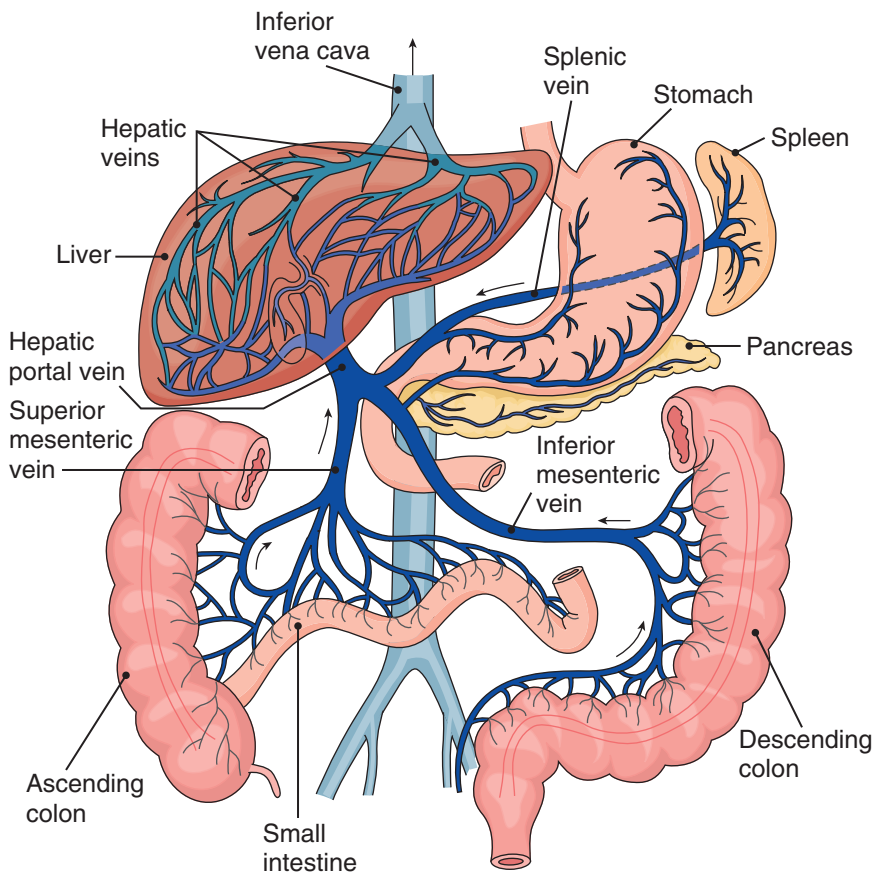


FIGURE 23-6. Hepatic–portal circulation.

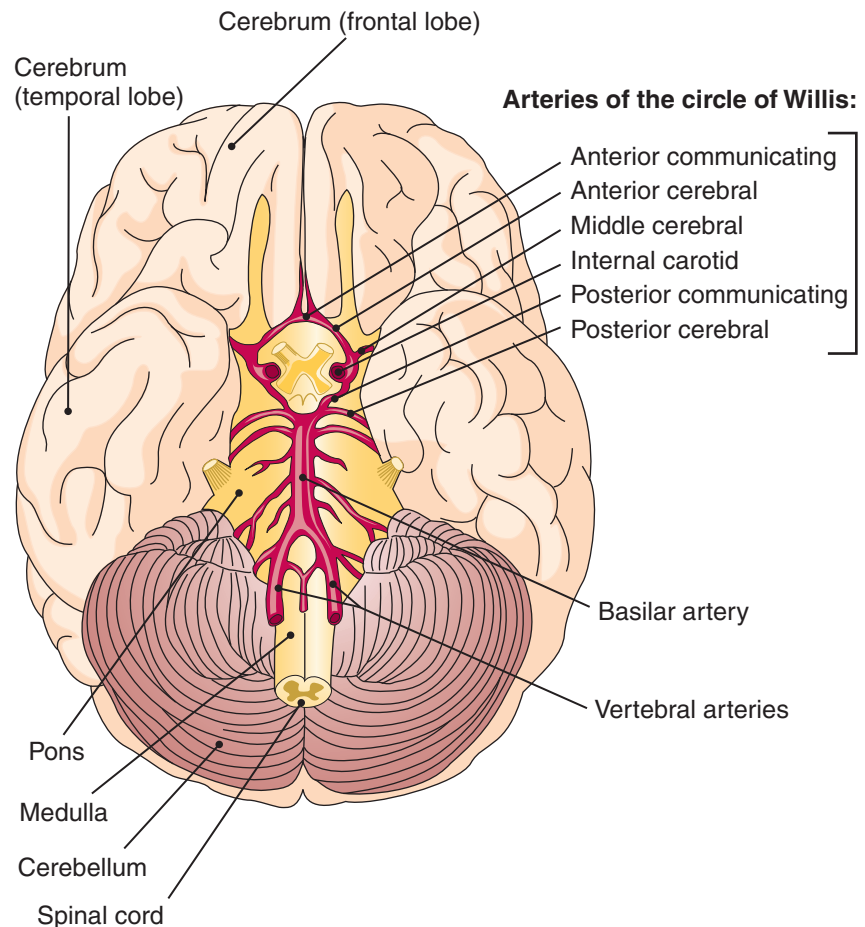


FIGURE 23-7. Arteries that supply the brain, viewed from behind. The arteries that make up the circle of Willis are shown in the center of the brain.

The circle of Willis is important because it allows blood to continue to flow in the brain if there is a blockage in one of the arteries that supplies the circle of Willis. An *embolus* is a clot that can lodge in an artery, thereby causing a blockage. In the brain, the *middle cerebral artery* branch is the most likely location for emboli (Porth, 2004). A disruption of blood flow for any reason, for even a short period of time, can cause unconsciousness. Brain damage or death can occur if the disruption lasts for more than a few minutes (due to brain cell death).

Blood–Brain Barrier. The blood–brain barrier (BBB) is an “adaptation of the circulation” that protects the brain. Specialized cells in brain capillaries allow only certain substances from the blood to enter the brain. Capillaries in the brain are less permeable and much tighter than other capillaries in the body, thus limiting what substances are admitted into the cerebral circulation and to the brain tissue.) Also, specialized brain neuroglia called *astrocytes* assist in creating selective permeability in the brain.



Key Concept The blood–brain barrier works to protect the brain from harmful substances.

Lymphatic Circulation

Lymph only carries fluid *away* from tissues. It does not have a pumping system of its own. Its circulation depends on the movement of skeletal muscles. As stated previously, muscu-

lar contractions and pressure changes that the thoracic cavity produces during respiration also assist with lymph circulation.

The lymph from the upper right quadrant of the body drains into the *right lymphatic duct*. The remainder of the body’s lymph drains into the left lymphatic duct, commonly known as the *thoracic duct*. The right lymphatic duct and the thoracic duct then drain into the *left subclavian vein* at the base of the neck, where lymph mixes with blood plasma and becomes part of the general circulation.

Lymph enters lymph nodes through several *afferent* (“bringing toward”) lymph vessels. The lymph nodes filter out dangerous substances (such as cancer cells and bacteria), dead RBCs, and foreign matter (eg, smoke by-products) that become trapped in the nodes. The lymph then continues to flow away from the node through one or two *efferent* (“taking away”) lymph vessels into the bloodstream. Plasma cells and lymphocytes that have reproduced within a lymph node can also be added to lymph for transportation to the blood.

Disorders of the blood and lymph can be quickly life-threatening. Chapter 80 discusses heart and blood vessel disorders; Chapter 81 describes blood and lymph disorders; and Chapter 82 discusses cancer, which is often spread via the lymphatic system.

EFFECTS OF AGING ON THE SYSTEM

In the older adult, hematopoiesis may decline due to a loss of active bone marrow. Alterations in tissue oxygenation may therefore occur, especially during periods of stress, due

Table 23-3. Effects of Aging on the Hematologic and Lymphatic Systems

Factor	Result	Nursing Implications
Stem cells and marrow reserves decrease	Increased vulnerability to problems with clotting, oxygen transport, and fighting infection Decreased blood volume	Assess the aging adult for a weakened ability to compensate for illness or injury.
Hemoglobin levels decrease	May be secondary to decreased intake of iron-rich foods	Assess for evidence of gastrointestinal or other internal bleeding before concluding that anemia is due to aging. Ensure adequate dietary intake of iron-rich foods. Encourage regular medical check-ups, including colon and bladder exams. Assess PSA in men.
Leukocyte production decreases	Less of a response to infection; may feel less pain	Monitor closely for early signs of infection (eg, increased fatigue, anorexia, or mental confusion) because the body may not show fever or elevated leukocyte count.

to ineffective RBC production. The number of platelets in older adults may also slightly decrease, although fibrinogen levels and coagulation factors may increase. WBC production itself typically shows no real change. However, age-related changes in organs of the immune system can result

in altered antigen-antibody responses and increased incidence of infection. Blood volume is reduced in older adults, due to decreased muscle mass and metabolic rate. The range for albumin also drops. Table 23-3 presents the effects of aging on these systems.

STUDENT SYNTHESIS

KEY POINTS

- The functions of the hematologic system include transportation, regulation, and protection.
- Hematopoiesis, the formation of blood cells, originates in stem cells in red bone marrow.
- Blood is composed of plasma and formed elements, including RBCs, WBCs, and platelets.
- Plasma is 90% water. The remaining 10% is composed of proteins, salts, nutrients, wastes, gases, hormones, and enzymes.
- Erythrocytes, or RBCs, are the most numerous of the blood cells. Each RBC contains hemoglobin, which is responsible for carrying oxygen.
- WBCs fight infection. Each of the five types (basophil, eosinophil, neutrophil, lymphocyte, monocyte) has different mechanisms to combat invaders.
- Platelets and numerous clotting factors must react in sequence before clotting of blood can occur.
- Hemorrhage is usually thought of as the loss of a considerable amount of blood. Hemostasis refers to the stoppage of bleeding.
- The ABO and Rh blood groups are inherited combinations of antigens and antibodies.
- Lymph tissues filter blood, destroy pathogens, and develop antibodies against antigens.
- Lymphatic organs include the tonsils, spleen, and thymus.
- The pulmonary circulation allows blood to be oxygenated for distribution in the systemic circulation.
- The largest circulatory route is the systemic circulation, which transports oxygen, nutrients, and wastes to and from all body cells.

- Several arteries come together in the brain to form the circle of Willis. This arterial circle helps to maintain and protect cerebral blood flow to the brain.
- The blood-brain barrier selectively determines what substances will enter the brain from the blood. Its purpose is to prevent harmful substances from entering the brain.
- The hepatic-portal circulation moves venous blood from the abdominal organs (GI system, pancreas, spleen) to the liver via the portal vein. The blood travels through the liver, where it undergoes a variety of changes before entering the hepatic vein and then the inferior vena cava that will transport blood back to the heart.
- The lymph system drains interstitial fluid into lymphatic vessels, which empty into the veins.

CRITICAL THINKING EXERCISES

1. Explain how blood, interstitial fluid, and lymph are related to the maintenance of homeostasis.
2. Explain why you think some people choose to have some of their own blood removed and stored for possible future use in an emergency.
3. Discuss how inhalation promotes or inhibits the flow of lymphatic fluid.

NCLEX-STYLE REVIEW QUESTIONS

1. Which of the following helps maintain circulating blood volume?
 - a. Albumin
 - b. Fibrin
 - c. Globin
 - d. Thrombin

2. Which blood group is known as the universal donor?
 - a. A
 - b. AB
 - c. B
 - d. O
3. The effects of normal aging often include which of the following?
 - a. Bone marrow reserves increase
 - b. Hemoglobin levels decrease
 - c. Leukocyte production increases
 - d. Vulnerability to infection decreases
4. A client with a bacterial infection would most likely show an increase in which of the following?
 - a. Neutrophils
 - b. Eosinophils
 - c. Basophils
 - d. Monocytes
5. Which of the following is essential for the formation of clotting factors?
 - a. Vitamin C
 - b. Vitamin D
 - c. Vitamin E
 - d. Vitamin K