THE CIRCULATORY SYSTEM

LEARNING OBJECTIVES:

Identify the parts of the circulatory system.

Explain the major components and functions of the circulatory system.

The circulatory system called the vascular system consists of blood, heart, and blood vessels. The circulatory system is close circuited (i.e., there is no opening to external environment of the body). The function of this system is to move blood between the cells and the organs of the integumentary, digestive, respiratory, and urinary systems that communicate with the external environment of the body. This function is facilitated by the heart pumping blood through blood vessels. The blood travels throughout the body transporting nutrients and wastes, and permitting the exchange of gases (carbon dioxide and oxygen).

BLOOD

Blood is fluid tissue composed of formed elements (i.e. cells) suspended in plasma. It is pumped by the heart through arteries, capillaries, and veins to all parts of the body. Total blood volume of the average adult is 5 to 6 liters.

Plasma

Plasma is the liquid part of blood (Fig. 6-34). Plasma constitutes 55 percent of whole blood (plasma and cells). It is a clear, slightly alkaline, straw-colored liquid consisting of about 92 percent water. The remainder is made up mainly of proteins. One of these proteins, fibrinogen, contributes to coagulation.

Blood Cells

The blood cells suspended in the plasma constitute 45 percent of whole blood. Its cells, which are formed mostly in red bone marrow, include red blood cells (RBCs) and white blood cells (WBCs). The blood also contains cellular fragments called blood platelets. When blood components are separated, the WBCs and platelets form a thin layer, called the buffy coat, between the layers of plasma and RBCs. These layers are illustrated in Figure 6-34.

Figure 6-34.—Blood Sample Illustrating Blood Components
RED BLOOD CELLS.—Red blood cells (RBC), or erythrocytes, are small, biconcave, non-nucleated disks, formed in the red bone marrow (Fig. 6-35). Blood of the average man contains 5 million red cells per cubic millimeter. Women have fewer red cells, 4.5 million per cubic millimeter. Emotional stress, strenuous exercise, high altitudes, and some diseases may cause an increase in the number of RBCs.

During the development of the red blood cell, a substance called hemoglobin is combined with it. Hemoglobin is the key of the red cell's ability to carry oxygen and carbon dioxide. The main function of erythrocytes is the transportation of respiratory gases. The red cells deliver oxygen to the body tissues, holding some oxygen in reserve for an emergency. Carbon dioxide is picked up by the same cells and discharged via the lungs.

The color of the red blood cell is determined by the hemoglobin content. Bright red (arterial) blood is due to the combination of oxygen and hemoglobin. Dark red (venous) blood is the result of hemoglobin combining with carbon dioxide.

Red blood cells live only about 100 to 120 days in the body. There are several reasons for their short life span. These delicate cells have to withstand constant knocking around as they are pumped into the arteries by the heart. These cells travel through blood vessels at high speed, bumping into other cells, bouncing off the walls of arteries and veins, and squeezing through narrow passages. They must adjust to continual pressure changes. The spleen is the graveyard where old, worn out cells are removed from the blood stream. Fragments of red blood cells are found in the spleen and other body tissues.

WHITE BLOOD CELLS.—White blood cells (WBC), or leukocytes, are almost colorless, nucleated cells originating in the bone marrow and in certain lymphoid tissues of the body (Fig. 6-35). There is only one white cell to every 600 red cells. Normal WBC count is 6,000 to 8,000 per cubic millimeter. The number of white cells may be 15,000 to 20,000 or higher during infection.

Figure 6-35.—The formed elements of blood. Red blood cells (erythrocytes), white blood cells (leukocytes), and platelets (thrombocytes) constitute the formed elements of blood.


6-45
Leukocytes are important for the protection of the body against disease. Leukocytes can squeeze between the cells that form blood cell walls. This movement, called diapedesis, permits them to leave the bloodstream through the capillary wall and attack pathogenic bacteria. They can travel anywhere in the body and are often named the wandering cells. They protect the body tissues by engulfing disease-bearing bacteria and foreign matter, a process called phagocytosis. When white cells are undermanned, more are produced, causing an increase in their number and a condition known as leukocytosis. Another way WBCs protect the body from disease is by producing bacteriolysins that dissolve the foreign bacteria. The secondary function of WBCs is to aid in blood clotting.

**BLOOD PLATELETS.** — Blood platelets, or thrombocytes, are irregular- or oval-shaped discs in the blood that contain no nucleus, only cytoplasm (Fig. 6-35). They are smaller than red blood cells and average about 250,000 per cubic millimeter of blood. Blood platelets play an important role in the process of blood coagulation, clumping together in the presence of jagged, torn tissue.

**Blood Coagulation**

To protect the body from excessive blood loss, blood has its own power to coagulate, or clot. If blood components and linings of vessels are normal, circulating blood will not clot. Once blood escapes from its vessels, however, a chemical reaction begins that causes it to become solid. Initially a blood clot is a fluid, but soon it becomes thick and then sets into a soft jelly that quickly becomes firm enough to act as a plug. This plug is the result of a swift, sure mechanism that changes one of the soluble blood proteins, fibrinogen, into an insoluble protein, fibrin, whenever injury occurs.

Other necessary elements for blood clotting are calcium salts; a substance called prothrombin, which is formed in the liver; blood platelets; and various factors necessary for the completion of the successive steps in the coagulation process.

Once the fibrin plug is formed, it quickly enmeshes red and white blood cells and draws them tightly together. Blood serum, a yellowish clear liquid, is squeezed out of the clot as the mass shrinks. Formation of the clot closes the wound, preventing blood loss. A clot also serves as a network for the growth of new tissues in the process of healing. Normal clotting time is 3 to 5 minutes, but if any of the substances necessary for clotting are absent, severe bleeding will occur.

Hemophilia is an inherited disease characterized by delayed clotting of the blood and consequent difficulty in controlling hemorrhage. Hemophiliacs can bleed to death as a result of minor wounds.

**THE HEART**

The heart is a hollow, muscular organ, somewhat larger than the closed fist, located anteriorly in the chest and to the left of the midline. It is shaped like a cone, its base directed upward and to the right, the apex down and to the left. Lying obliquely in the chest, much of the base of the heart is immediately posterior to the sternum.
Heart Composition

The heart is enclosed in a membranous sac, the pericardium. The smooth surfaces of the heart and pericardium are lubricated by a serous secretion called pericardial fluid. The inner surface of the heart is lined with a delicate serous membrane, the endocardium, similar to and continuous with that of the inner lining of blood vessels.

The interior of the heart (Fig. 6-36) is divided into two parts by a wall called the interventricular septum. In each half is an upper chamber, the atrium, which receives blood from the veins, and a lower chamber, the ventricle, which receives blood from the atrium and pumps it out into the arteries. The openings between the chambers on each side of the heart are separated by flaps of tissue that act as valves to prevent backward flow of blood. The valve on the right has three flaps, or cusps, and is called the tricuspid valve. The valve on the left has two flaps and is called the mitral, or bicuspid, valve. The outlets of the ventricles are supplied with similar valves. In the right ventricle, the pulmonary valve is at the origin of the pulmonary artery. In the left ventricle, the aortic valve is at the origin of the aorta. See Figure 6-36 for valve locations.

The heart muscle, the myocardium, is striated like the skeletal muscles of the body, but involuntary in action, like the smooth muscles. The walls of the atria are thin with relatively little muscle fiber because the blood flows from the atria to the ventricles under low pressure.

However, the walls of the ventricles, which comprise the bulk of the heart, are thick and muscular. The wall of the left ventricle is considerably thicker than that of the right because more force is required to pump the blood into distant or outlying locations of the circulatory system than into the lungs located only a short distance from the heart.

Heart Functions

The heart acts as four interrelated pumps. The right atrium receives deoxygenated blood from the body via the superior and inferior vena cava. It pumps the deoxygenated blood through the tricuspid valve to the right ventricle. The right ventricle pumps the blood past the pulmonary valve through the pulmonary artery to the lungs, where it is oxygenated. The left atrium receives the oxygenated blood from the lungs through four pulmonary veins and pumps it to the left ventricle past the mitral valve. The left ventricle pumps the blood to all areas of the body via the aortic valve and the aorta.

The heart's constant contracting and relaxing forces blood into the arteries. Each contraction is followed by limited relaxation or dilation. Cardiac muscle never completely relaxes: It always maintains a degree of tone. Contraction of the heart is called systole or "the period of work." Relaxation of the heart is called diastole or "the period of rest." A complete cardiac cycle is the time from onset of one contraction, or heart beat, to the onset of the next.
Figure 6-36.—Chambers and valves of the heart. A, During atrial contraction cardiac muscle in the atrial wall contracts, forcing blood through the atrioventricular (AV) valves and into the ventricles. Bottom illustration shows superior view of all four valves, with semilunar (SL) valves closed and AV valves open. B, During ventricular contraction that follows, the AV valves close and the blood is forced out of the ventricles through the SL valves and into the arteries. Bottom illustration shows superior view of SL valves open and AV valves closed.

Cardiac Cycle

The cardiac cycle is coordinated by specialized tissues that initiate and distribute electrical (cardiac) impulses (Fig. 6-37). The contractions of the heart are stimulated and maintained by the sinoatrial (SA) node, commonly called the pacemaker of the heart. The SA node is an elongated mass of specialized muscle tissue located in the upper part of the right atrium. The SA node sets off cardiac impulses, causing both atria to contract simultaneously. The normal heart rate, or number of contractions, is about 80 beats per minute. This same cardiac impulse continues to travel to another group of specialized tissues called the atrioventricular (AV) node. The AV node is located in the floor of the right atrium near the septum that separates the atria. The cardiac impulse to the AV node is slowed down by junctional fibers. The junctional fibers conduct the cardiac impulse to the AV node; however, these fibers are very small in diameter, causing the impulse to be delayed. This slow arrival of the impulse to the AV node allows time for the atria to empty and the ventricles to fill with blood.

Figure 6-37.—Conduction system of the heart. Specialized cardiac muscle cells (boldface type) in the wall of the heart rapidly initiate or conduct an electrical impulse throughout the myocardium. Both the sketch of the conduction system (A) and the flowchart (B) show the origin and path of conduction. The signal is initiated by the SA node (pacemaker) and spreads to the rest of the right atrial myocardium directly, to the left atrial myocardium by way of a bundle of interatrial conducting fibers, and to the AV node by way of three internodal bundles. The AV node then initiates a signal that is conducted through the ventricular myocardium by way of the AV bundle (of His) and subendocardial branches (Purkinje fibers).

Once the cardiac impulse reaches the far side of the AV node, it quickly passes through a group of large fibers which make up the AV bundle (also called the bundle of His). The AV bundle starts at the upper part of the interventricular septum and divides into right and left branches. About halfway down the interventricular septum, the right and left branches terminate into Purkinje fibers. The Purkinje fibers spread from the interventricular septum into the papillary muscles, which project inward from the ventricular walls. As the cardiac impulse passes through the Purkinje fibers, these fibers in turn stimulate the cardiac muscle of the ventricles. This stimulation of the cardiac muscles causes the walls of the ventricles to contract with a twisting motion. This action squeezes the blood out of the ventricular chambers and forces it into the arteries. This is the conclusion of one cardiac cycle.

**Blood Pressure**

Blood pressure is the pressure the blood exerts on the walls of the arteries. The highest pressure is called systolic pressure, because it is caused when the heart is in systole, or contraction. A certain amount of blood pressure is maintained in the arteries even when the heart is relaxed. This pressure is the diastolic pressure, because it is present during diastole, or relaxation of the heart. The difference between systolic and diastolic pressure is known as pulse pressure.

Normal blood pressure can vary considerably with an individual’s age, weight, and general condition. For young adults, 120 systolic 80 diastolic is the average normal blood pressure, women have lower blood pressure than men.

**BLOOD VESSELS**

Blood vessels form a closed circuit of tubes that transport blood between the heart and body cells. The several types of blood vessels include arteries, arterioles, capillaries, venules, and veins.

**Blood Vessel Classifications**

The blood vessels of the body fall into three classifications:

- **Arteries and Arterioles**: Distributors
- **Capillaries**: Exchangers
- **Veins and Venules**: Collectors

**Arteries and Arterioles**

Arteries are elastic tubes constructed to withstand high pressure. They carry blood away from the heart to all parts of the body. The smallest branches of the arteries are called arterioles. The walls of arteries and arterioles consist of layers of endothelium, smooth muscle, and connective tissue. The smooth muscles of arteries and arterioles constrict and dilate in response to electrical impulses received from the autonomic nervous system.

**Capillaries**

At the end of the arterioles is a system of minute vessels that vary in structure, but which are spoken of collectively as capillaries. It is from these capillaries that the tissues of the body are fed. There are approximately 60,000 miles of capillaries in the body. As the blood passes through the capillaries, it releases oxygen and nutritive substances to the tissues and takes up various waste products to be carried away by venules. Venules continue from capillaries and merge to form veins.
Veins and Venules

Veins and venules form the venous system. The venous system is comprised of vessels that collect blood from the capillaries and carry it back to the heart. Veins begin as tiny venules formed from the capillaries. Joining together as tiny rivulets, veins connect and form a small stream. The force of muscles contracting adjacent to veins aids in the forward propulsion of blood on its return to the heart. Valves, spaced frequently along the larger veins, prevent the backflow of blood. The walls of veins are similar to arteries, but are thinner and contain less muscle and elastic tissue.

Arterial System

Arterial circulation is responsible for taking freshly oxygenated blood from the heart to the cells of the body (Fig. 6-38). To take this oxygenated blood from the heart to the entire body, the arterial system begins with the contraction of blood from the left ventricle into the aorta and its branches.

AORTA.—The aorta, largest artery in the body, is a large tubular-like structure arising from the left ventricle of the heart. It arches upward over the left lung and then down along the spinal column through the thorax and the abdomen, where it divides and sends arteries down both legs (Fig. 6-38).

KEY BRANCHES OF THE AORTA.—Key arterial branches of the aorta are the coronary, innominate (brachiocephalic), left common carotid, and left subclavian. The coronary arteries are branches of what is called the ascending aorta. The coronary arteries supply the heart with blood. There are three large arteries that arise from the aorta as it arches over the left lung. First is the innominate artery, which divides into the right subclavian artery to supply the right arm, and the right common carotid to supply the right side of the head. The second branch is the left common carotid, which supplies the left side of the head. The third branch is the left subclavian, which supplies the left arm.

ARTERIES OF THE HEAD, NECK, AND BRAIN.—The carotid arteries divide into internal and external branches. The external supplies the muscle and skin of the face and the internal supplies the brain and the eyes.

ARTERIES OF THE UPPER EXTREMITIES. The subclavian arteries are so named because they run underneath the clavicle. They supply the upper extremities, branching off to the back, chest, neck, and brain through the spinal column (Fig. 6-38).

The large artery going to the arm is called the axillary. The axillary artery becomes the brachial artery as it travels down the arm and divides into the ulnar and radial arteries. The radial artery is the artery at the wrist that is felt when taking the patient’s pulse (Fig. 6-38).

ARTERIES OF THE ABDOMEN.—In the abdomen, the aorta gives off branches to the abdominal viscera, including the stomach, liver, spleen, kidneys, and intestines. The aorta later divides into the left and right common iliacs, which supply the lower extremities (Fig. 6-38).

ARTERIES OF THE LOWER EXTREMITIES.—The left and right common iliacs, upon entering the thigh, become the femoral arteries. At the knee, this same vessel is named the popliteal artery (Fig. 6-38).
Figure 6-38.—Principal arteries of the body.

Venous System

Venous circulation is responsible for returning the blood to the heart after exchanges of gases, nutrients, and wastes have occurred between the blood and body cells (Fig. 6-39). To return this blood to the heart for reoxygenation, the venous system begins with the merging of capillaries into venules, venules into small veins, and small veins into larger veins. The blood vessel paths of the venous system are difficult to follow, unlike the arterial system. However, the larger veins are commonly located parallel to the course taken by their counterpart in the arterial system. For instance, the renal vein parallels the renal artery; the common iliac vein parallels the common iliac artery, and so forth.

THREE PRINCIPAL VENOUS SYSTEMS.—The three principal venous systems in the body are the pulmonary, portal, and systemic.

- The **pulmonary system** is composed of four vessels, two from each lung, which empty into the left atrium. These are the only veins in the body that carry freshly oxygenated blood.

- The **portal system** consists of the veins that drain venous blood from the abdominal part of the digestive tract the spleen, pancreas, and gallbladder, but not the lower rectum and deliver it to the liver. There, it is distributed by a set of venous capillaries. The blood in the portal system conveys absorbed substances from the intestinal tract to the liver for storage, alteration, or detoxification. From the liver the blood flows through the hepatic vein to the inferior vena cava.

- The **systemic system** is divided into the deep and superficial veins. The superficial veins lie immediately under the skin, draining the skin and superficial structures. The deep veins, usually located in the muscle or deeper layers, drain the large muscle masses and various other organs. Deep veins commonly lie close to the large arteries that supply the various organs of the body and typically have the same name as the artery they accompany.

VEINS OF THE HEAD, NECK, AND BRAIN.—The superficial veins of the head unite to form the **external jugular veins**. The external jugular veins drain blood from the scalp, face, and neck, and finally empty into the **subclavian veins**.

The veins draining the brain and internal facial structures are the **internal jugular veins**. These combine with the subclavian veins to form the **innominate veins**, which empty into the **superior vena cava** (Fig. 6-39).
VEINS OF THE UPPER EXTREMITIES.—The veins of the upper extremities begin at the hand and extend upward. A vein of great interest is the median cubital, which crosses the anterior surface of the elbow. It is the vein most commonly used for venipuncture. Also found in this area are the basilic and cephalic veins, which extend from the midarm to the shoulder.

The deep veins of the upper arm unite to form the axillary vein, which unites with the superficial veins to form the subclavian vein. This vein later unites with other veins to form the innominate and eventually, after union with still more veins, the superior vena cava (Fig. 6-39).

VEINS OF THE ABDOMEN AND THORACIC REGION.—The veins from the abdominal organs, with the exception of those of the portal system, empty directly or indirectly into the inferior vena cava, while those of the thoracic region eventually empty into the superior vena cava (Fig. 6-39).

VEINS OF THE LOWER EXTREMITIES.—In the lower extremities (Fig. 6-39) a similar system drains the superficial areas. The great saphenous vein originates on the inner aspect of the foot and extends up the inside of the leg and thigh to join the femoral vein in the upper thigh. The great saphenous vein is used for intravenous injections at the ankle.

The veins from the lower extremities unite to form the femoral vein in the thigh, which becomes the external iliac vein in the groin. Higher in this region, external iliac unites the internal iliac (hypogastric) vein from the lower pelvic region to form the common iliac veins. The right and left common iliac veins unite to form the inferior vena cava.
Figure 6-39.—Principal veins of the body.

THE LYMPHATIC SYSTEM

LEARNING OBJECTIVE:

Identify the parts of the lymphatic system and their function.

All tissues of the body are continuously bathed in interstitial fluid. This fluid is formed by leakage of blood plasma through minute pores of the capillaries. There is a continual interchange of fluids of the blood and tissue spaces with a free interchange of nutrients and other dissolved substances. Most of the tissue fluid returns to the circulatory system by means of capillaries, which feed into larger veins. Large protein molecules that have escaped from the arterial capillaries cannot reenter the circulation through the small pores of the capillaries. However, these large molecules, as well as white blood cells, dead cells, bacterial debris, infected substances, and larger particulate matter, can pass through the larger pores of the lymphatic capillaries and, thus, enter the lymphatic circulatory system with the remainder of the tissue fluid.

The lymphatic system helps defend the tissues against infections by supporting the activities of the lymphocytes, which give immunity, or resistance, to the effects of specific disease-causing agents.

PATHWAYS OF THE LYMPHATIC SYSTEM

The lymphatic pathway begins with lymphatic capillaries. These small tubes merge to form lymphatic vessels, and the lymphatic vessels in turn lead to larger vessels that join with the veins in the thorax.

Lymphatic Capillaries

Lymphatic capillaries are closed-ended tubes of microscopic size (Fig. 6-40). They extend into interstitial spaces, forming complex networks that parallel blood capillary networks. The lymphatic capillary wall consists of a single layer of squamous epithelial cells. This thin wall makes it possible for interstitial fluid to enter the lymphatic capillary. Once the interstitial fluid enters the lymphatic capillaries, the fluid is called lymph.
Figure 6-40.—Circulation plan of lymphatic fluid. This diagram outlines the general scheme for lymphatic circulation. Fluids from the systemic and pulmonary capillaries leave the bloodstream and enter the interstitial space, thus becoming part of the IF (interstitial fluid). The IF also exchanges materials with the surrounding tissues. Often, because less fluid is returned to the blood capillary than had left it, IF pressure increases—causing IF to flow into the lymphatic capillary. The fluid is then called lymph (lymphatic fluid) and is carried through one or more lymph nodes and finally to large lymphatic ducts. The lymph enters a subclavian vein, where it is returned to the systemic blood plasma. Thus fluid circulates through blood vessels, tissues, and lymphatic vessels in a sort of "open circulation."

Lymphatic Vessels

Lymphatic vessels are formed from the merging of lymphatic capillaries. Lymphatic vessels, also known simply as lymphatics, are similar to veins in structure. The vessel walls are composed of three layers: an inner layer of endothelial tissue, a middle layer of smooth muscle and elastic fibers, and an outer layer of connective tissue.

Like a vein, the lymphatic vessel has valves to prevent backflow of lymph. The larger lymphatic vessels lead to specialized organs called lymph nodes. After leaving these structures, the vessels merge to form still larger lymphatic trunks (Fig. 6-41).

Figure 6-41.—Structure of a typical lymphatic capillary. Notice that interstitial fluid enters through clefts between overlapping endothelial cells that form the wall of the vessel. Valves ensure one-way flow of lymph out of the tissue. Small fibers anchor the wall of the lymphatic capillary to the surrounding ECM (extracellular matrix) and cells, thus holding it open to allow entry of fluids and small particles.


6-58
Lymphatic Trunks and Ducts

Lymphatic trunks drain lymph from large regions in the body. The lymphatic trunks are usually named after the region they serve, such as the subclavian trunk that drains the arm. There are many lymphatic trunks throughout the body. These lymphatic trunks then join one of two collecting ducts, the thoracic duct or the right lymphatic duct (Fig. 6-42).

Lymphatic trunks from the upper half of the right side of the body converge to form the right lymphatic duct, which empties into the right subclavian vein. Drainage from the remainder of the body is by way of the thoracic duct, which empties into the left subclavian vein.

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**Figure 6-42.** Lymphatic drainage. The right lymphatic duct drains lymph from the upper right quadrant (dark blue) of the body into the right subclavian vein. The thoracic duct drains lymph from the rest of the body (green) into the left subclavian vein. The lymphatic fluid is thus returned to the systemic blood just before entering the heart.

LYMPH NODES

Lymph nodes, which are frequently called glands but are not true glands, are small bean-shaped bodies of lymphatic tissue found in groups of two to fifteen along the course of the lymph vessels (Fig. 6-43). Major locations of lymph nodes are in the following regions: cervical, axillary, inguinal, pelvic cavity, abdominal cavity, and thoracic cavity. Lymph nodes vary in size and act as filters to remove bacteria and particles from the lymph stream. Lymph nodes produce lymphocytes, which help defend the body against harmful foreign particles, such as bacteria, cells, and viruses. Lymph nodes also contain macrophages, which engulf and destroy foreign substances, damaged cells, and cellular debris.

Figure 6-43.—Principal organs of the lymphatic system.

IMMUNE SYSTEM

LEARNING OBJECTIVE:

Identify how the immune system works.

"First, it is important to recognize that cells, viruses, and other particles have unique molecules and groups of molecules on their surfaces that can be used to identify them. These molecular markers visible to the immune system are called antigens. Human cells have unique cell markers embedded in our plasma membranes that identify each of our cells as self—that is, belonging to us as an individual. Foreign cells or particles have nonself molecules that serve as recognition markers for our immune system. The ability of our immune system to attack abnormal or foreign cells but spare our own normal cells is called self-tolerance."

"The body takes a number of measures to prevent infection. The body’s primary defenses against infection include the skin, tears, stomach acid, urine, sweat, mucus, and saliva. By having this range of both physical and chemical defenses, the body is able to defend against a range of pathogens.

Secondary defenses bring about inflammation. The swelling, redness, and warmth of the infected area cause the body to call in macrophages and neutrophils to consume the bacteria [see chap 10 for more details]. If the pathogen is a virus, interferon (interferon proteins interfere with the ability of viruses to cause diseases) is produced so that other cells in that region of the body can block the virus from attacking any healthy cells.

The body’s third line of defense is the way the body remembers specific pathogens and their structures. If the pathogen enters the body again, the body’s response will be much quicker than the first time the pathogen invaded the body. Antibodies, specific to each pathogen, are ready to respond should this occur.

The memorization and production of antibodies is called active immunity. In passive immunity the antibodies have been obtained from outside the body, either from another animal or person.

A number of cells are involved in combating the invasion of viruses and bacteria. B cells have antigen receptors and antibodies, and they work to fight off bacteria. B cells can form plasma cells and memory cells. The plasma cells produce antibodies that bind to antigens, whereas the memory B cells form new plasma cells if the bacteria enter the body again. T cells are responsible for recognizing nonself cells. On engagement with nonself cells, they produce killer T cells and memory T cells. The killer T cells have the task of binding to cells that have been infected by viruses. The memory T cells are ready to produce more killer T cells if the virus enters the body again. In both cases, bacterial and viral infections, helper T cells are available to recognize the antigens that have been ingested and displayed by macrophages."

THE NERVOUS SYSTEM

LEARNING OBJECTIVES:

Identify the components and function of a neuron.

Identify the process of impulse transmission.

Identify the components and functions of the central and peripheral nervous systems.

The activity of widely diverse cells, tissues, and organs of the body must be monitored, regulated, and coordinated to effectively support human life. The interaction of the nervous and endocrine systems provides the needed control through communication.

The nervous system is specifically adapted to the rapid transmission of impulses from one area of the body to another. On the other hand, the endocrine system, working at a far slower pace, maintains body metabolism at a fairly constant level.
This section will cover the study of the glia and neuron, the two main types of cells of the nervous system. It will discuss the components and functions of the different categories of the nervous system: the central nervous system (CNS) and the peripheral nervous system (PNS). Another division of the nervous system is the autonomic nervous system (ANS), which is further subdivided into the sympathetic and parasympathetic nervous systems (Fig. 6-44).

GLIA

Glia cells do not usually conduct information themselves but support the functions of the neurons in various ways. Unlike neurons, glia cells retain their capacity for cell division throughout adulthood. This characteristic gives them the ability to replace themselves and it makes them susceptible to abnormalities of cell division – such as cancer.

There are five major types of glia cells, Astrocytes, Microglia, Ependymal cells, Oligodendrocytes, and Schwann cells. The first four types of glia are located in the CNS and the Schwann cells are located in the PNS. Astrocytes help feed the brain and make up the Blood Brain Barrier. Microglia enlarge, engulf, and destroy microorganisms and cellular debris. Ependymal cells have two functions in the CNS; they help produce the fluid and some have cilia that help move the fluid around. The Oligodendrocytes produce the fatty myelin sheath around the nerve fibers in the CNS.

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Figure 6-44.— Organizational plan of the nervous system. Diagram summarizes the scheme used by most neurobiologists in studying the nervous system. Both the somatic nervous system (SNS) and the autonomic nervous system (ANS) include components in the CNS and PNS. Somatic sensory pathways conduct information toward integrators in the CNS, and somatic motor pathways conduct information toward somatic effectors. In the ANS, visceral sensory pathways conduct information toward CNS integrators, whereas the sympathetic and parasympathetic pathways conduct information toward autonomic effectors.

THE NEURON

The structure and functional unit of the nervous system is the nerve cell, or neuron, which can be classified into three types. The first is the sensory neuron, which conveys sensory impulses inward from the receptors towards the spine and brain. The second is the motor neuron, which carries command impulses from a central area to the responding muscles or organs. The third type is the interneuron, which links the sensory neurons to the motor neurons. All pathways do not have an interneuron.

The neuron is composed of dendrites, a perikaryon (cell body), and an axon (Fig. 6-45). The dendrites are thin receptive branches, and vary greatly in size, shape, and number with different types of neurons. They serve as receptors, conveying impulses toward the cell body. The perikaryon (literally, means surrounding the nucleus) is the cell body containing the nucleus. The single, thin extension of the cell outward from the cell body is called the axon. It conducts impulses away from the cell body to its terminal branches at the synaptic knobs, which transmit the impulses to the dendrites of the next neuron.

Axons of the peripheral nerves are commonly enclosed in a sheath, called neurilemma, composed of Schwann cells (Figs. 6-45 and 6-46). Schwann cells wrap around the axon and act as an electrical insulator. The membranes of the Schwann cell are composed largely of a lipid-protein called myelin, which forms a myelin sheath called myelinated fibers, or white fibers on the outside of an axon. The myelin sheath has gaps between adjacent Schwann cells called nodes of Ranvier. Nerve cells without Schwann cells also lack myelin and neurilemma sheaths which are called unmyelinated fibers, or gray fibers. Myelin is important as it aids in conduction of the electrical impulse (Fig. 6-46).
Figure 6-46.— Development of the myelin sheath. A Schwann cell (neurolemmocyte) migrates to a neuron and wraps around an axon. The Schwann cell's cytoplasm is pushed to the outer layer, leaving a dense multilayered covering of plasma membrane around the axon. Because the plasma membrane of the Schwann cell is mostly the phospholipid myelin, the dense wrapping around the axon is called a myelin sheath. The outer layer of cytoplasm is called the neurilemma. The extensions of oligodendrocytes also wrap around axons to form a myelin sheath.


IMPULSE TRANSMISSION

When dendrites receive a sufficiently strong stimulus, a short and rapid change in electrical charge, or polarity, of the neuron is triggered. Sodium ions rush through the plasma membrane into the cell, potassium ions leave, and an electrical impulse is formed, which is conducted toward the cell body. The cell body receives the impulse and transmits it to the terminal filaments of the axon. At this point a chemical transmitter such as acetylcholine is released into the synapse, a space between the axon of the activated nerve and the dendrite receptors of another neuron. This chemical transmitter activates the next nerve. In this manner, the impulse is passed from neuron to neuron down the nerve line to a central area of up to speeds of 300 miles per hour being the fastest. It depends on the diameter, the bigger the diameter the faster the speed, along with that if it is myelinated it also moves faster.

Almost immediately after being activated, the chemical transmitter in the synapse is neutralized by the enzyme acetylcholinesterase, and the first neuron returns to its normal state by pumping out the sodium ions and drawing potassium ions back in through the plasma membrane. When these actions are completed, the nerve is ready to be triggered again. A particularly strong stimulus will cause the nerve to fire in rapid succession, or will trigger many other neurons, thus giving a feeling of intensity to the perceived sensation.

NERVES

A nerve is a cordlike bundle of fibers held together with connective tissue. Each nerve fiber is an extension of a neuron. Nerves that conduct impulses into the brain or the spinal cord are called sensory nerves, and those that carry impulses to muscles and glands are termed motor nerves. Most nerves, however, include both sensory and motor fibers, and they are called mixed nerves.
CENTRAL NERVOUS SYSTEM

The central nervous system (CNS) consists of the brain and spinal cord. The brain is almost entirely enclosed in the skull, but it is connected with the spinal cord, which lies in the canal formed by the vertebral column.

Brain

The brain has six major divisions, the medulla oblongata, pons, midbrain, diencephalon, cerebrum and the cerebellum. The cerebrum is the largest and most superiorly situated portion of the brain. It occupies most of the cranial cavity. The outer surface is called the cortex. This portion of the brain is also called "gray matter" because the nerve fibers are unmyelinated (not covered by a myelin sheath), causing them to appear gray. Beneath this layer is the medulla, often called the white matter of the brain because the nerves are myelinated (covered with a myelin sheath), giving them their white appearance.

CEREBRUM.—The cortex of the cerebrum is irregular in shape. It bends on itself in folds called convolutions, which are separated from each other by grooves, also known as fissures. The deep sagittal cleft, a longitudinal fissure, divides the cerebrum into two hemispheres. Other fissures further subdivide the cerebrum into lobes, each of which serves a localized, specific brain function (Fig. 6-47). For example, the frontal lobe is associated with the higher mental processes such as memory, the parietal lobe is concerned primarily with general sensations, the occipital lobe is related to the sense of sight, and the temporal lobe is concerned with hearing (Fig. 6-47).

CEREBELLMUM.—The cerebellum is situated posterior to the brain stem and inferior to the occipital lobe. The cerebellum is concerned chiefly with bringing balance, harmony, and coordination to the motions initiated by the cerebrum.

BRAINSTEM.—It is made up of the medulla oblongata which forms the lowest part, the pons which forms the mid portion, and the midbrain which forms the uppermost part of the brainstem. The brainstem also acts as a connection to the rest of the brain.

The medulla oblongata is the inferior portion of the brain, the last division before the beginning of the spinal cord. It connects to the spinal cord at the upper level of the first cervical vertebra (C-1). In the medulla oblongata are the centers for the control of heart action, breathing, circulation, and other vital processes such as blood pressure.

The midbrain deals with certain auditory functions, contains the visual centers, and it is involved in muscular control.
MENINGES. The outer surface of the brain and spinal cord is covered with three layers of membranes called the meninges. The dura mater is the strong outer layer; the arachnoid membrane is the delicate middle layer; and the pia mater is the vascular innermost layer that adheres to the surface of the brain and spinal cord. Inflammation of the meninges is called meningitis. The type of meningitis contracted depends upon whether the brain, spinal cord, or both are affected, as well as whether it is caused by viruses, bacteria, protozoa, yeasts, or fungi.

CEREBROSPINAL FLUID.—Cerebrospinal fluid is formed by a plexus, or network, of blood vessels in the central ventricles of the brain. It is a clear, watery solution similar to blood plasma. The total quantity of spinal fluid bathing the spinal cord is about 75 ml. This fluid is constantly being produced and reabsorbed. It circulates over the surface of the brain and spinal cord and serves as a supportive protective cushion as well as a means of exchange for nutrients and waste materials. It monitors for changes in the internal environment.

Spinal Cord

The spinal cord is continuous with the medulla oblongata and extends from the foramen magnum, through the atlas, to the lower border of the first lumbar vertebra, where it tapers to a point (Fig. 6-48). The spinal cord is surrounded by the bony walls of the vertebral canal. Ensheathed in the three protective meninges and surrounded by fatty tissue and blood vessels, the spinal cord does not completely fill the vertebral canal, nor does it extend the full length of it. The nerve matter is shaped roughly like the letter H. It establishes sensory communication between the brain and the spinal nerves, conducting sensory impulses from the body parts.

Figure 6-48.—The central nervous system. Details of both the brain and the spinal cord are easily seen in this Figure.

The spinal cord may be thought of as an electric cable containing many wires (nerves) that connect parts of the body with each other and with the brain. Sensations received by a sensory nerve are brought to the spinal cord, and the impulse is transferred either to the brain or to a motor nerve. The majority of impulses go to the brain for action. However, a system exists for quickly handling emergency situations. It is called the reflex arc (Fig. 6-49).

![Figure 6-49.—Patellar reflex. Neural pathway involved in the patellar (knee jerk) reflex.]


If a person touches a hot stove, the person must remove the hand from the heat source immediately or the skin will burn very quickly.

The passage of a sense impulse to the brain and back again to a motor nerve takes too much time. The reflex arc responds instantaneously to emergency situations (like the one described). The sensation of heat travels to the spinal cord on a sensory nerve. When the sensation reaches the spinal cord, it is picked up by an interneuron in the gray matter. This reception triggers the appropriate nerve to stimulate a muscle reflex drawing the hand away. An illustrated example of the reflex arc is shown in Figure 6-50.

![Figure 6-50.—Functional classification of neurons in a reflex arc. Neurons can be classified according to the direction in which they conduct impulses. Notice that the most basic route of signal conduction follows a pattern called the reflex arc.]


The reflex arc works well in simple situations requiring no action of the brain. Consider what action is involved if the individual touching the stove pulls back, in so doing, loses balance and has to grab a chair to regain stability. Then the entire spinal cord is involved.

Additional impulses must travel to the brain, down to the muscles of the legs and arms to enable the individual to maintain balance and to hold on to a steadying object. As this activity takes place, the stimulus is relayed through the sympathetic autonomic nerve fibers to the adrenal glands, causing adrenalin to flow, and stimulating heart action. The stimulus moves to the brain making the individual conscious of pain. In this example, the spinal cord has functioned not only as a center for spinal relaxes, but also as a conduction pathway for other areas of the spinal cord to the autonomic nervous system and to the brain.
PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system (PNS) consists of the nerves that branch out from the CNS and connects it to the other parts of the body. The PNS includes 12 pairs of cranial nerves (Fig. 6-51) and 31 pairs of spinal nerves (Fig. 6-52).

While the cranial nerves are numbered in a specific order, the spinal nerves are merely numbered according to where they emerge from the spinal cord. Cranial and spinal nerves carry both voluntary and involuntary impulses.

Figure 6-51.—Cranial nerves. Ventral surface of the brain showing attachment of the cranial nerves.

Figure 6-52.—Spinal nerves. Each of 31 pairs of spinal nerves exits the spinal cavity from the intervertebral foramina. The names of the vertebrae are given on the left and the names of the corresponding spinal nerves on the right. Note that after leaving the spinal cavity, many of the spinal nerves interconnect to form networks called plexuses. The inset shows a dissection of the cervical region, showing a posterior view of cervical spinal nerves exiting intervertebral foramina on the right side. (Courtesy Vidic B, Suarez RF: Photographic atlas of the human body, St Louis, 1984, Mosby.)

Cranial Nerves

The 12 pairs of cranial nerves (Table 6-6) are sensory, motor, or mixed (sensory and motor). The following saying helps in the memorization of the nerves: On Old Olympus Tower Tops A Famous Vocal German Viewed Some Hops or I-Olfactory, II-Optic, III-Oculomotor, IV-Trochlear, V-Trigeminal, VI-Abducens, VII-Facial, VIII-Vestibulocochlear (Auditory), IX-Glossopharyngeal, X-Vagus, XI-Spinal (Accessory), and XII-Hypoglossal (Fig. 6-51). The figure below shows the 12 cranial nerves and parts of the body they service.

<table>
<thead>
<tr>
<th>NAME</th>
<th>NUMBER</th>
<th>FUNCTIONAL CLASSIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olfactory</td>
<td>I</td>
<td>Sensory</td>
</tr>
<tr>
<td>Optic</td>
<td>II</td>
<td>Sensory</td>
</tr>
<tr>
<td>Oculomotor</td>
<td>III</td>
<td>Motor</td>
</tr>
<tr>
<td>Trochlear</td>
<td>IV</td>
<td>Motor</td>
</tr>
<tr>
<td>Trigeminal</td>
<td>V</td>
<td>Mixed</td>
</tr>
<tr>
<td>Abducens</td>
<td>VI</td>
<td>Motor</td>
</tr>
<tr>
<td>Facial</td>
<td>VII</td>
<td>Mixed</td>
</tr>
<tr>
<td>Vestibulocochlear</td>
<td>VIII</td>
<td>Sensory</td>
</tr>
<tr>
<td>Glossopharyngeal</td>
<td>IX</td>
<td>Mixed</td>
</tr>
<tr>
<td>Vagus</td>
<td>X</td>
<td>Mixed</td>
</tr>
<tr>
<td>Accessory</td>
<td>XI</td>
<td>Motor</td>
</tr>
<tr>
<td>Hypoglossal</td>
<td>XII</td>
<td>Motor</td>
</tr>
</tbody>
</table>

*The first letters of the words in the following sentence are the first letters of the names of the cranial nerves, in the correct order. Many anatomy students find that using this sentence, or one like it, helps in memorizing the names and numbers of the cranial nerves. It is “On Old Olympus’ Tiny Tops, A Friendly Viking Grew Vines And Hops.” The functional classification of each cranial nerve can be remembered by using this sentence: “Some Say ‘Marry Money,’ But My Brothers Say ‘Bad Business, Marry Money.’” In this sentence, S indicates sensory, M indicates motor, and B indicates both sensory and motor (mixed).*

Table 6-6.—Cranial Nerves


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"The cranial nerves are the 12 pairs of nerves emerging from the cranial cavity through various openings in the skull. Beginning with the most anterior (front) on the brain stem, they are appointed Roman numerals. An isolated cranial nerve lesion is an unusual finding in decompression sickness or gas embolism, but deficits occasionally occur.

1. **Olfactory**: The olfactory nerve provides the sense of smell.

2. **Optic**: The optic nerve is for vision. It functions in the recognition of light and shade and in the perception of objects. Blurring of vision, loss of vision, spots in the visual field or peripheral vision loss (tunnel vision) are also indicative of nerve involvement.

3. **Oculomotor, 4. Trochlear, 5. Abducent**: These three nerves control eye movements in the six directions (fields) and eye movement towards the tip of the nose (giving a "crossed-eyed" look). The oculomotor nerve is responsible for movement of the pupils.

6. **Trigeminal**: The Trigeminal Nerve governs sensation of the forehead and face and the clenching of the jaw. It also supplies the muscle of the ear (tensor tympani) necessary for normal hearing.

**Facial**: The Facial Nerve controls the face muscles. It stimulates the scalp, forehead, eyelids, muscles of facial expression, cheeks, and jaw. Symmetry of the nasolabial folds (lines from nose to outside corners of the mouth) should be observed.


9. **Glossopharyngeal**: The Glossopharyngeal Nerves transmit sensation from the upper mouth and throat area. It supplies the sensory component of the gag reflex and constriction of the pharyngeal wall when saying "aah."

10. **Vagus**: The Vagus Nerve has many functions, including control of the roof of the mouth, vocal cords, and tone of the voice; hoarseness may also indicate vagus nerve involvement.

11. **Spinal Accessory**: The Spinal Accessory Nerve controls the turning of the head from side to side and shoulder shrug against resistance.

12. **Hypoglossal**: The Hypoglossal Nerve governs the muscle activity of the tongue. An injury to one of the hypoglossal nerves causes the tongue to twist to that side when stuck out of the mouth"
Spinal Nerves

There are 31 pairs of spinal nerves that originate from the spinal cord. Although spinal nerves are not named individually, they are grouped according to the level from which they arise, and each nerve is numbered in sequence. Thus, there are 8 pairs of cervical nerves, 12 pairs of thoracic nerves, 5 pairs of lumbar nerves, 5 pairs of sacral nerves, and 1 pair of coccygeal nerves (Fig. 6-53).

Spinal nerves (mixed) send fibers to sensory surfaces and muscles of the trunk and extremities. Nerve fibers are also sent to involuntary smooth muscles and glands of the gastrointestinal tract, urogenital system, and cardiovascular system.

AUTONOMIC NERVOUS SYSTEM

The autonomic nervous system (ANS) is the portion of the PNS that functions independently, automatically, and continuously, without conscious effort. It helps to regulate the smooth muscles, cardiac muscle, digestive tract, blood vessels, sweat and digestive glands, and certain endocrine glands. The autonomic nervous system is not directly under the control of the brain but usually works in harmony with the nerves that are under the brain's control. The autonomic nervous system includes two subdivisions (the sympathetic and parasympathetic nervous systems) that act together.

The sympathetic nervous system's primary concern is to prepare the body for energy-expending, stressful, or emergency situations, also known as fight or flight. On the other hand, the parasympathetic nervous system is most active under routine, restful situations. The parasympathetic system also counterbalances the effects of the sympathetic system, and restores the body to a resting state. For example, during an emergency the body's heart and respiration rate increases. After the emergency, the parasympathetic system will decrease heart and respiration rate to normal. The sympathetic and parasympathetic systems work together to preserve a harmonious balance of body functions and activities.

Figure 6-53.—Spinal Nerves

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