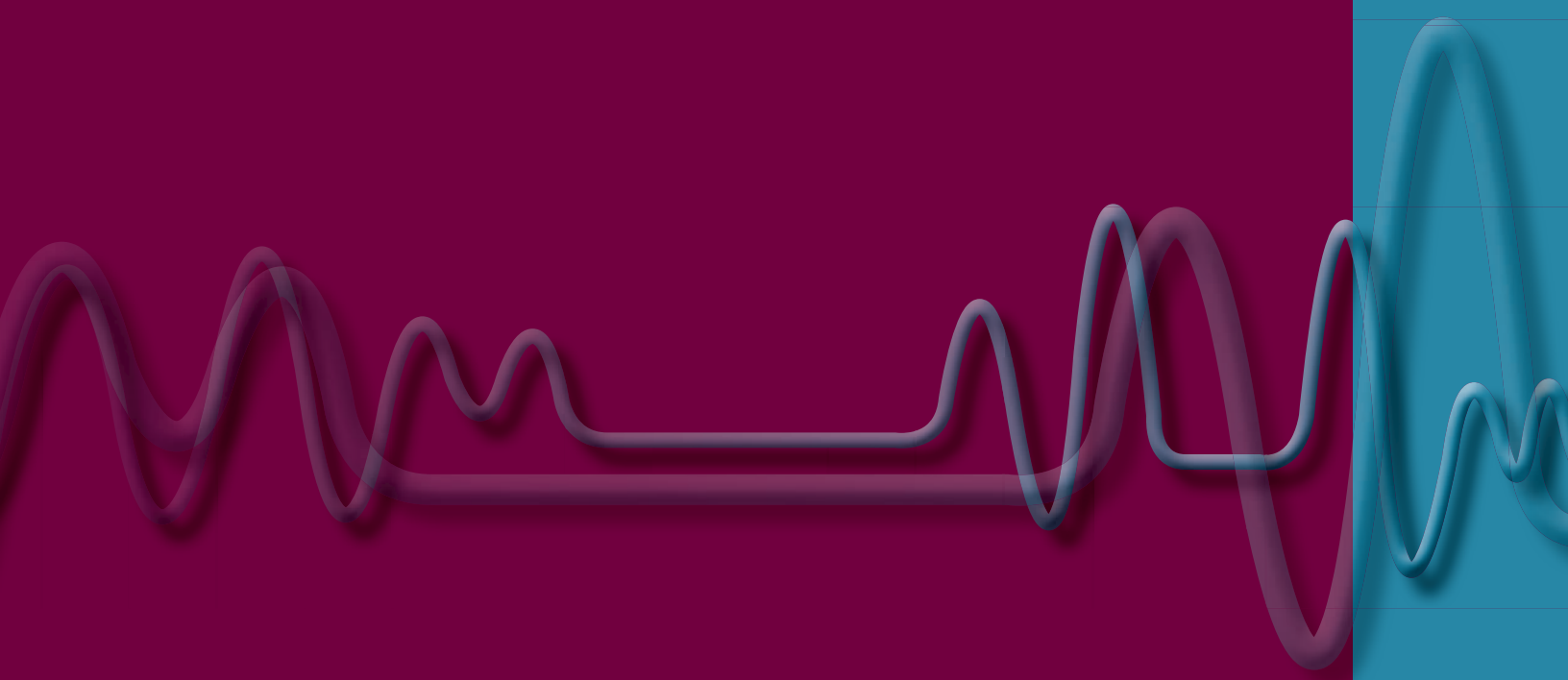
UNIT I

Introduction to the Respiratory Care Profession



CHAPTER 1

Cardiopulmonary and Central Nervous System Structures and Functions

OUTLINE

OBJECTIVES

Upon completion of this chapter, the reader should be able to do the following:

1. Name the structures that compose the cardiovascular system.
2. Distinguish among the various coverings of the heart and the layers that compose the heart wall.
3. Discuss the cardiac cycle and blood pressure.
4. Compare the structures and functions of the major types of blood vessels.
5. Identify the general functions of the respiratory system.
6. Describe the locations of the organs of the respiratory system.
7. Describe the functions of each organ of the respiratory system.
8. Explain the mechanisms of inspiration and expiration.
9. Describe the four main parts of the brain and their functions.
10. Explain the effect of the sympathetic and parasympathetic nervous systems upon the cardiopulmonary system.

KEY TERMS

Aerobic
Aerobic metabolism
Aorta
Aortic valve
Atria
Brainstem
Bronchial tree
Carbaminohemoglobin
Carbonic anhydrase
Cardiac cycle
Cardiac veins
Coronary arteries
Coronary sinus
Cricoid cartilage
Depolarization
Diaphragm
Diastole
ECG
EKG
Electrocardiogram
Endocardium
Epicardium
Epiglottis
Esophagus
Expiration
External respiration
Hemoglobin (Hb)
Inspiration

KEY TERMS (cont'd)

Internal respiration
Mediastinum
Medulla oblongata
Midbrain
Mitral valve
Myocardium
Nasal septum
Neurons
Parietal pleura
Pons
Pulmonary valve
Respiration
Septum
Systole
Thyroid cartilage
Tricuspid valve
Visceral pleura

INTRODUCTION

The cardiovascular system circulates blood to all parts of the body. The pumping of the heart provides oxygen to the body's cells as well as nutritive elements. It also removes waste materials and carbon dioxide. The heart is a muscular pump that is the central organ of the cardiovascular system, which also includes the arteries, veins, and capillaries.

The pulmonary system consists of the nose, pharynx, larynx, trachea, bronchi, and lungs. It furnishes oxygen for individual tissue cells and takes away their gaseous waste products. This process is accomplished through the act of **respiration**, which consists of external and internal processes. **External respiration** is the method in which the lungs are ventilated, and oxygen and carbon dioxide are exchanged between the alveoli of the lungs and the blood in the pulmonary capillaries. **Internal respiration** occurs when oxygen and carbon dioxide are exchanged between the blood in systemic capillaries and the body's tissues and cells (see **Figures 1–1** and **1–2**). The various organs, components, and functions of the cardiopulmonary system are described in this chapter.

The brain and autonomic nervous system control the operation of the cardiovascular and respiratory system. Therefore, this chapter will include a discussion of the brain's four major regions: cerebrum, diencephalon, brainstem, and cerebellum. It will also discuss the sympathetic and parasympathetic divisions of the autonomic nervous system.

Organs of the Cardiovascular System

The heart never rests; it beats approximately 100,000 times each day, pumping nearly 8000 liters of blood. The heart is a small organ that is nearly the size of an adult's closed fist.

The Heart

The heart is a hollow organ that is somewhat cone shaped. It is found within the thoracic cavity, resting upon the diaphragm. The heart contains four muscular chambers: the left and right atria, and the left and right ventricles. The heart itself weighs about 300 grams (in an

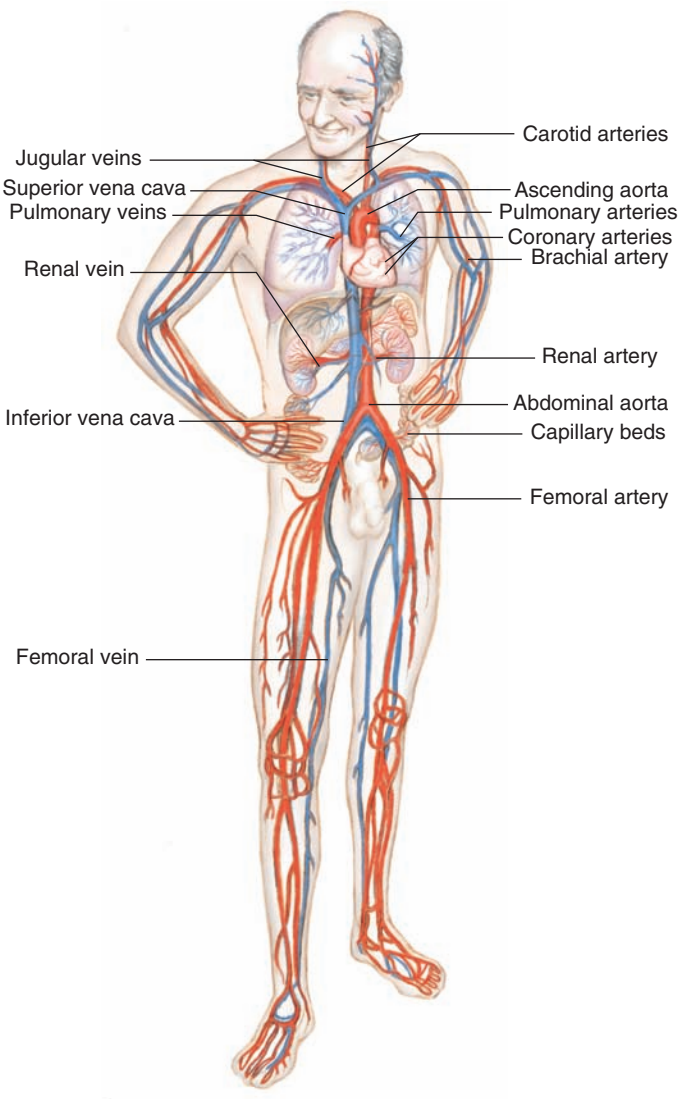


FIGURE 1–1 The cardiovascular system. Note its many similarities to a river.

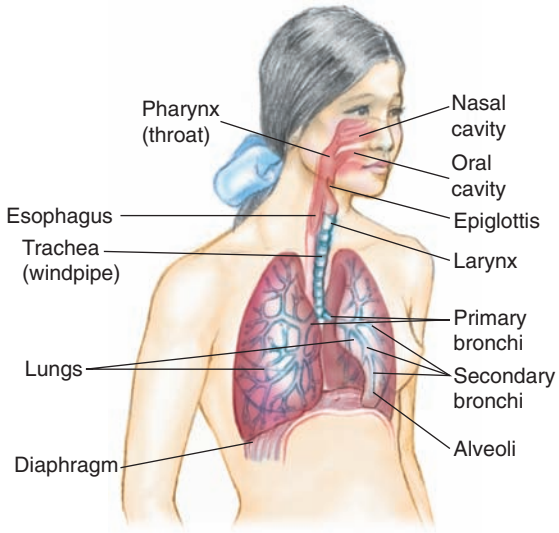


FIGURE 1–2 The respiratory system.

average adult male) and lies slightly to the left of the body's midline. It contains three layers of muscle tissue, which will be discussed later in this chapter.

The Heart Chambers

The heart consists of four hollow chambers: two on the left, and two on the right. The upper chambers are called **atria** and have thin walls. The lower chambers are called ventricles; they receive blood from the atria and contract to force blood out of the heart and into the arteries.

The left atrium collects blood from the pulmonary veins. It then moves this blood into the left ventricle, which pumps it into the systemic circuit (via the aorta). The right atrium collects blood from the systemic circuit (via the inferior and superior vena cava) as well as the coronary sinus and conducts it into the right ventricle. This ventricle pumps the blood into the pulmonary artery, which separates into the left and right pulmonary branches. The left and right atria, as well as the left and right ventricles, are separated from one another by wall-like structures, each of which is known as a **septum**. Because of the septums, blood from each side of the heart never mixes with blood from the other side (see **Figure 1–3**).

When the heart beats, the atria contract first, followed by the ventricles. The ventricles contract at the same time, ejecting equal amounts of blood into the pulmonary and systemic circuits.

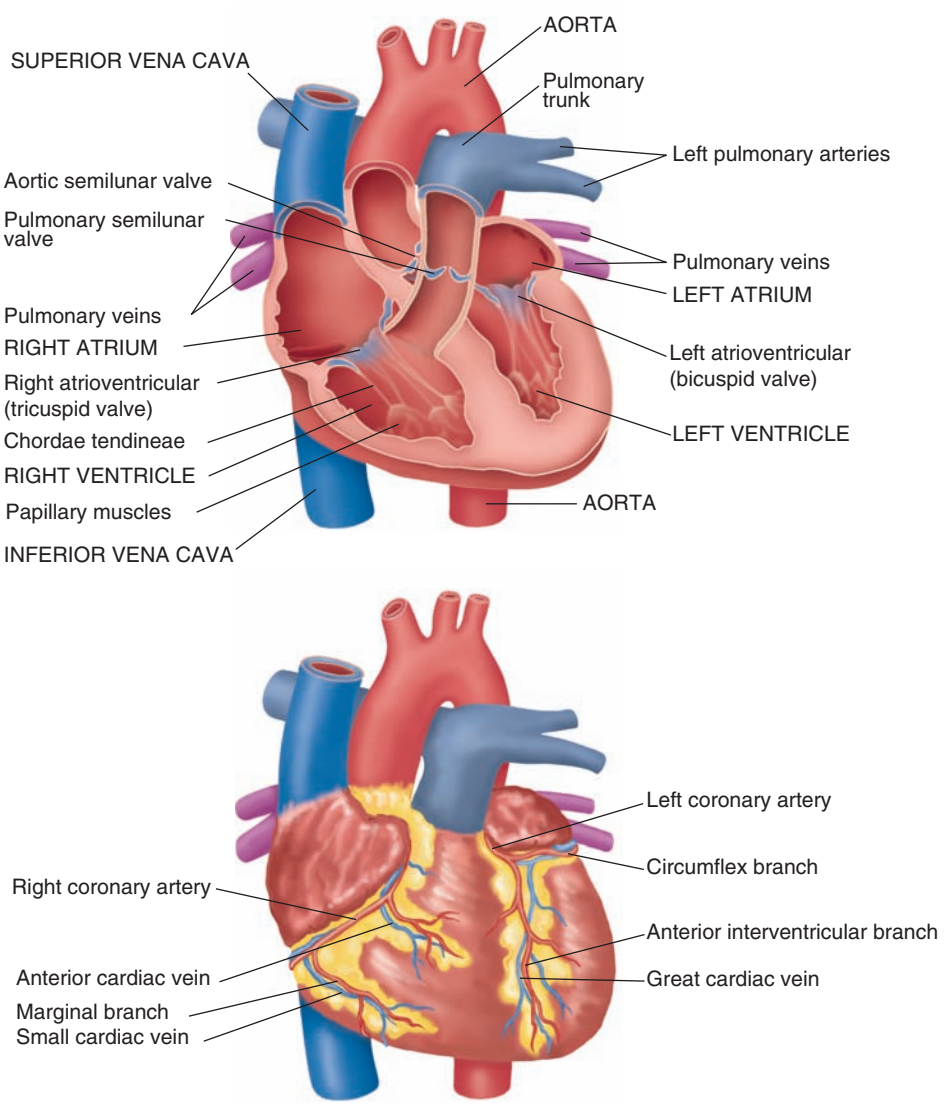


FIGURE 1–3 Anatomy of the heart.

The Heart Valves

An atrioventricular valve (A-V valve), including the **tricuspid valve** on the right and the **mitral valve** on the left, makes the blood flow one way between the atria and ventricles. The **pulmonary valve** allows blood to flow from the right ventricle while preventing backflow into the ventricle. As the left ventricle contracts, the mitral valve closes, and blood can only exit through a large artery known as the **aorta**. The **aortic valve**, located at the base of the aorta, opens to allow blood to leave the left ventricle when it contracts. Both the pulmonary and aortic valves are called semilunar valves because their cusps are shaped like half-moons. **Table 1–1** explains the locations and functions of the heart valves.

TABLE 1–1 Heart Valves

Valve	Location	Function
Mitral (bicuspid) valve	Opens between the left atrium and left ventricle	Prevents the blood from moving from the left ventricle into the left atrium when the ventricle contracts
Aortic valve	At the entrance to the aorta	Prevents the blood from moving from the aorta into the left ventricle when the ventricle relaxes
Tricuspid valve	Opens between the right atrium and right ventricle	Prevents the blood from moving from the right ventricle into the right atrium when the ventricle contracts
Pulmonary valve	At the entrance to the pulmonary trunk	Prevents the blood from moving from the pulmonary trunk into the right ventricle when the ventricle relaxes

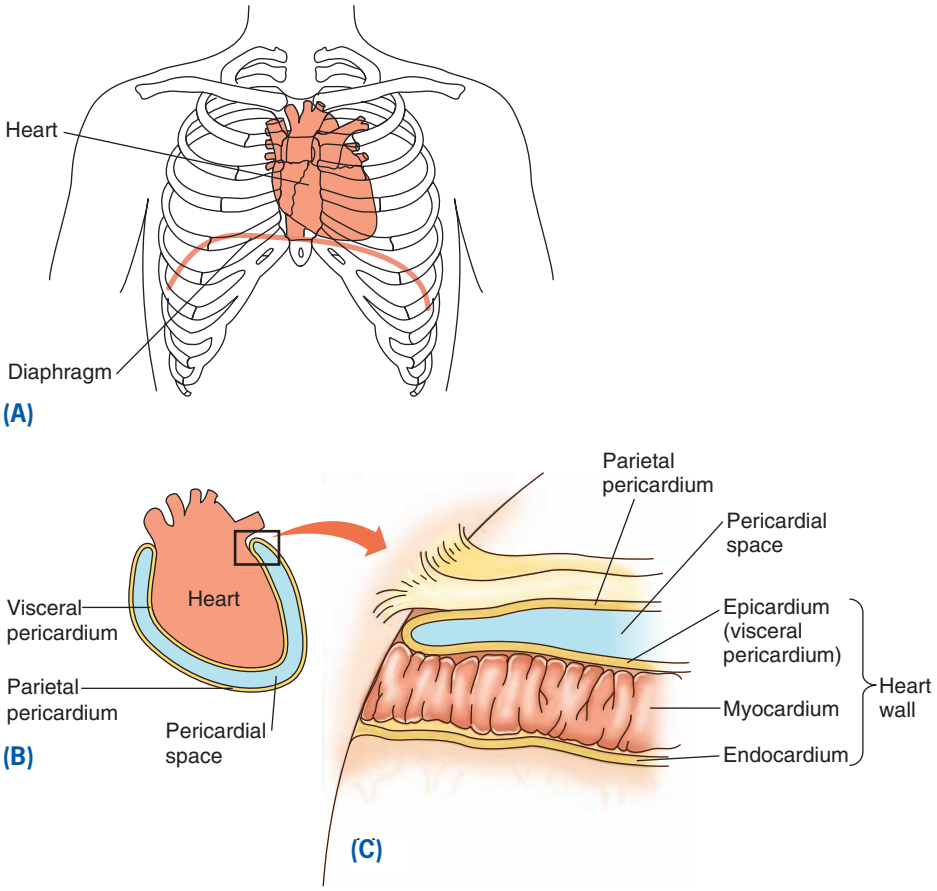


FIGURE 1–4 The heart is located in the mediastinum (**A**). It is surrounded by the pericardium, which contains the pericardial space (**B**). There are three layers to the heart wall (**C**).

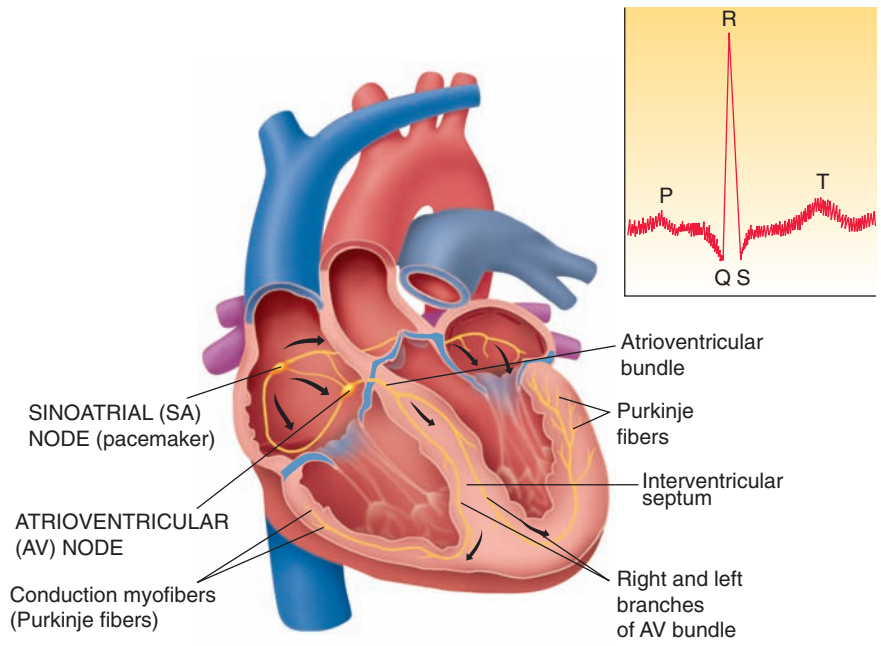


FIGURE 1–5 The impulse generation and conduction system of your heart. The fibrotendinous ring is shown in blue. Also shown is the tracking of an EKG. The p wave corresponds to atrail depolarization, the QRS complex to ventricular depolarization, and the T wave to ventricular repolarization.

The Heart Wall

The heart wall is made up of three distinct layers: the inner endocardium, the middle myocardium, and the outer epicardium. **Figure 1–4** shows these three heart layers.

The heart's inner surfaces (including the heart valves) are covered by the **endocardium**. The **myocardium** (the muscular heart wall) forms both the atria and ventricles. It contains cardiac muscle tissue, nerves, and blood vessels. The **epicardium** is the layer that covers the heart's outer surface.

Blood Supply to the Heart

The right and left **coronary arteries** are the first two branches of the aorta. They supply blood to the heart's tissues. Cardiac muscle cells require steady supplies of oxygen and nutrients because the heart works continuously. Branches of the **cardiac veins** drain blood from the myocardial capillaries into the **coronary sinus**, emptying into the right atrium.

The Conduction System of the Heart

The heart requires electrical impulses to maintain a heartbeat. A network of highly specialized muscle tissue transmits these impulses originating from the sinoatrial (SA) and atrioventricular (AV) nodes. This network includes the conducting fibers between the nodes, the bundle of His (AV bundle), the left and right bundle branches, and the Purkinje fibers (see **Figure 1–5**).

Electrocardiogram

An **electrocardiogram** graphically depicts, onto a moving strip of paper, a representation of the electrical impulses of the heart as it beats. The paper can be printed or the graph can be viewed on a variety of monitoring devices. An electrocardiogram is abbreviated as both **ECG** and **EKG**. Every time

the heart beats, a wave of **depolarization** moves through the atria, reaches the AV nodes, and moves down the intraventricular septum to the apex. This wave then turns and spreads through the ventricular myocardium toward its base.

An ECG collects its electric information from electrodes at different places on the surface of the body. An ECG can reveal normal and abnormal patterns of heart conduction, such as when part of the heart has been damaged by a heart attack. The following are the components of an ECG:

- A small P wave accompanies the atrial depolarization.
- The QRS complex appears during ventricular depolarization. The ventricles begin to contract briefly after the peak of the R wave.
- A smaller T wave indicates ventricular repolarization. Note: The QRS complex helps to mask any indication of atrial repolarization, which occurs while the ventricles are depolarizing.
- The P–R interval extends from the beginning of atrial depolarization to the start of the QRS complex.
- The Q–T interval indicates the time needed for the ventricles to depolarize and repolarize one time. This is usually measured from the end of the P–R interval.

Refer back to Figure 1–5 once more to examine the appearance of the electrical phases of the heart.

Blood Vessels

The blood vessels form a closed circuit of tubes that carry blood from the heart to the cells of the body and back again. Blood leaves the heart via the pulmonary trunk (which originates at the right ventricle) and the aorta (which originates at the left ventricle). The pulmonary arteries branch from the pulmonary trunk, carrying blood to the lungs. Systemic arteries branch from the aorta, distributing blood to all other body organs (see **Figures 1–6** and **1–7**).

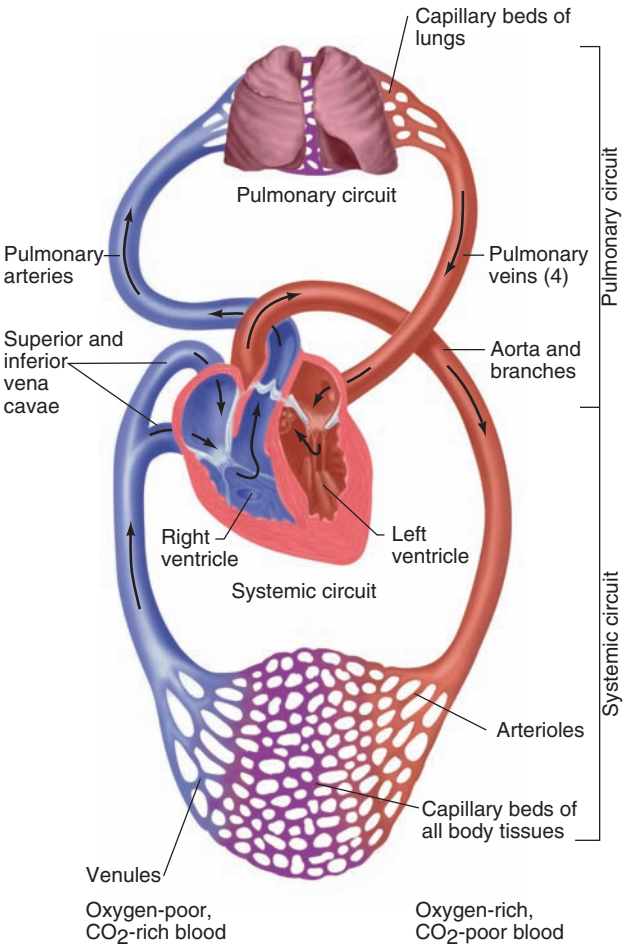


FIGURE 1–6 The blood pathway includes two circuits. The right ventricle supplies the pulmonary circuit, and the left ventricle supplies the systemic circuit.

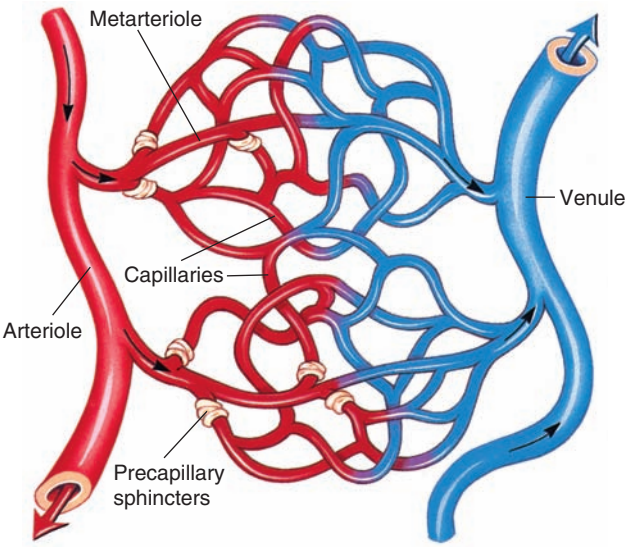


FIGURE 1–7 Just as we travel on different types of roads, our vasculature consists of several different types of vessels.

The blood vessels include arteries, arterioles, capillaries, venules, and veins. They are defined as follows:

- An artery is a blood vessel that carries blood away from the heart and toward peripheral capillaries.
- An arteriole is a smaller blood vessel that works with the arteries to carry blood to the capillaries.
- A capillary is the smallest type of blood vessel in the cardiovascular system. Capillaries allow the blood to distribute oxygen and nutrients to individual cells while picking up carbon dioxide and waste products from these cells. Blood is passed from the arterioles to the capillaries, eventually moving on to the venules.
- A venule is a small blood vessel that passes blood from the capillaries to the veins. Venules are smaller in size than veins and perform the reverse function of the arterioles.
- A vein is a blood vessel that carries blood back to the heart. Except for the pulmonary vein, all veins carry blood that is oxygen depleted and darker in color than that of oxygenated arterial blood. Veins are more numerous than arteries and hold a greater volume of blood. They contain valves that prevent blood from flowing backward. Vein walls are thinner than the walls of corresponding arteries because the blood pressure in the veins is lower than the blood pressure in the arteries. Large veins include the superior and inferior venae cavae, which carry less-oxygenated blood into the right atrium.

The Cardiac Cycle

The **cardiac cycle** is the period between the start of one heartbeat and the start of the next heartbeat. Atrial contraction regulates the heart chambers in an action known as atrial **systole**. During this action, the ventricles relax (called ventricular **diastole**). Next, the ventricles contract (ventricular systole) while the atria relax (atrial diastole). Finally, both the atria and ventricles relax for a brief interval.

Blood Pressure

Blood pressure is defined as the force that the blood exerts against the walls of the blood vessels. It is influenced by the amount of blood that the heart pumps, how much blood volume is in the circulatory system, and the squeezing force of the smooth muscle in the blood vessel walls. Normal blood pressure (in adults) is considered to be less than 120/80 millimeters of mercury (mm Hg).

Pulmonary and Systemic Circuits

Blood flows through the blood vessel network between the heart and peripheral tissues. This network can be subdivided into a pulmonary circuit (which carries blood between the gas exchange surfaces of the lungs) and a systemic circuit (which transports blood to and from the remainder of the body). Each circuit begins and ends at the heart. Oxygenated blood is sent from the left ventricle to the aorta and then circulated through the body (the systemic circuit). Therefore, once deoxygenated, the blood returns to the right atrium. It moves into the right ventricle and is then sent into the pulmonary trunk. Through pulmonary circulation, the exchange of oxygen and carbon dioxide occurs, and the blood returns to the left atrium. The process then begins again.

All body cells need energy for maintenance, growth, defense, and division. Energy is obtained mostly through **aerobic** mechanisms that require oxygen and produce carbon dioxide. Circulating blood contains oxygen, carrying it from the lungs to the peripheral tissues. This blood also transports carbon dioxide generated by the peripheral tissues to the lungs so that it can be exhaled. Deoxygenated blood is reoxygenated by the lungs.

Organs of the Respiratory System

The organs of the respiratory system can be divided into two tracts: the upper respiratory tract (nose, nasal cavity, paranasal sinuses, and pharynx) and the lower respiratory tract (larynx, trachea, bronchial tree, and lungs). The bronchial trees terminate into grapelike clusters (alveoli) in the lungs.

Nose and Nasal Cavity

The nose is the main passage that allows air to enter the respiratory system. Air moves through the two external nares (nostrils), which open into the nasal cavity. The **nasal septum** divides the nasal cavity into a right and a left portion, and the anterior portion of the septum consists of hyaline cartilage. The nasal cavity's lateral and superior walls are formed by the maxillary, nasal, frontal, ethmoid, and sphenoid bones of the skull (see **Figure 1–8**).

The superior, middle, and inferior nasal conchae project toward the nasal septum from the nasal cavity's lateral walls.

Pharynx

The pharynx is a hollow chamber that is also part of the respiratory and digestive systems. It is divided into the nasopharynx, oropharynx, and laryngopharynx (see **Figure 1–9**).

Larynx

The larynx (voice box) is a chamber surrounded by cartilage that

POINT TO REMEMBER

The most sensitive areas of the air passages are in the larynx, as well as in regions near the branches of the major bronchi.

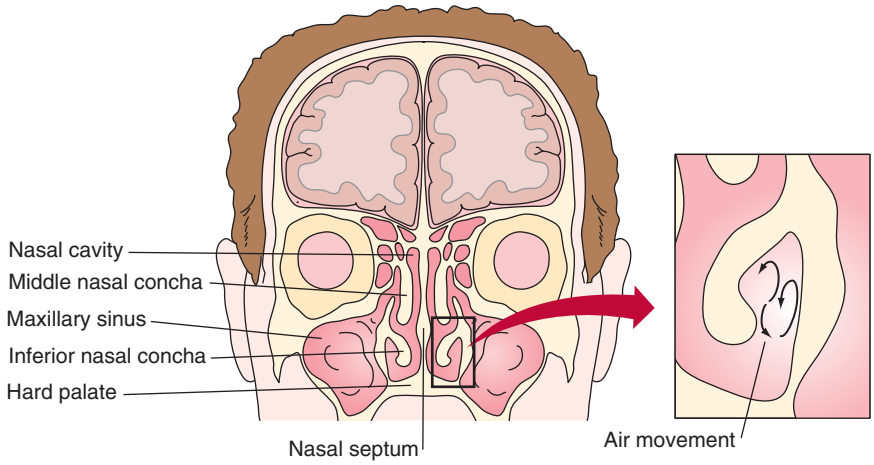


FIGURE 1–8 The nasal concha causes air to swirl as it passes through this cavity.

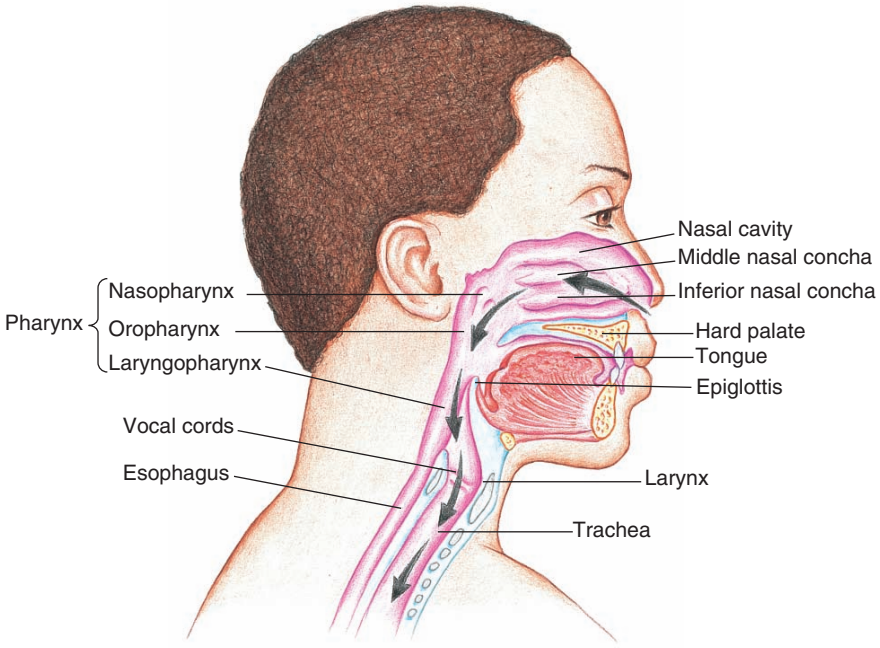


FIGURE 1–9 The upper respiratory tract.

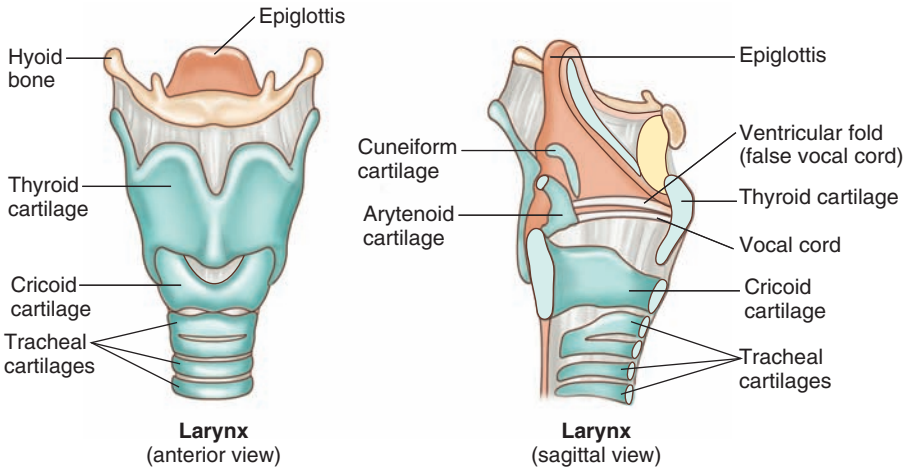


FIGURE 1–10 The larynx.

primarily functions to keep food and liquids out of the airway. It also contains the vocal cords (see **Figure 1–10**).

There are three types of cartilage that form the larynx:

- Thyroid cartilage: The **thyroid cartilage** is the largest of the three; it forms most of the anterior and lateral laryngeal walls.
- Cricoid cartilage: The **cricoid cartilage** is inferior to the thyroid cartilage; it also helps to protect the glottis and entrance to the trachea.
- Epiglottis: Shaped like a shoehorn, the **epiglottis** is cartilage that forms a lid over the glottis.

During swallowing, the larynx is elevated, with the epiglottis folding back over the glottis to prevent the entry of either liquids or solid food into the respiratory tract.

Trachea

The laryngeal epithelium is continuous with the trachea (windpipe), which is a tough, flexible tube about 1 inch in diameter. It contains 15 to 20 tracheal cartilages (see **Figure 1–11**). These serve to make the tracheal walls stiff, protecting the airway and preventing it from collapsing or expanding too greatly when pressures change in the respiratory system.

The tracheal cartilages are all C shaped, with the open part of the C facing posteriorly toward the **esophagus**. Because they are not continuous cartilages, the posterior wall of the trachea can distort easily when swallowing, allowing large pieces of food to pass through the esophagus.

Bronchial Tree

The primary bronchi, along with their branches, form the **bronchial tree**. The left and right primary bronchi are located outside the lungs, so they are called extrapulmonary bronchi. As the primary bronchi enter into the lungs, they divide into smaller passageways known as secondary bronchi. In each lung, one of the secondary bronchi connects to each lobe. It is important

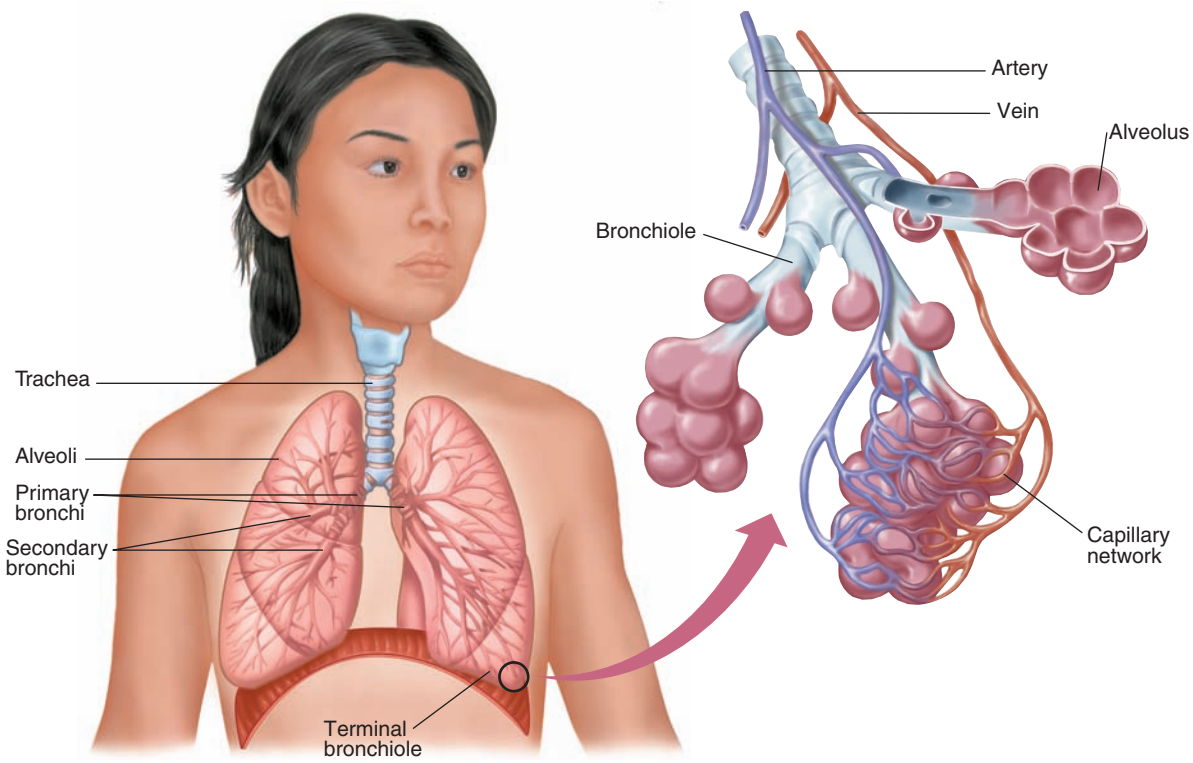


FIGURE 1–11 The trachea conveys air from the larynx to the bronchi, which distribute air throughout the lungs. The bronchioles lead to the alveoli.

to remember that the right lung has three secondary bronchi, and the left lung has only two.

Lungs

The lungs are located in the thoracic cavity and have a soft, spongy structure in a cone-shaped form. The right and left lungs are separated medially by the **mediastinum**, and they are enclosed by the thoracic cage and **diaphragm** (see **Figure 1–12**).

Each lung fills most of the thoracic space where it is located. The lungs are suspended by a bronchus and some large blood vessels, with a layer of serous membrane (the **visceral pleura**) attached firmly to the surface of each lung. This pleura folds back, becoming the **parietal pleura**, which also forms part of the mediastinum and lines the inner thoracic cavity walls.

Breathing Mechanism

POINT TO REMEMBER

Sometimes a person who is emotionally upset may hyperventilate, become dizzy, and lose consciousness.

The general term *respiration* refers to the processes of external and internal respiration. External respiration includes the processes involved in exchanging oxygen and carbon dioxide between the lungs and the external environment. Because the epithelium is continuous from the nares to the alveoli, the lungs are actually considered part of the external environment. External respiration occurs between the alveoli of the lungs and the pulmonary capillaries. Internal respiration is the absorption of oxygen and the release of carbon dioxide by the cells of the respiratory system. It occurs between the systemic capillaries and body tissues and cells.

Breathing (ventilation), is the physical movement of air from the outside of the body into and out of the bronchial tree and alveoli. This air movement is provided by actions collectively called **inspiration** (inhalation) and **expiration** (exhalation).

Respiratory Air Volumes and Capacities

There are four different respiratory volumes as measured by using spirometry (see **Figure 1–13**). A respiratory cycle consists of one inspiration and its subsequent

POINT TO REMEMBER

A person should never hyperventilate to help hold the breath while swimming because it is possible to lose consciousness under water and drown.

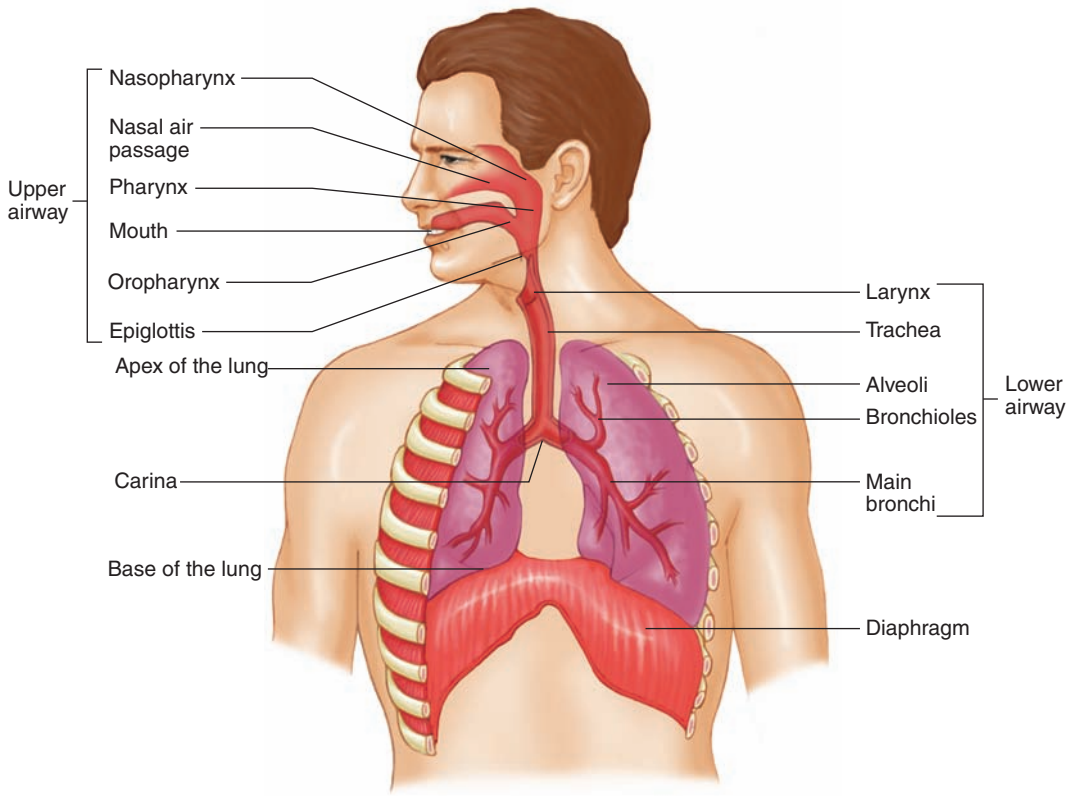


FIGURE 1–12 Structures of the respiratory system.

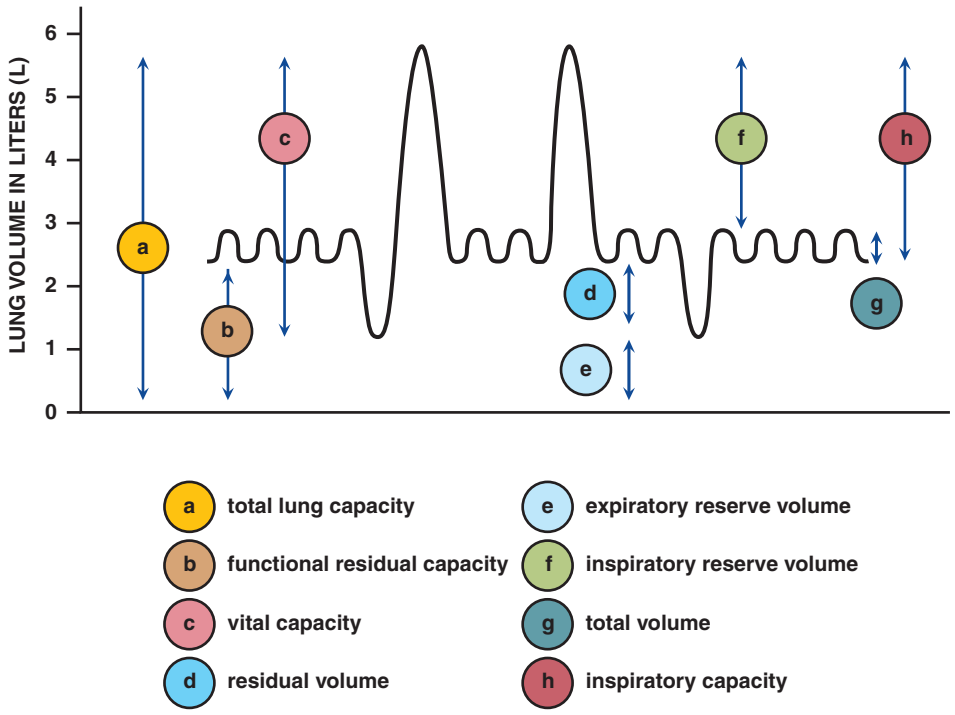


FIGURE 1–13 Respiratory air volumes and capacities.

expiration. The amount of air entering and leaving during one respiratory cycle is called the tidal volume. This consists of approximately 500 mL of air. Nearly the same amount of air leaves during a normal, resting expiration and is known as resting tidal volume.

Air that is in addition to the resting tidal volume is known as inspiratory reserve volume (complemental air) and totals about 3000 mL. The lungs can also expel about 1100 mL beyond the resting tidal volume, known as expiratory reserve volume (supplemental air). Even after forceful expiration, about 1200 mL of air remains in the lungs, known as residual volume. When fresh air is inhaled into the lungs, it mixes with the air already present and prevents wide fluctuations between oxygen and carbon dioxide concentrations.

The four respiratory capacities are as follows:

- Vital capacity (4600 mL): a combination of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume
- Inspiratory capacity (3500 mL): a combination of the tidal volume plus the inspiratory reserve volume
- Functional residual capacity (2300 mL): a combination of the expiratory reserve volume and the residual volume
- Total lung capacity (5800 mL): a combination of the vital capacity plus the residual volume (total lung capacity varies with age, body size, and gender)

Control of Breathing

The brainstem regulates the involuntary and rhythmic delivery and removal of oxygen and carbon dioxide. Control of the respiratory centers comes from the **medulla oblongata** and the **pons** (see **Figure 1–14**).

Factors That Affect Breathing

Factors that affect breathing and the depth of ventilation include certain body chemicals, level of physical activity, emotional states, and the stretchability of the lung tissues. As carbon dioxide accumulates in the blood, it stimulates breathing depth and rate. Low blood oxygen has only small direct effects on central chemoreceptors in the respiratory system. Normal breathing can be altered by emotional upset, and fear or pain usually increases the breathing rate. Because the respiratory muscles are voluntary, conscious control of breathing is also possible.

Alveolar Gas Exchanges

Pulmonary ventilation ensures that the alveoli have adequate oxygen supply. It also removes carbon dioxide from the bloodstream, and the gas exchanges occur between the blood and alveolar air across the respiratory membranes (see **Figure 1–15**).

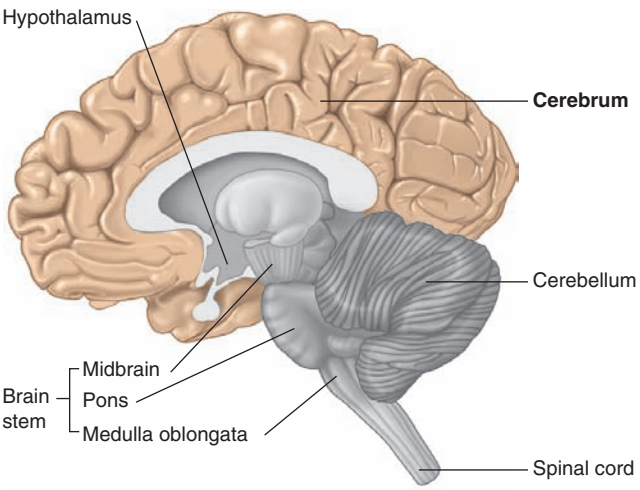


FIGURE 1–14 Cross-section of the brain.

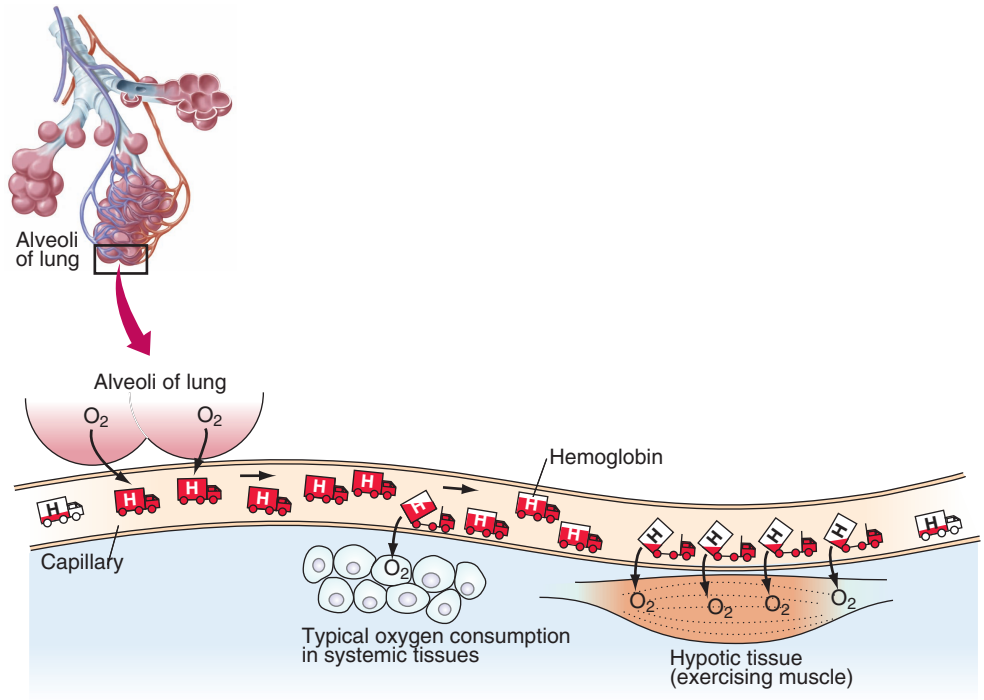


FIGURE 1–15 The relationship between the partial pressure of oxygen and hemoglobin.

Gas Transport

Oxygen (O_2) and carbon dioxide (CO_2) are not readily soluble in blood plasma. This situation of limited solubility is a problem because peripheral tissues need more oxygen than plasma can absorb and transport. The peripheral tissues also generate more carbon dioxide than the plasma can absorb and transport. Gases that are dissolved are bound to **hemoglobin (Hb)** molecules. This action forms oxyhemoglobin (HbO_2). This reversible reaction is summarized as follows:

$$Hb + O_2 \longleftrightarrow HbO_2$$

Aerobic metabolism generates carbon dioxide in body tissues. When a CO_2 molecule enters the bloodstream, it is either converted to a carbonic acid molecule, bound to the protein in hemoglobin molecules inside red blood cells, or dissolved in the blood plasma. These three reactions can be completed in reverse order.

Most of the carbon dioxide that is absorbed in the blood, which is almost 70% of the total amount, is transported as carbonic acid molecules. Carbon dioxide is converted to carbonic acid through **carbonic anhydrase** enzyme activity in the red blood cells. Carbonic acid molecules dissociate immediately into hydrogen and bicarbonate ions. This reaction can be summarized as follows:

$$CO_2 + H_2O \longleftrightarrow H^+ + HCO_3^-$$

Approximately 23% of the carbon dioxide in the blood is bound to the protein of the Hb molecules inside the red blood cells. This compound is then called **carbaminohemoglobin**.

Plasma becomes saturated with carbon dioxide. This process is rapid. Approximately 7% of the carbon dioxide is absorbed by the peripheral capillaries and transported as dissolved molecules of gas. The remainder is absorbed by the red blood cells, where it is converted (via carbonic anhydrase) or stored as carbaminohemoglobin.

POINT TO REMEMBER

Exposure to high oxygen concentration for a prolonged time may damage lung tissue, particularly capillary walls.

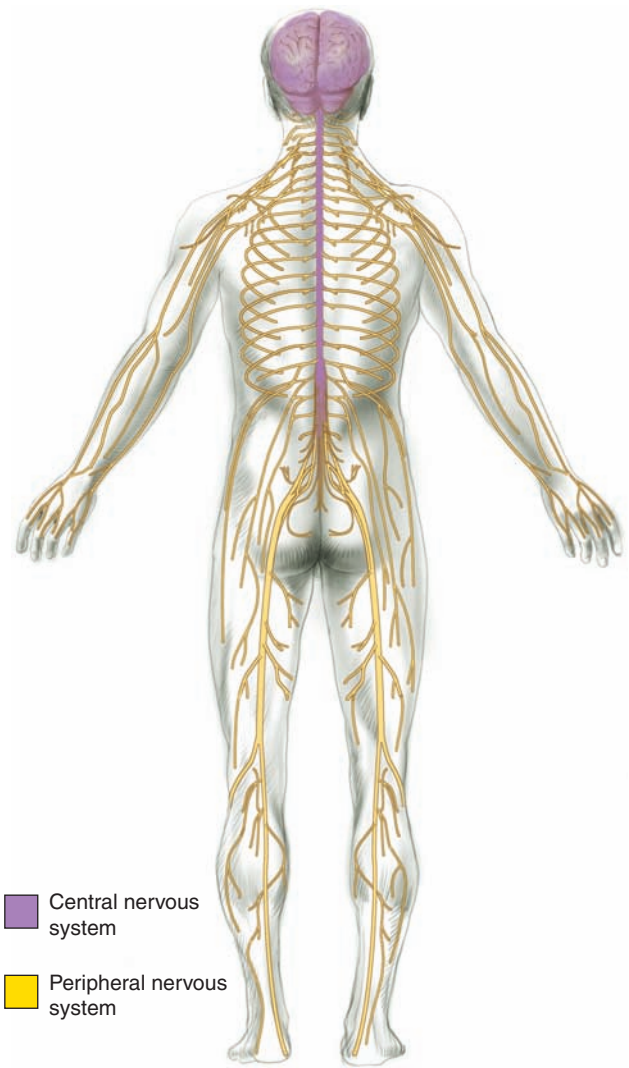


FIGURE 1–16 The nervous system can be divided into the central nervous system and peripheral nervous system.

Overview of the Nervous System

The nervous system is made up of the central nervous system, which contains the brain and the spinal cord. The peripheral nervous system is composed of the peripheral nerves, which connect the central nervous system to the rest of the body. It also contains the autonomic nervous system, which utilizes autonomic neurotransmitters to function. See **Figure 1–16** for a depiction of the central and peripheral nervous systems, and also see **Figure 1–17** for the major subdivisions of the nervous system.

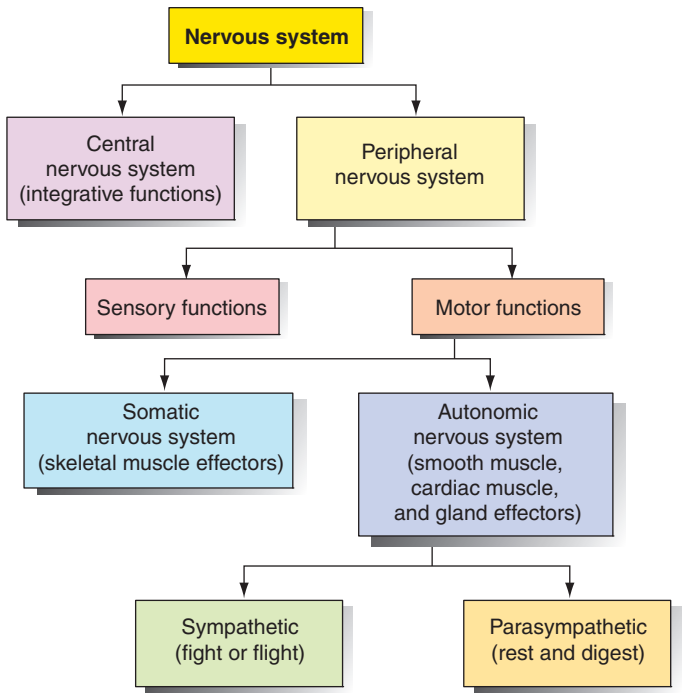


FIGURE 1–17 Major subdivisions of the nervous system.

Central Nervous System

The central nervous system (CNS) is made up of the brain and the spinal cord. It functions by utilizing sensory receptors that detect changes both inside and outside the body. These receptors transmit impulses over peripheral nerves to the CNS. Nervous tissue consists of masses of nerve cells (neurons), which are the structural and functional units of the nervous system. They transmit information as nerve impulses to other neurons and also to cells that are outside of the nervous system.

Nerves are bundles of axons. An axon is an extension from a neuron's cell body that sends out nerve impulses. Another type of extension, the dendrite, receives electrochemical messages. The junction between any two neurons is called a synapse. Synaptic transmission is accomplished by biochemicals known as neurotransmitters, which may be either excitatory (increasing the chance that a nerve impulse will occur) or inhibitory (decreasing the chance that a nerve impulse will occur). Nerves that conduct impulses to the brain or spinal cord are called sensory nerves, and those that carry impulses to muscles or glands are called motor nerves. Most nerves have both types of fibers and are called mixed nerves.

Brain

The brain receives and processes large amounts of information. The 100 billion **neurons** of the brain control many activities simultaneously. The brain is divided into four major portions: cerebrum, diencephalon, brainstem, and cerebellum (see **Figure 1–18**). The brain can respond to various stimuli in many diverse ways.

Cerebrum

The cerebrum is made up of the two large hemispheres of the brain. It is the center of conscious thought, sensory perception, memory, and motor activities. Its outer layer is known as gray matter (the cerebral cortex), and its inner layer is known as white matter. Its surface is covered with elevated ridges (gyri) separated by grooves called sulci and fissures. The cerebrum contains many neurons required for analytical functions. Each cerebral hemisphere is divided into five lobes.

The cerebrum is categorized into three functional areas: motor, sensory, and association. The motor areas are located within the frontal lobes. The sensory areas are located within the parietal, temporal, and occipital lobes. The association areas are located throughout various lobes.

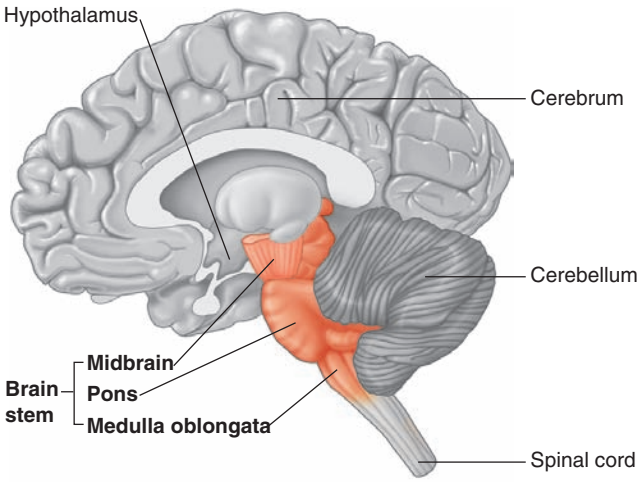


FIGURE 1–18 Major portions of the brain.

Diencephalon

The diencephalon is located between the inferior regions of the two cerebral hemispheres. It contains the epithalamus, thalamus, and hypothalamus. The epithalamus contains the pineal gland, which is important for the regulation of the body's day and night cycles. The thalamus is the main point of processing sensory information. The hypothalamus is attached to the pituitary gland by a thin funnel-like stalk called the infundibulum. The hypothalamus controls the autonomic nervous system, endocrine system, body temperature, emotions, eating, drinking, and sleeping.

Brainstem

The **brainstem** helps to connect the cerebellum to the spinal cord and is divided into three regions: mesencephalon, pons, and medulla oblongata. The brainstem houses the nuclei of many of the cranial nerves and contains many critical autonomic and reflex centers. The mesencephalon is also known as the **midbrain**. It contains cranial nerves, motor tracts, axons, sensory nuclei, and other important structures.

POINT TO REMEMBER

Injuries to the respiratory center or to spinal nerve tracts that transmit motor impulses may paralyze the breathing muscles.

The pons bulges out on the anterior brainstem and houses sensory and motor tracts connecting the brain and spinal cord. The medulla oblongata is continuous with the spinal cord and even resembles it. All communication between the brain and spinal cord flows through the medulla oblongata. The most important autonomic centers of the medulla oblongata regulate the heart, blood pressure, and breathing.

Cerebellum

The cerebellum is the second largest section of the brain. Similar to the cerebrum, it also consists of two hemispheres primarily composed of white matter, with a thin gray matter layer on its surface. The cerebellum controls skeletal muscle movements and contractions to control equilibrium and posture. It is important in keeping the skeletal muscle activity fine-tuned so that the body has correct and adequate muscle tone and strength.

The cerebellum interacts with the CNS via three paired nerve tracts called the cerebellar peduncles. It is basically a reflex center concerned with body position.

When damaged, the results often include tremors, impaired muscle control, imbalance, and reduced muscle tone.

Spinal Cord

The spinal cord occupies the vertebral canal inside the vertebral column. Between the bony coverings and soft tissues of the CNS, layered membranes called meninges are found. Meninges have three layers: dura mater, arachnoid mater, and pia mater. The dura mater is attached to the cranial cavity and continues into the vertebral canal. The arachnoid mater is a weblike membrane between the dura and pia maters. The pia mater contains nerves and blood vessels that are important for nourishing brain and spinal cells. Between the arachnoid and pia maters is the subarachnoid space, which contains the clear and watery cerebrospinal fluid (CSF).

The spinal cord itself is a slender column of nerves that passes from the brain into the vertebral canal. It begins where nervous tissue exits the cranial cavity, and it ends near the intervertebral disc that separates the first and second lumbar vertebrae. The spinal cord has 31 segments that each have a pair of spinal nerves attached. It is divided by two grooves that separate the cord into right and left halves. Gray matter divides the spinal cord's white matter into anterior, lateral, and posterior funiculi regions, which contain bundled nerve fibers.

The spinal cord functions primarily to conduct nerve impulses and control spinal reflexes. The axons inside the spinal cord allow two-way communication between the brain and body parts. The ascending tracts of the spinal cord carry sensory information to the brain, and the descending tracts conduct motor impulses from the brain to the muscles and glands.

Peripheral Nervous System

The peripheral nervous system (PNS) contains the cranial and spinal nerves, which branch out from the CNS. These nerves connect to the rest of the body. The PNS is divided into the somatic and autonomic nervous systems. The somatic nervous system oversees conscious activities and actions of the skin and skeletal muscles. The autonomic nervous system oversees the actions of the heart, stomach, intestines, and other viscera. It controls unconscious activities.

Cranial Nerves

There are 12 pairs of cranial nerves that extend from the underside of the brain, all of which (except for the first pair) originate in the brainstem. These nerves lead to various areas of the head, neck, and trunk. **Table 1–2** lists the 12 pairs of cranial nerves.

Spinal Nerves

The 31 pairs of spinal nerves are grouped by the level of the spinal cord from which they arise. In general, they are associated with their respective spinal vertebrae.

TABLE 1–2 Cranial Nerves

Number	Nerve	Type
I	Olfactory	Sensory (smell)
II	Optic	Sensory (vision)
III	Oculomotor	Primarily motor (eye muscles)
IV	Trochlear	Primarily motor (eye muscles)
V	Trigeminal (ophthalmic, maxillary, mandibular)	Mixed (eyes, tear glands, scalp, forehead, upper eyelids, teeth, gums, lips, palate, face, jaw)
VI	Abducens	Primarily motor (eye muscles)
VII	Facial	Mixed (taste and tongue, expression, tear glands, salivary glands)
VIII	Vestibulocochlear	Sensory (equilibrium, hearing)
IX	Glossopharyngeal	Mixed (pharynx, tonsils, tongue, carotid arteries, swallowing, salivary glands)
X	Vagus	Mixed (speech, swallowing, transmission of impulses to heart, smooth muscles, thoracic glands, abdominal glands; also impulses from pharynx, larynx, esophagus, and viscera)
XI	Accessory (cranial and spinal)	Primarily motor (soft palate, pharynx, larynx, neck, back)
XII	Hypoglossal	Primarily motor (muscles that move the tongue)

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. Except for the thoracic region, the main portions of spinal nerves form complex networks (plexuses), wherein nerve fibers are sorted and recombined. This allows them to innervate certain peripheral body parts even though they originate from different spinal nerves.

Autonomic Nervous System

The autonomic nervous system (ANS) governs involuntary actions and works with the somatic nervous system to regulate body organs and functions. Both are part of the central as well as the peripheral nervous systems. The ANS functions mostly unconsciously, such as the stomach's process of digestion or the blood vessels' processes of coordinating blood pressure. It is activated by visceral sensory neurons. The ANS is subdivided into the parasympathetic and sympathetic divisions, which focus on the control of the body's internal environment.

Parasympathetic Division

The parasympathetic division arises from the brainstem and the sacral region of the spinal cord (see **Figure 1–19**). It conserves energy and replaces nutrients, so it is called the rest-and-digest division. It helps to maintain homeostasis in the body. Its preganglionic axons are longer, and the relatively short postganglionic fibers continue from the ganglia to specific muscles or glands within the viscera. Only one or a few structures become innervated by this system at the same time.

Sympathetic Division

The sympathetic division prepares the body for emergencies, hence its fight-or-flight name. The preganglionic fibers originate from the neurons of the spinal cord (see Figure 1–19). Increased sympathetic activity causes increased alertness and metabolism. When this system causes innervation, all of its components become stimulated.

Autonomic Neurotransmitters

The sympathetic and parasympathetic divisions secrete the neurotransmitter known as acetylcholine from their preganglionic fibers (cholinergic fibers). Most sympathetic postganglionic neurons secrete norepinephrine (noradrenaline), so they are also called adrenergic fibers. Most body organs are innervated by the actions of these various autonomic neurotransmitters. The sympathetic and parasympathetic nervous systems use these neurotransmitters to achieve opposing actions.

Other neurotransmitters released from the brain include dopamine, serotonin, and gamma-aminobutyric acid (GABA). However, their actions may not be directly opposed to one another (antagonistic). **Table 1–3** explains the opposing actions of the sympathetic and parasympathetic nervous system neurotransmitters.

Patient Education

Respiratory therapists should be familiar with the structures and functions of the cardiovascular system. They should advise patients who are suffering

TABLE 1–3 Opposing Neurotransmitter Actions

Body structure or function	Sympathetic	Parasympathetic
Eye pupils	Dilation	Constriction
Tear glands	No action	Secretion
Salivary glands	Decreased secretion	Increased secretion
Lung bronchioles	Dilation	Constriction
Heart rate	Increased	Decreased
Blood distribution	Increased to skeletal muscles, decreased to digestive organs	Decreased to skeletal muscles, increased to digestive organs
Blood glucose	Increased	Decreased
Intestinal wall muscles	Peristalsis decreased	Peristalsis increased
Intestinal glands	Secretion decreased	Secretion increased
Gallbladder muscles	Relaxed	Contracted
Urinary bladder muscles	Relaxed	Contracted

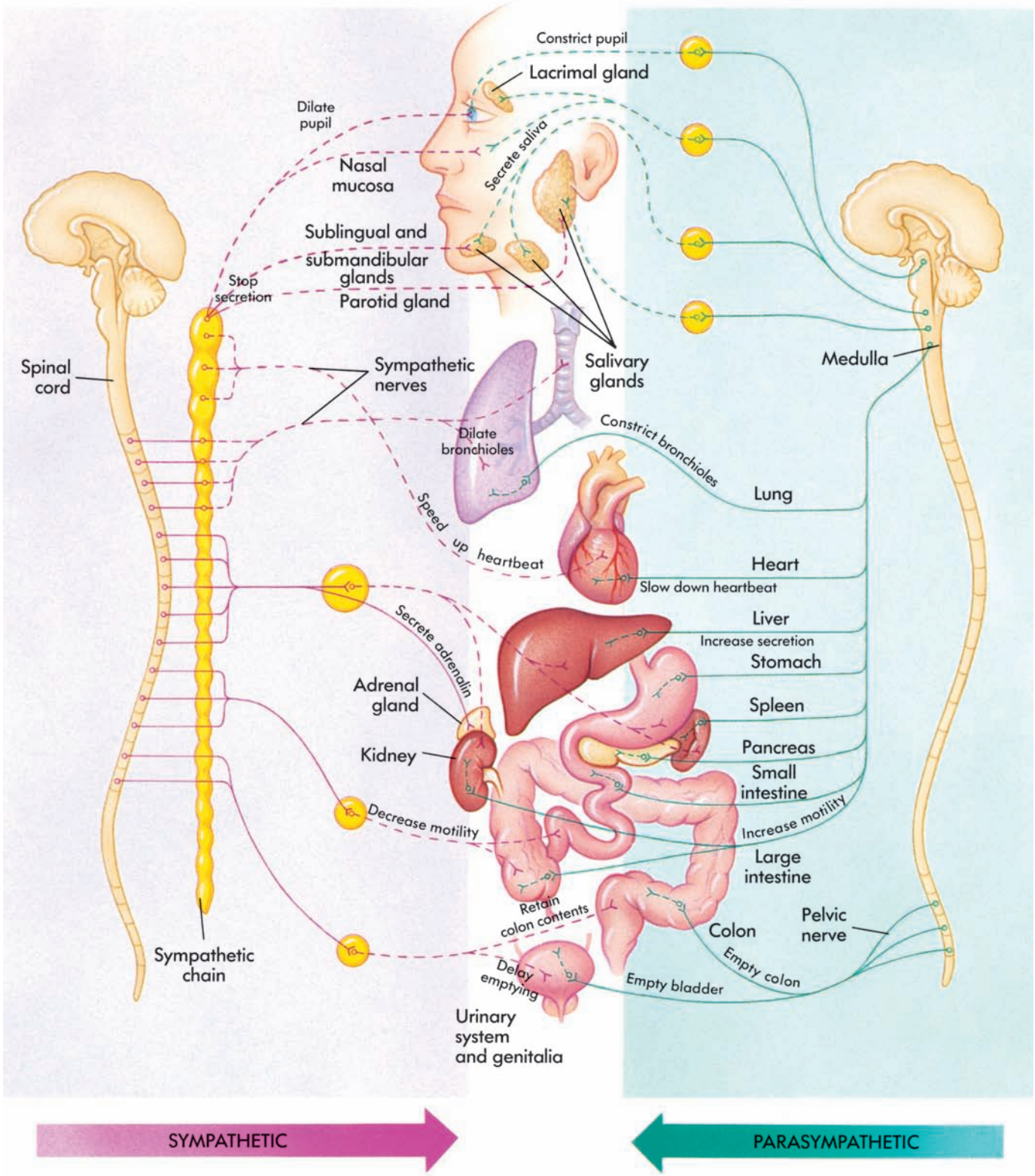


FIGURE 1–19 Divisions of the autonomic nervous system.

from congestive heart failure to restrict their intake of sodium, lose weight, avoid smoking, and see their physician on a regular basis. Respiratory therapists should also instruct patients to take their medications exactly as prescribed.

SUMMARY

The heart pumps nearly 8000 liters of blood per day, yet is only about the size of an adult's clenched fist. It consists of two hollow atria and two hollow ventricles. When the heart beats, the atria contract first, followed by the ventricles. Special valves in the heart control blood flow and keep it from flowing back into areas where it should not flow. The heart valves include the mitral (bicuspid), aortic, tricuspid, and pulmonary valves. The heart wall is made up of three distinct layers: endocardium, myocardium, and epicardium. The heart requires electrical impulses to maintain a heartbeat. These impulses may be charted on a graph known as an electrocardiogram (ECG or EKG).

The cardiopulmonary vessels include arteries, arterioles, capillaries, venules, and veins. Blood pressure is defined as the force that the blood exerts against the walls of the blood vessels. The organs of the respiratory system include the upper respiratory tract (nose, nasal cavity, paranasal sinuses, and pharynx) and the lower respiratory tract (larynx, trachea, bronchial tree, and lungs). The pharynx is also part of the digestive system because food and liquids pass through it. The lungs are the primary organs of respiration, and the processes of inspiration and exhalation are controlled by the brainstem, primarily the medulla oblongata and pons. However, because the respiratory muscles are voluntary, conscious control of breathing is also possible.

The central nervous system (CNS) is made up of the brain and spinal cord. The four major parts of the brain are the cerebrum, diencephalon, brainstem, and cerebellum. The spinal cord is a slender column of nerves that passes from the brain through the vertebral canal. The peripheral nervous system (PNS) contains the cranial and spinal nerves. The autonomic nervous system (ANS) governs involuntary actions to stimulate or inhibit the activity of the visceral organs. It consists of the sympathetic and parasympathetic nervous systems.

LEARNING GOALS

These learning goals correspond to the objectives at the beginning of the chapter, providing a clear summary of the chapter's most important points.

1. The structures of the cardiovascular system include the heart (including its chambers, valves, and wall) and the blood vessels.
2. The heart's inner surfaces (including the heart valves) are covered by the endocardium. The myocardium (the muscular heart wall) forms both the atria and ventricles. It contains cardiac muscle tissue, nerves, and blood vessels. The epicardium is the layer that covers the heart's outer surface.
3. The cardiac cycle is the period between the start of one heartbeat and the start of the next heartbeat. Atrial contraction regulates the heart chambers in an action known as atrial systole. During this action, the ventricles relax (called ventricular diastole). Next, the ventricles contract (ventricular systole) while the atria relax (atrial diastole). Finally, both the atria and ventricles relax for a brief interval.

   Blood pressure is defined as the force that the blood exerts against the walls of the blood vessels. It is influenced by the amount of blood that the heart pumps, how much blood volume is in the circulatory system, and the squeezing force of the smooth muscle in the blood vessel walls. Normal blood pressure (in adults) is considered to be 120/80 millimeters of mercury (mm Hg).
4. The blood vessels include arteries, arterioles, capillaries, venules, and veins. They are defined as follows:
   - An artery is a blood vessel that carries blood away from the heart and toward peripheral capillaries.
   - An arteriole is a smaller blood vessel that works with the arteries to carry blood to the capillaries.
   - A capillary is the smallest type of blood vessel in the cardiovascular system. Capillaries allow the blood to distribute oxygen and nutrients to individual cells while picking up carbon dioxide and waste products from these cells. Blood is passed from the arterioles to the capillaries, eventually moving on to the venules.
   - A venule is a small blood vessel that passes blood from the capillaries to the veins. Venules are smaller than veins and perform the reverse function of the arterioles.
   - A vein is a blood vessel that carries blood back to the heart. Except for the pulmonary vein, all veins carry blood that is oxygen depleted and darker in color than that of oxygenated arterial blood. Veins are more numerous than arteries and hold a greater volume of blood. They contain valves that prevent blood from flowing backward. Vein walls are thinner than the walls of corresponding arteries because the blood pressure in the veins is lower than the blood pressure in the arteries. Large veins include the superior and inferior venae cavae, which carry less-oxygenated blood into the right atrium.

5. The respiratory system furnishes oxygen for individual tissue cells and takes away their gaseous waste products. Through the act of respiration, consisting of external and internal processes, this process is accomplished. External respiration is the method in which the lungs are ventilated, and oxygen and carbon dioxide are exchanged between the air in the alveoli of the lungs and the blood in the pulmonary capillaries. Internal respiration occurs when oxygen and carbon dioxide are exchanged between the blood in systemic capillaries and the body's tissues and cells.
6. The locations of the respiratory system organs are in the upper respiratory tract (nose, nasal cavity, and paranasal sinuses in the skull; and pharynx in the neck) and the lower respiratory tract (larynx and trachea in the neck; and bronchial tree and lungs in the thoracic cavity).
7. The nose is the main passage that allows air to enter the respiratory system. Air moves through the two external nares (nostrils), which open into the nasal cavity. The pharynx is a hollow chamber that is also part of the respiratory and digestive systems. It is divided into the nasopharynx, oropharynx, and laryngopharynx. The larynx (voice box) is a chamber surrounded by cartilage that primarily functions to keep food and liquids out of the airway. It also contains the vocal cords. During swallowing, the larynx is elevated, with the epiglottis folding back over the glottis to prevent the entry of either liquids or solid food into the respiratory tract. The laryngeal epithelium is continuous with the trachea (windpipe), which is a tough, flexible tube about 1 inch in diameter. It contains 15 to 20 tracheal cartilages. These serve to make the tracheal walls stiff and protect the airway, as well as preventing it from collapsing or expanding too greatly when pressures change in the respiratory system. The primary bronchi, along with their branches, form the bronchial tree. The right lung has three secondary bronchi, and the left lung has only two. The lungs are located in the thoracic cavity, with a soft, spongy structure in a cone-shaped form. The right and left lungs are separated medially by the mediastinum and are enclosed by the thoracic cage and diaphragm.
8. The general term *respiration* refers to the processes of external and internal respiration. External respiration includes the processes involved in exchanging oxygen and carbon dioxide between the lungs and the external environment. Internal respiration is the absorption of oxygen and the release of carbon dioxide by the cells of the respiratory system. Breathing (ventilation) is the physical movement of air from the outside of the body into and out of the bronchial tree and alveoli. This air movement is provided by actions collectively called inspiration (inhalation) and expiration (exhalation).
9. The four main parts of the brain and their functions are as follows:
   - Cerebrum: The cerebrum is the center of conscious thought, sensory perception, memory, and motor activities; it contains many neurons required for analytical functions. There are three functional areas: motor, sensory, and association.
   - Diencephalon: The diencephalon contains the pineal gland, which is important for the regulation of the body's day and night cycles. Another structure, the thalamus, is the main point of processing sensory information. The part of the thalamus known as the hypothalamus controls the autonomic nervous system, endocrine system, body temperature, emotions, eating, drinking, and sleeping.
   - Brainstem: The brainstem is divided into three regions: mesencephalon (midbrain), pons, and medulla oblongata. It contains many critical autonomic and reflex centers. All communication between the brain and spinal cord flows through the medulla oblongata, and its most important autonomic centers regulate the heart, blood pressure, and breathing.
   - Cerebellum: The cerebellum controls skeletal muscle movements and contractions to control equilibrium and posture, and it is important in keeping the skeletal muscle activity fine-tuned so the body has correct and adequate muscle tone and strength.
10. The cardiopulmonary system is affected by the parasympathetic and sympathetic nervous systems as follows:
    - Parasympathetic: The parasympathetic nervous system conserves energy and replaces nutrients; therefore it is called the rest-and-digest division. It helps to main homeostasis in the body.
    - Sympathetic: The sympathetic nervous system prepares the body for emergencies, hence its fight-or-flight name. Increased sympathetic activity causes increased alertness and metabolism.

CRITICAL THINKING QUESTIONS

1. Cigarette smoke contains thousands of chemicals, including nicotine and carbon monoxide. Nicotine constricts blood vessels. Carbon monoxide prevents

oxygen from binding to hemoglobin. How do these two components of smoke affect the cardiovascular system?

2. If a tracheostomy bypasses the upper respiratory passages, how might the air entering the trachea differ from air normally passing through this tube? What problems might this cause for the patient?

WEB SITES

http://hes.ucfsd.org/gclaypo/repiratorysys.html
http://science.nationalgeographic.com/science/health-and-human-body/human-body/lungs-article.html
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CNS.html
http://www.americanheart.org/presenter.jhtml?identifier=4463
http://www.cardiovascularcs.org/
http://www.cvphysiology.com/Heart%20Disease/HD002.htm
http://www.daviddarling.info/encyclopedia/B/bronchial_tree.html
http://www.fi.edu/learn/heart/structure/structure.html
http://www.tutorvista.com/content/biology/biology-ii/respiration/breathing-mechanism.php

REVIEW QUESTIONS

Multiple Choice

Select the best response to each question.

1. Breathing is regulated by the
   - A. thalamus
   - B. cerebellum
   - C. hypothalamus
   - D. pons
2. The artery that carries deoxygenated blood from the heart to the lungs is the
   - A. coronary artery
   - B. renal artery
   - C. pulmonary artery
   - D. aorta
3. Which part of the heart receives oxygenated blood from the pulmonary veins?
   - A. right atrium
   - B. left atrium
   - C. right ventricle
   - D. left ventricle
4. Where in the lung does the exchange of gases take place?
   - A. trachea
   - B. alveoli
   - C. bronchioles
   - D. larynx
5. Which of the following is *not* a function of the sympathetic division of the autonomic nervous system?
   - A. It increases the heart rate and breathing rate.
   - B. It prepares the body for an emergency.
   - C. It increases digestive system motility and activity.
   - D. It dilates the pupils.
6. Which of the following is *not* part of the respiratory system?
   - A. larynx
   - B. pharynx
   - C. thoracic duct
   - D. bronchi
7. Which of the following is *not* a function of the hypothalamus?
   - A. It regulates the sleep–wake cycle.
   - B. It controls the autonomic nervous system.
   - C. It initiates voluntary skeletal muscle movement.
   - D. It controls the endocrine system.
8. Which valve is located between the left atrium and left ventricle?
   - A. bicuspid valve
   - B. tricuspid valve
   - C. aortic valve
   - D. pulmonary valve
9. The heart's pacemaker is located in the
   - A. right ventricle
   - B. right atrium
   - C. left ventricle
   - D. left atrium
10. Which structure contains some autonomic centers involved in regulating respiration?
    - A. pons
    - B. cerebellum
    - C. thalamus
    - D. cerebrum
11. Which part of the pleura is attached to the lung surface?
    - A. parietal
    - B. apical
    - C. visceral
    - D. mediastinum
12. Which of the following keeps the airways of the trachea open?
    - A. ciliated epithelium
    - B. surfactant
    - C. smooth muscle
    - D. cartilage

13. Which of the following large vessels drains low-oxygen blood from the majority of the lower body into the right atrium?
    - **A.** hepatic vein
    - **B.** inferior vena cava
    - **C.** superior vena cava
    - **D.** azygos vein
14. Which of the following is a part of both the respiratory and digestive systems and allows the passage of food, drink, and air?
    - **A.** nasopharynx
    - **B.** trachea
    - **C.** oropharynx
    - **D.** glottis
15. In the respiratory system, which of the following is the last and smallest conducting portion?
    - **A.** terminal bronchiole
    - **B.** respiratory bronchiole
    - **C.** nasopharynx
    - **D.** alveolus

CASE STUDY

In 1799, a 67-year-old man had flulike symptoms for a few days during the winter. He began having trouble breathing and swallowing, and his voice became muffled. His doctors tried a variety of therapies that were popular, including bleeding and using beetles to bite his legs to produce blisters. One of the doctors suggested a tracheostomy so the patient could breathe, but the other doctors said it would not help. The man later died with no improvement in his condition. If a tracheostomy had been performed, would it likely have saved his life?