CHAPTER 04

SUPPORTING SYSTEMS

LEARNING OBJECTIVES

1 | Name and describe the body's supporting organ systems outside the nervous, skeletal, and muscular systems.

2 | Differentiate between the types of respiration the body can perform.

3 | List the endocrine hormones and their functions.

4 | Identify the organs of the digestive system and their individual functions.

The human body is a complex and interconnected synergy of 11 organ systems. All organ systems have unique functions that are necessary for proper body function. The nervous, muscular, and skeletal systems work together to generate human movement. However, a fitness professional must also understand the body's other organ systems to understand their importance in overall function, health, and wellness.

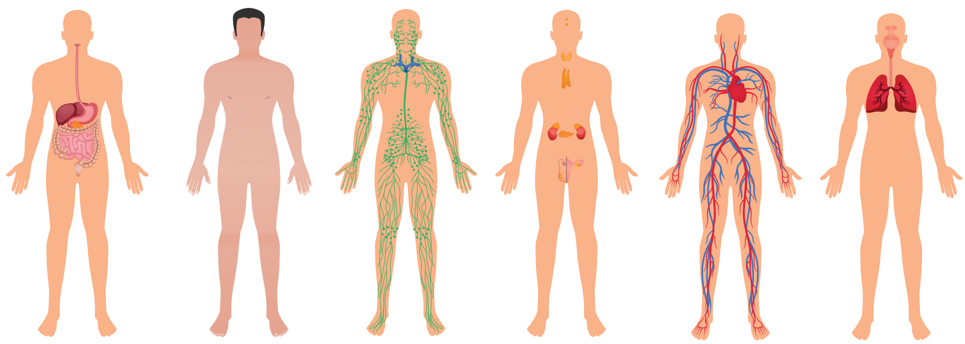


Figure 4.1 Human Organ Systems

Although all organ systems play a critical role in the overall functioning of the human body beyond human movement, systems such as the respiratory, circulatory, and endocrine systems have a direct impact on the responses and adaptations to physical activity and exercise. Organ systems like the reproductive and urinary system are less applicable to the work of a fitness professional.

THE CIRCULATORY SYSTEM

The **circulatory system** consists of the heart, arteries, veins, capillaries, and blood and is responsible for circulating blood throughout the body. The primary function of the circulatory system is to facilitate the exchange of oxygen and carbon dioxide, thereby transporting oxygen from the lungs to the body tissues and moving carbon dioxide from the tissues to the lungs to be excreted. Moreover, this system is considered a **closed system**, circulating the blood within its own vascular system, and, therefore, maintaining blood flow within the organ system itself.

In addition, the circulatory system is also responsible for the transport of nutrients from the digestive system to body tissues and serves as a clearing house for the biochemical waste products resulting from physical activity, such as weight training or aerobic exercise. The **arteries** carry oxygenated blood away from the heart and to the tissues, **veins** carry blood toward the heart to remove waste and pick up more oxygen, and **capillaries** transport nutrients and oxygen or carbon dioxide at the sites of exchange (extremities, organs, and bone marrow).

CIRCULATORY SYSTEM: A closed system circulating blood through the body, consisting of the heart, blood vessels, and blood.

CLOSED SYSTEM: A physical system that does not allow for the movement of matter into or out of the system.

ARTERIES: Blood vessels carrying oxygenated blood away from the heart and to the tissues.

VEINS: Blood vessels carrying blood toward the heart to remove waste and pick up more oxygen.

CAPILLARIES: Fine-branching blood vessels forming a network between the arterioles and venules, where transport of nutrients and oxygen or carbon dioxide occurs on a microscopic scale.

Blood vessels are elastic, smooth muscle tissues that expand and contract to facilitate the flow of blood throughout the body. Healthy blood vessels maintain their elasticity and allow blood to flow easily, whereas unhealthy blood vessels lose their elasticity, impede blood flow, and increase the risk for blood clots. However, regular and consistent cardiovascular exercise can help preserve the overall function of the blood vessels.

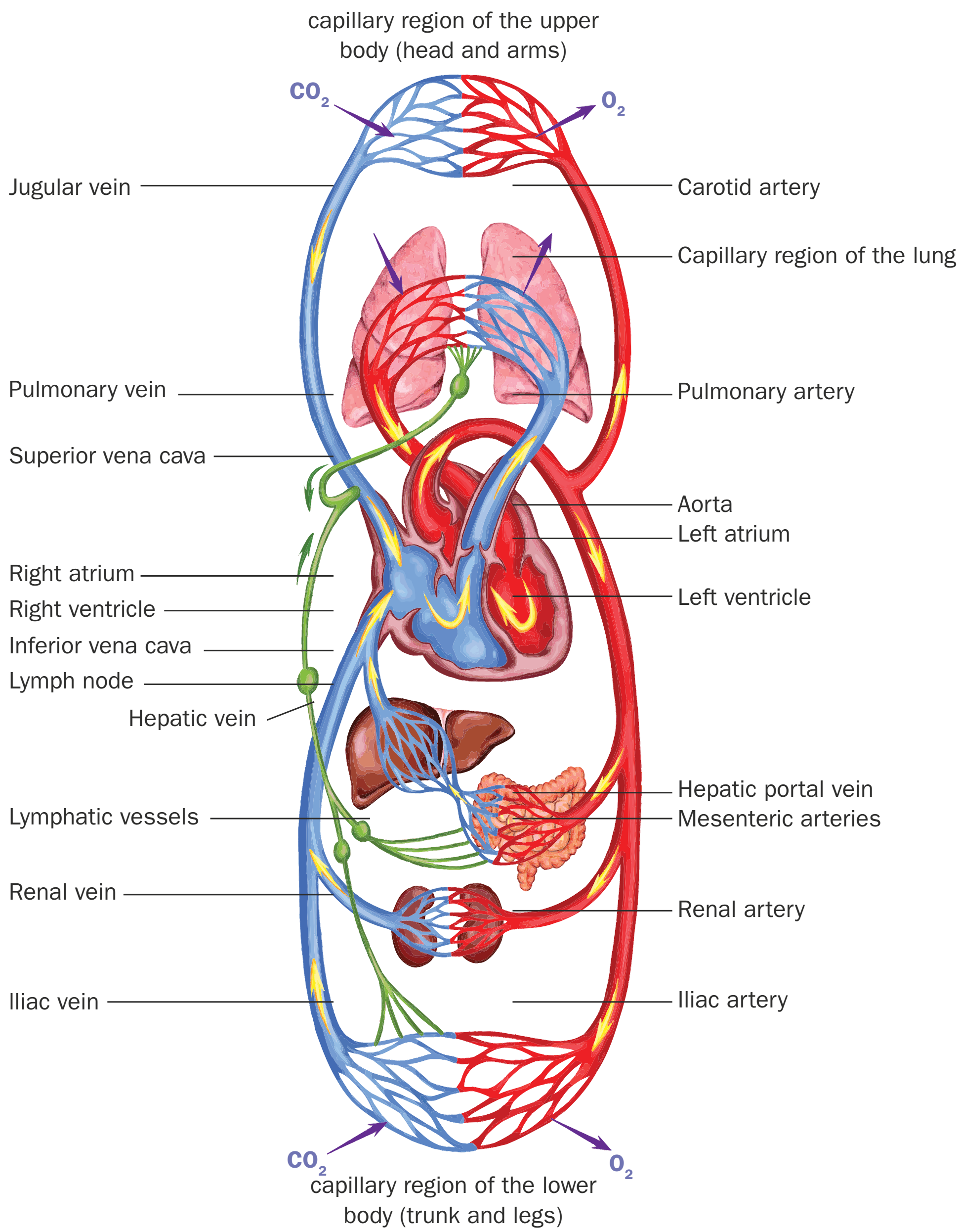


Figure 4.2 Circulatory System

THE CARDIOVASCULAR SYSTEM

The main structures of the cardiovascular system are the blood vessels and the heart. "Cardio" comes from the Greek word "kardia," meaning "pertaining to the heart." "Vascular" comes from the Latin term "vascularis" and means "pertaining to vessels that circulate fluids."

Blood Vessels

ARTERIOLES:
The smaller branches of the arteries leading to the capillaries.

VENULES:
The small branches of the veins gathering blood from the capillaries.

There are five types of blood vessels found in the body. The blood vessels that carry oxygenated blood away from the heart to the body's tissues are the arteries. As the arteries narrow and blood moves farther away from the heart, it enters smaller branches of the arteries called **arterioles**. The arterioles provide approximately 80 percent of the total resistance of blood throughout the body as they further distribute blood to the capillaries. These vessels are so small that a single red blood cell can barely pass through them. After the oxygen has been moved into the body's tissues for cellular use, oxygen-poor blood is transported back to the heart through increasingly larger **venules** before reaching the veins.

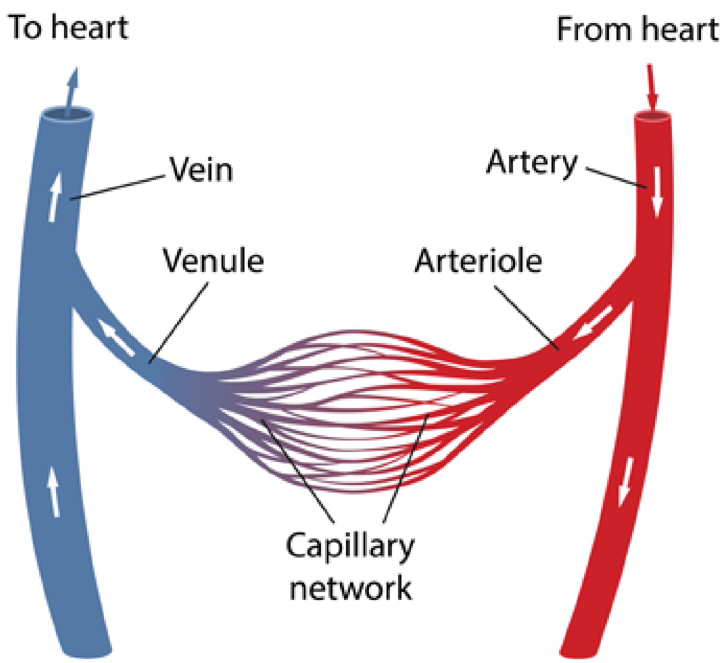


Figure 4.3 The Blood Vessels

The Heart

The heart is a four-chambered organ made of cardiac muscle that is referred to as the myocardium. The left **atrium** and right atrium are the two upper chambers of the heart, while the left **ventricle** and the right ventricle are the two lower chambers of the heart. The right atrium receives deoxygenated blood from the body. It then moves on to the right ventricle, where it is pumped via the **pulmonary arteries** to the lungs to receive oxygen. This oxygenated blood then returns from the lungs via the **pulmonary veins** to the left atrium, where it is moved into the left ventricle through the **aorta** and out to the rest of the body. The aorta is the main artery in the body that supplies oxygenated blood to the circulatory system. Circulation within the heart is known as **pulmonary circulation**, whereas blood flow between the heart and the rest of the body is defined as **systemic circulation**.

The heart beats about 100,000 times per day. For every minute of work, the heart pumps five to six quarts of blood around the body, which is roughly 2,000 gallons of blood pumped per day.

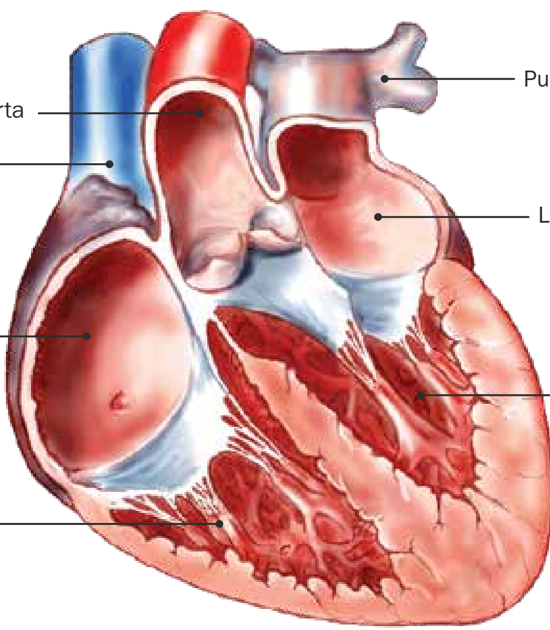


Figure 4.4 Interior View of the Heart

ATRIUM:
One of the two upper cavities of the heart passing blood to the ventricles. The plural is "atria."

VENTRICLE:
One of the two lower cavities of the heart passing blood to the body or to the lungs.

PULMONARY ARTERIES:
Blood vessels moving blood from the heart to the lungs.

PULMONARY VEINS:
Blood vessels returning oxygenated blood to the heart from the lungs.

AORTA:
The main artery in the body that supplies oxygenated blood to the circulatory system.

PULMONARY CIRCULATION:
The blood flow between the heart and the lungs.

SYSTEMIC CIRCULATION:
The blood flow between the heart and the rest of the body.

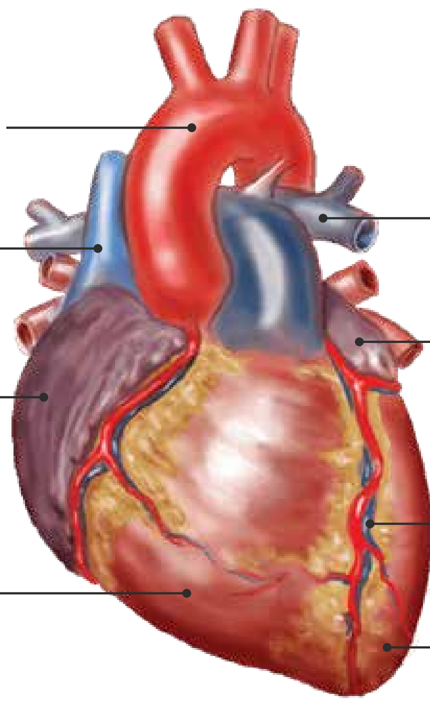


Figure 4.5 Vascularization of the Heart

SUPERIOR VENA CAVA: The blood vessel moving blood from the upper body and head to the heart.

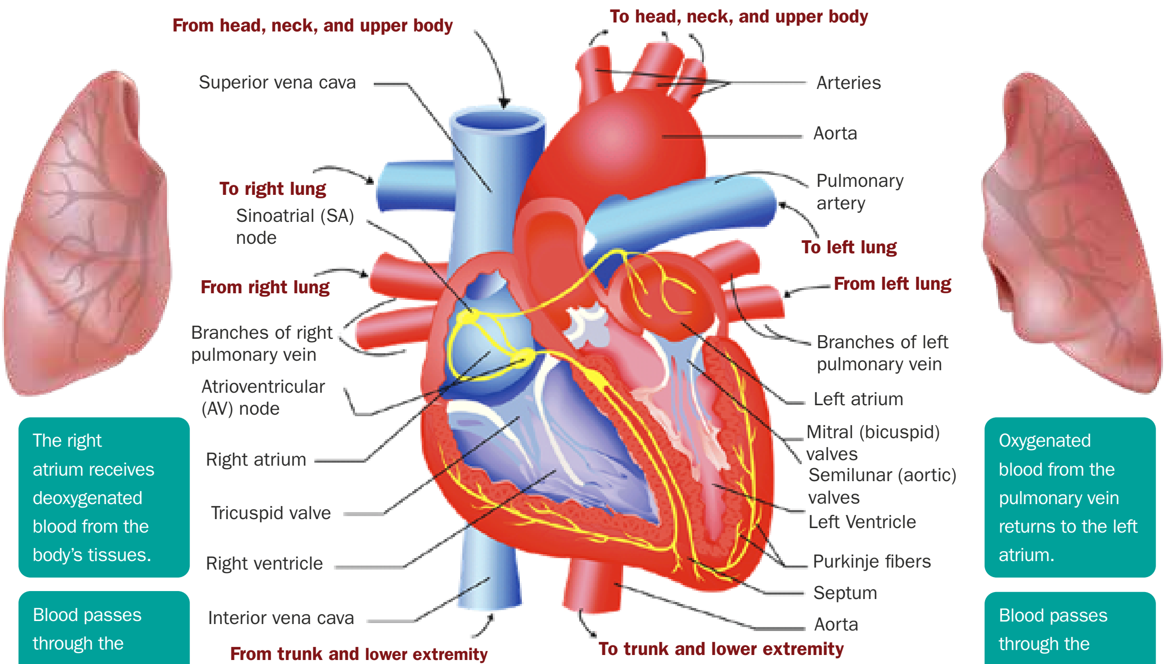
INFERIOR VENA CAVA: The blood vessel moving blood from the lower body to the heart.

METABOLISM: All of the chemical processes that occur in the body to support life including converting food into energy.

ATRIOVENTRICULAR (AV) VALVES: Valves between the atria and ventricles preventing the backward flow of blood during cardiac contractions.

Oxygen-rich blood returning from the lungs flows from the pulmonary vein into the left atrium of the heart. The atrium contracts, pushing blood down into the left ventricle. When the ventricle contracts, the blood moves through the aorta and out into the body for circulation.

Blood returns from the body to the heart via the **superior vena cava** and the **inferior vena cava**. The superior vena cava carries deoxygenated blood from the arms, head, and upper body, while the inferior vena cava carries deoxygenated blood from the lower body to the aorta. The returning blood is oxygen poor, having distributed oxygen to cells throughout the body to support **metabolism**. The right atrium fills with the deoxygenated blood, which then flows into the right ventricle. From the right ventricle, the blood leaves the heart via the pulmonary artery and travels to the lungs to pick up oxygen and diffuse carbon dioxide out of the body. Between each atrium and ventricle are **atrioventricular (AV) valves** (also called cuspid valves), which keep the blood flowing in one direction.



The right atrium receives deoxygenated blood from the body's tissues.

Blood passes through the tricuspid (AV valve) to the right ventricle.

The right ventricle pumps blood into the pulmonary artery.

Oxygenated blood from the pulmonary vein returns to the left atrium.

Blood passes through the bicuspid (mitral) valve to the left ventricle.

The left ventricle ejects blood through the aortic (semilunar) valve into the aorta for transport in the systemic circuit.

Figure 4.6 Chambers of the Heart

TEST TIP!

The heart anatomy can be confusing. Use these tips to remember how blood flows through the heart:

The atrium (plural: atria) receives blood; ventricles pump it out.

Blood leaving the right ventricle will be right back—it moves to the lungs for oxygen before returning to the heart.

Blood leaving the left ventricle has left—it is headed out to the body.

"Tri before you bi"—the tricuspid valve is on the right side of the heart and the bicuspid valve is on the left side. Blood passes through the "tri" before the "bi"—right side, then left.

CARDIAC CYCLE:
The action of the heart from the start of one heartbeat to the beginning of the next.

SYSTOLE:
The heartbeat phase where muscle contraction moves blood from the heart chambers to the arteries.

DIASTOLE:
The heartbeat phase where the cardiac muscle relaxes and the heart chambers fill with blood.

SINOATRIAL (SA) NODE:
The pacemaker of the heart that generates the first electrical signal of a heartbeat and stimulates the atria to contract.

ATRIOVENTRICULAR (AV) NODE:
The nerve node between the right atrium and right ventricle that propagates the electrical signal from the SA node to more distal heart nerves that cause ventricular contraction.

STROKE VOLUME:
The amount of blood pumped by the left ventricle of the heart in one contraction.

HEART RATE:
The number of heartbeats per minute.

The heartbeat that moves blood throughout the body and through the lungs is an intricate rhythm between the atria and ventricles. A **cardiac cycle** is one alternating cycle of contraction and relaxation of the heart during one heartbeat. The contraction phase is known as **systole**. When the ventricle contracts, it increases the pressure in the blood vessels. The relaxation phase is known as **diastole**. Systole and diastole are controlled by a pathway of nerves that create the consistent, rhythmic heartbeat. Inside the right atrium is the **sinoatrial (SA) node**. The SA node initiates the heartbeat by generating an electrical signal that causes the atria to contract. The electrical signal moves through atria through the nerve pathway to a junction located between the right atrium and right ventricle called the **atrioventricular (AV) node**. When excited, the AV node excites additional nerve branches (bundle of His and the Purkinje fibers) and causes the subsequent contraction of the ventricles. Since the SA node contracts first and its electrical stimulation cascades to cause the ventricular contraction of the heart, it is considered the natural pacemaker of the heart.

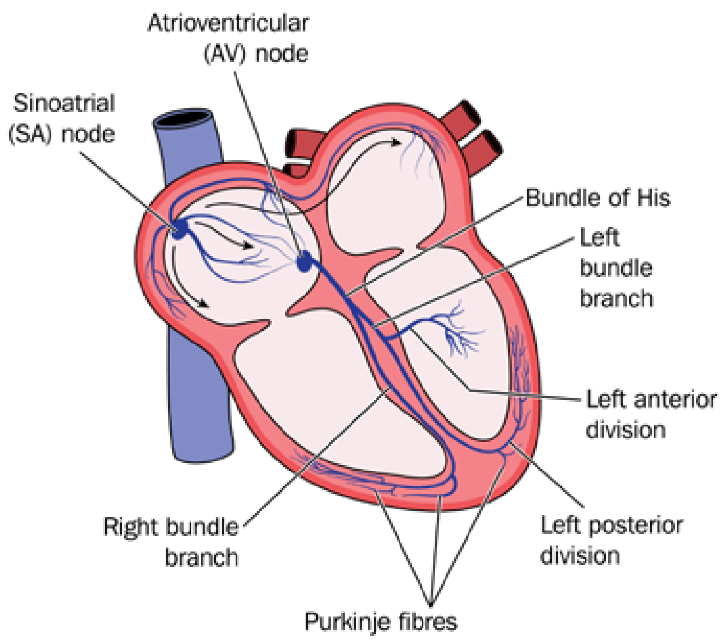


Figure 4.7 The Nerves of the Heart

The amount of blood the left ventricle pushes out in one heartbeat is known as **stroke volume**. Exercise strengthens the smooth muscles of the heart and increases stroke volume. The physiological adaptation occurring with cardiovascular exercise causes the heart to beat more efficiently (more slowly) when circulating blood, thus lowering the **heart rate**. The heart rate is the number of beats per minute of the heart. Changes in heart rate are facilitated in the cardiac center of the brain—the medulla oblongata. Here, sympathetic and parasympathetic messages are interpreted, and heart rate is adjusted to meet the oxygen and energy demands of the body. Factors beyond the sympathetic and parasympathetic nervous system such as emotions, ion concentration (e.g., sodium), level of conditioning, and body temperature also influence heart rate.

In unconditioned individuals, stroke volume will likely be lower, while the heart rate both at rest and during activity will likely be higher. This means the heart must beat more times to pump the same volume of blood, and it is pumping faster, which can, over time, lead to weakening of the heart muscle or even heart failure. When the heart pumps faster as with an increased heart rate, this allows less time for the ventricle to fill with blood after each heartbeat, which also reduces stroke volume.

TEST TIP!

Application of Heart Rate and Conditioning

The American Heart Association norms state that resting heart rates can range between 60 beats per minute (bpm) and 100 bpm, depending on the person. A more conditioned individual will have a lower resting heart rate in general. Assuming two people were at complete rest for 24 hours, a comparison of their heart rates may look like this:

Conditioned person:

60 bpm x 60 minutes = 3,600 beats per hour (bph)

3,600 bph x 24 hours = 86,400 beats per day (bpd)

Deconditioned person:

80 bpm x 60 minutes = 4,800 bph

4,800 bph x 24 hours = 115,200 bpd

Even at rest, a deconditioned individual's heart is beating nearly 30,000 more beats per day than a more conditioned person. However, no one is completely at rest 24 hours a day. Ordinary activities of daily living along with additional deliberate exercise will cause the deconditioned heart to beat proportionately faster than a conditioned heart during the same activity. Over the life of the individual, the additional work and strain on the heart of a deconditioned person can be detrimental.

PULSE:
A rhythmical throbbing of the arteries as blood is propelled through them.

BLOOD PRESSURE:
The force of blood pushing against the walls of the arteries during the two phases of the cardiac cycle.

The **pulse** is the rhythmic expansion of the blood vessel each time blood is pushed from the left ventricle. It can be found anywhere an artery is close to the surface of the skin and rests against something solid like a bone, tendon, or ligament. The most common sites to take a pulse are at the radial artery in the wrist and the carotid artery in the neck. **Blood pressure** is a measurement of the force of blood flow within the blood vessels. It is measured using a sphygmomanometer.

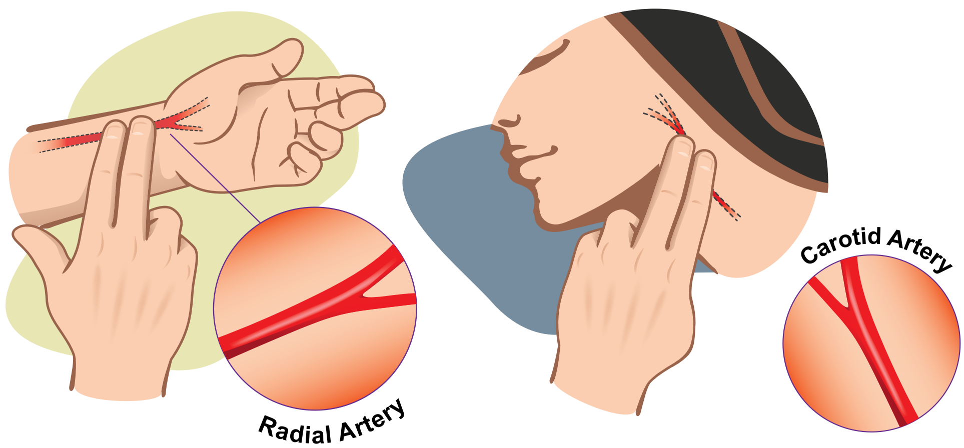


Figure 4.8 Radial and Carotid Artery Pulse

SYSTOLIC:
The pressure in blood vessels when the heart beats (ventricular contraction).

DIASTOLIC:
The pressure in blood vessels when the heart rests (ventricular filling).

HYPOTENSION:
Low blood pressure measuring 90/60 mm Hg or lower.

HYPERTENSION:
High blood pressure measuring more than 140/90 mm Hg.

According to the American Heart Association, normal blood pressure is anything less than 120/80 mm Hg. Blood pressure is written as **systolic** pressure (the pressure during the contraction phase of the heartbeat) over **diastolic** pressure (the pressure during the relaxation phase of the heartbeat). **Hypotension** is the condition of low blood pressure measuring 90/60 mm Hg or less. During hypotension, the brain does not receive enough oxygen, which can cause dizziness or fainting. **Hypertension** is the term for blood pressure measured at or above 140/90 mm Hg. Chronic hypertension can cause health issues like heart disease. Symptoms of hypertension include headaches, vision problems, chest pain, and an irregular heartbeat.

TEST TIP!

To remember which number is where in a blood pressure measurement, remember that the heart has to contract before it relaxes. Systolic pressure is pressure on artery walls during contraction, while diastolic pressure is the pressure when the heart is at rest.

Therefore, systolic/diastolic.

The reading *with* pressure (systolic) will always be bigger than the reading at *rest* (diastolic).

Table 4.1 Blood Pressure Categories

CATEGORY	SYSTOLIC MM HG	DIASTOLIC MM HG
Normal	<120	<80
Elevated	120–129	<80
Pre-Hypertensive (Stage 1)	130–139	80–89
Hypertension (Stage 2)	140+	90+
Hypertensive Crisis	>180	>120

There are four factors affecting blood pressure measurements. When these factors increase, so does blood pressure.

1. **Cardiac output:** how much blood the heart is pumping per minute.
2. **Blood volume:** the total volume of blood contained in the circulatory system.
3. **Peripheral resistance** of arteries: the elasticity (or lack thereof) of artery walls.
4. **Blood viscosity:** the thickness of blood moving through circulation.

CARDIAC OUTPUT: The amount of blood pumped through the heart per minute.

BLOOD VOLUME: The total volume of blood within the circulatory system of an individual.

PERIPHERAL RESISTANCE: The vascular resistance of the arteries to blood flow.

BLOOD VISCOSITY: The thickness and "stickiness" of blood and how it affects its flow through the blood vessels.

Blood

Blood is a specialized type of connective tissue. It is found in all areas of the body, except epithelial tissue, and is approximately 55–60 percent plasma, 40 percent red blood cells, and 2 percent white blood cells and platelets.

Red blood cells are also known as erythrocytes and are, by volume, the most numerous type of blood cells in the body. Their primary function is carrying oxygen from the lungs to the body's tissues. Platelets are irregularly shaped cells found in the blood and the spleen. Their primary function is to help form blood clots to stop bleeding and promote wound healing.

The white blood cells are integral in the body's immune response. There are several types of white blood cells, each with unique functions:

- Basophil—a large white blood cell that locates and destroys cancerous cells and is responsible for the histamine response during an allergic reaction.
- Neutrophil—the most numerous white blood cells (40–70 percent in humans) responsible for the primary immune response of the ingestion or enzymatic digestion of foreign microorganisms.

- Eosinophil—white blood cells that play a role in allergic reactions and immune defense against multicellular parasites.
- Monocyte—an immune cell that helps remove dead or damaged tissues and provides support to the other types of white blood cells.
- Lymphocyte—white blood cells that include natural killer cells, B cells, and T cells, which kill tumor cells, produce **antibodies**, and kill infected or cancerous cells, respectively.

ANTIBODIES:
Blood proteins that combine with other substances in the body to recognize foreign bodies as part of the immune response.

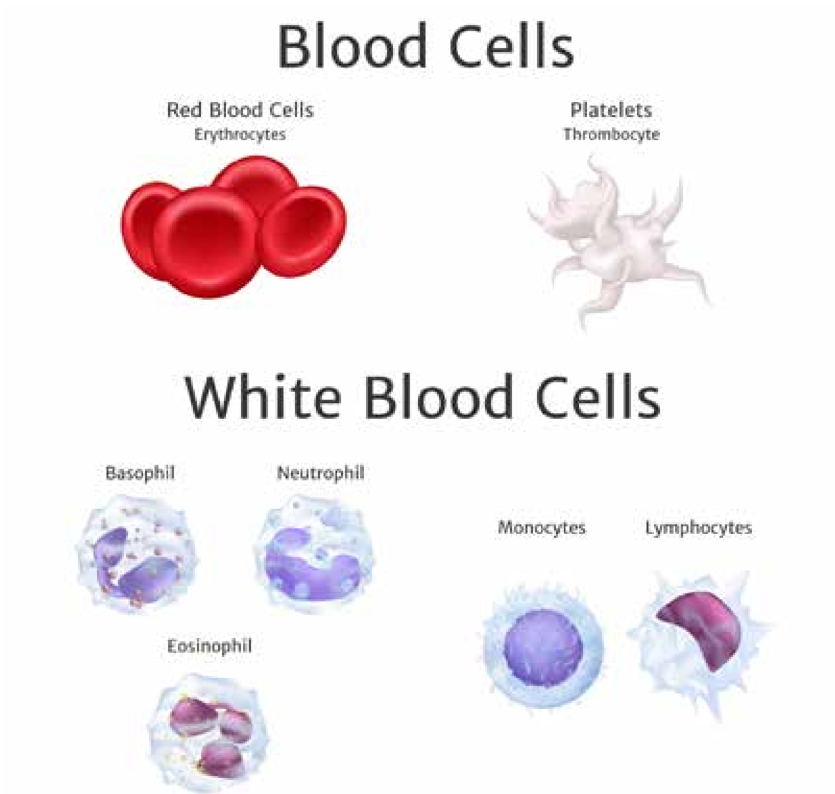


Figure 4.9 Types of Blood Cells

THE LYMPHATIC SYSTEM

LYMPH:
The colorless fluid of the lymphatic system.

INTERSTITIAL FLUID:
The fluid found between cells.

The lymphatic system is considered a part of the circulatory system. During exercise, the lymphatic system regulates fluid volume and pressure within the tissues. The major structures of the lymphatic system include the lymph nodes, tonsils, spleen, and thymus. This system contains **lymph**, a colorless fluid surrounding tissues that carries white blood cells. Lymph is created when blood plasma flows through the capillary walls and into the **interstitial fluid** between cells. Approximately 90 percent of the fluid leaving the capillaries is returned via the lymphatic system.

The key functions of this system include:

- Balancing interstitial fluids
- Absorbing fats and fat-soluble vitamins
- Defending against illness and disease

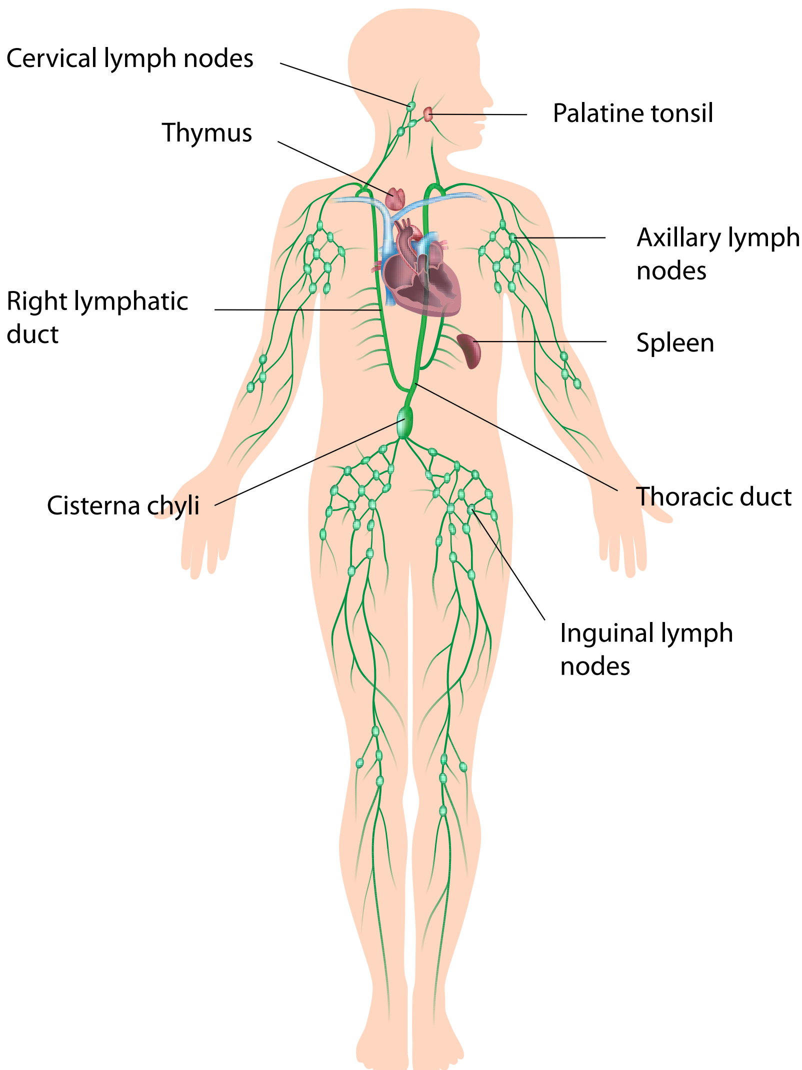


Figure 4.10 The Lymphatic System

Lymph nodes are found throughout the body and help to filter lymph before it is returned to the blood for circulation. The lymph nodes remove diseases (pathogens), create antibodies, generate lymphocytes and store other white blood cells. Antibodies are blood proteins that combine with other substances in the body to recognize foreign bodies such as viruses and bacteria as part of the immune response. The tonsils are clusters of lymphatic tissue found on either side of the back of the throat. They serve to protect the body from any foreign pathogens that may be introduced to the body through the nose or mouth.

The spleen is the largest lymphatic structure in the human body. It filters and serves as a reservoir for blood. In the case of severe blood loss, the spleen contracts to release more blood into circulation. Finally, the thymus serves to manage the immune T cells (lymphocytes that target foreign particles in the body), which travel from the bone marrow to the thymus gland to mature.

THE RESPIRATORY SYSTEM

The respiratory system consists of the following structures:

Nose and nasal cavities: The nose is made of bone and cartilage. Air and particles enter the body through the nose.

Pharynx: The pharynx is commonly called the throat and is a passageway for both air and food.

Larynx: This passageway is between the pharynx and trachea.

Trachea: This is the main passageway of air into the lungs.

Bronchi: This is the passageway of air into the functional tissues of the lungs.

Lungs: The right lung has three lobes, while the left lung has two lobes. The lungs are separated by a membrane partition called the mediastinum, which is where the heart sits.

The primary function of the respiratory system is to bring fresh air into the body while removing waste gases like carbon dioxide. Other functions of this system include:

- Providing oxygen for metabolic processes
- Removing waste products of metabolism
- Regulating the pH of blood

RESPIRATION:
The intake of oxygen and subsequent release of carbon dioxide in an organism.

PULMONARY VENTILATION:
The process of exchange of air between the lungs and the ambient air.

Respiration is the act of breathing and is the process through which the respiratory system completes these necessary tasks. Every few seconds, autonomic nerve impulses initiate inhalation and exhalation—a task that requires no effort or thought in healthy individuals.

Pulmonary ventilation is also known as breathing. When we breathe in, air from the external environment travels through the nose or mouth, down through the pharynx, and past the larynx. The trachea is the main airway to the lungs. From here, the air passageway divides into the left and right bronchi, which supply the left and right lungs with air. Inside the lungs, the bronchi branch into smaller vessels known as bronchioles and eventually to alveoli, the smallest functional pulmonary tissues.

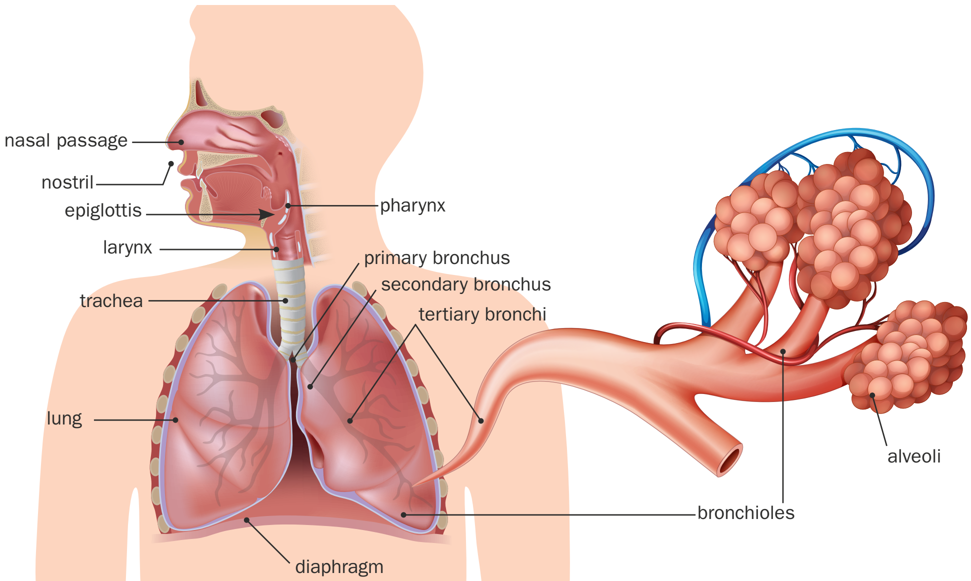


Figure 4.11 Pulmonary Anatomy

PULMONARY VENTILATION

Air moves into the lungs during **inspiration** and out during **expiration**. Inspiration is breathing air into the lungs, while expiration is the exhale of air out of the lungs during a single breath. The movement of air into and out of the lungs is controlled by changes in atmospheric pressure caused by the contraction and relaxation of the **diaphragm**. The diaphragm is the dome-shaped muscle that separates the lungs and pleural cavity from the abdomen and, upon contraction, increases the volume of the lungs to draw air in.

Gases move from areas of high pressure to areas of low pressure in a process called **diffusion**. During inspiration, the diaphragm muscles contract. This pulls the rib cage out and up, increasing the space (volume) inside the **thoracic cavity**. The thoracic cavity is also known as the chest cavity, and it is enclosed by the ribs, sternum, and spinal column. As the volume of the thoracic cavity increases, the pressure within the alveoli—known as **intra-alveolar pressure**—decreases so that air is pulled into the lungs. The opposite is true for expiration as the diaphragm relaxes. The pressure in the alveoli is slightly above atmospheric pressure, and the lungs are slightly elastic, which drives air out of the lungs. Therefore, inhalation is an active process, as muscle contraction is required, while expiration is passive, as the diaphragm relaxes to push air out of the lungs.

INSPIRATION:
Breathing air into the lungs.

EXPIRATION:
Breathing air out of the lungs.

DIAPHRAGM:
The dome-shaped muscle that separates the lungs and pleural cavity from the abdomen.

DIFFUSION:
The passive movement of molecules or particles along a concentration gradient or from regions of higher concentration to regions of lower concentration.

THORACIC CAVITY:
The chest cavity enclosed by the ribs, sternum, and spinal column.

INTRA-ALVEOLAR PRESSURE:
The pressure within the alveoli that changes throughout respiration.

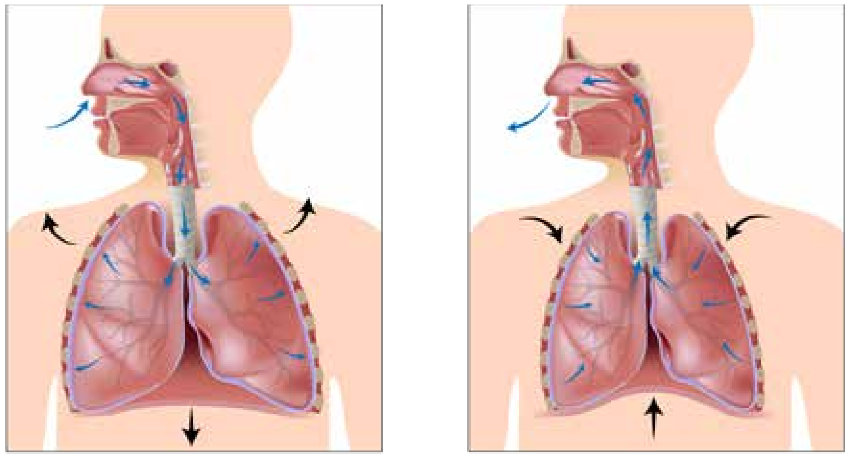


Figure 4.12 Respiration

External Respiration

EXTERNAL RESPIRATION:
The exchange of gases between the lungs and the blood.

The exchange of gases between the lungs and blood is known as **external respiration**, and this exchange occurs at the alveoli. Alveoli are encapsulated by capillaries, which facilitate the exchange of gases between the lungs and the blood. Deoxygenated blood returning to the lungs is high in carbon dioxide and low in oxygen. During inspiration, oxygen from the lungs (high-level concentration) diffuses into the blood, and during expiration, carbon dioxide moves from the blood to the lungs to be excreted. The oxygenated blood following diffusion continues through the circulatory system to deliver oxygen to the necessary organs and tissues.

Internal Respiration

INTERNAL RESPIRATION:
The process of diffusing oxygen from the blood into the interstitial fluid and into the cells.

Internal respiration occurs at the cellular level. Following external respiration, oxygen binds to hemoglobin, a protein found in the red blood cells, which carries the oxygen to the cells. As oxygen is delivered to the necessary cells, biomolecular waste products, such as carbon dioxide, are released. Carbon dioxide then binds to the hemoglobin, which carries it back to the lungs to be removed.

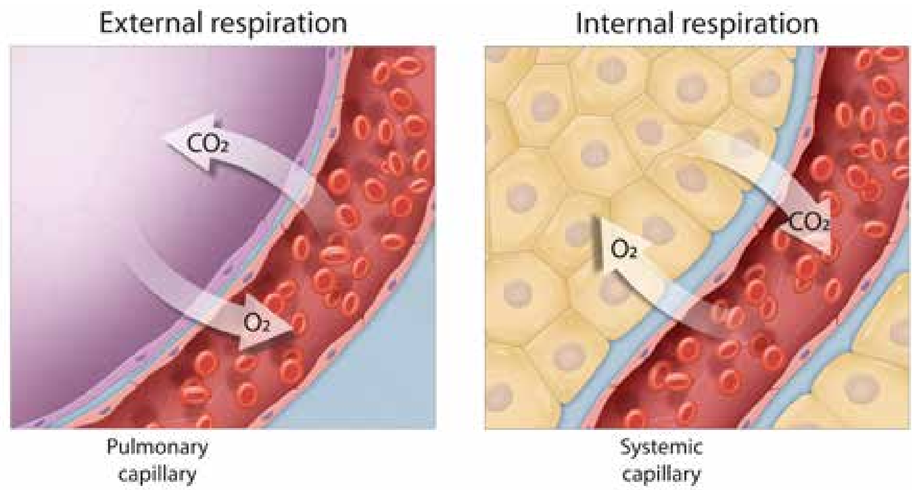


Figure 4.13 External vs. Internal Respiration

THE ENDOCRINE SYSTEM

The endocrine system regulates growth, development, homeostasis, reproduction, and metabolic activities through chemical messengers known as **hormones**. Hormones are stored, created, and released by **endocrine glands** and regulate most bodily functions. The endocrine system is also composed of **exocrine glands**, which produce substances that are released through a duct or opening on the body's surface.

Hormones regulate nearly all our bodily functions. They regulate growth and development, help us cope with both physical and mental stress, and regulate all forms of training responses, including protein metabolism, fat mobilization, and energy production. Resistance training is a natural stimulus that can cause an increase in tissue mass. These adaptations are influenced by the changes in circulating hormonal concentrations as a result of exercise.

HORMONES

Hormones are made of **amino acids**, lipids, or peptides (chains of amino acids). The sex hormones estrogen and testosterone and those secreted by the adrenal cortex (aldosterone and cortisol) are lipid hormones, also known as **steroids**.

Lipid hormones can diffuse across the plasma membrane of cells, while other hormones cannot. Amino acid and peptide hormones must attach to cells with surface receptors that will, once bound, trigger a desired reaction within a cell.

A negative feedback loop is one method of hormone regulation in the body. When a hormone

HORMONES:
Chemical messengers stored, created, and released by endocrine glands.

ENDOCRINE GLANDS:
Ductless glands releasing hormones that remain within the body.

EXOCRINE GLANDS:
Glands that produce and release substances through ducts or openings on the body's surface.

AMINO ACIDS:
Simple organic compounds known as the building blocks of proteins.

STEROIDS:
A class of chemicals characterized by their carbon structure, working to reduce inflammation and the activity of the immune system.

is secreted and received by another cell, that cell sends information back to the endocrine system to stop or reverse the production of that hormone.

Some hormones are controlled by the release of other hormones. For example, the pituitary gland releases corticotropin, which begins the production of cortisol (from the adrenal glands) during stress. Thyrotropin, or thyroid-stimulating hormone (TSH), stimulates the production of hormones from the thyroid.

Other hormones are released after direct neural stimulation. For example, antidiuretic hormone (ADH) is released into the bloodstream from nerve cells in the hypothalamus.

Table 4.2 Endocrine Glands and Their Hormones

HOST	HORMONE	HORMONE FUNCTION	CONTROL OF HORMONE SECRETION	EFFECTS OF EXERCISE ON HORMONE SECRETION
Anterior pituitary	Growth hormone (GH)	Stimulates tissue growth; mobilizes fatty acids for energy; inhibits carbohydrate metabolism	Hypothalamic-releasing factor	↑ with increasing exercise
	Thyrotropin (TSH)	Stimulates production and release of thyroxine from thyroid gland	Hypothalamic TSH-releasing factor; thyroxine	↑ with increasing exercise
	Corticotropin (ACTH)	Stimulates production and release of cortisol, aldosterone, and other adrenal hormones	Hypothalamic ACTH-releasing factor; cortisol	Effects unknown
	Gonadotropin (FSH & LH)	FSH works with LH to stimulate production of estrogens and progesterone by ovaries and testosterone by male testes	Hypothalamic FSH- and LH-releasing factor; female: estrogen and progesterone; male: testosterone	No change
	Prolactin (PRL)	Inhibits testosterone; mobilizes fatty acids	Hypothalamic PRL-inhibiting factor	↑ with increasing exercise
	Endorphins	Block pain; promote euphoria; affect feeding and female menstrual cycle	Stress: physical/ emotional	↑ with long-duration exercise

Table 4.2 Endocrine Glands and Their Hormones (CONT)

HOST	HORMONE	HORMONE FUNCTION	CONTROL OF HORMONE SECRETION	EFFECTS OF EXERCISE ON HORMONE SECRETION
Posterior pituitary	Vasopressin (ADH)	Controls water excretion by kidneys	Hypothalamic secretory neurons	↑ with increasing exercise
	Oxytocin	Stimulates muscles in uterus and breasts; important in birth and lactation	Hypothalamic secretory neurons	Effects unknown
Adrenal cortex	Cortisol Corticosterone	Promotes use of fatty acids and protein catabolism; conserves blood sugar: insulin antagonist; has anti-inflammatory effects with epinephrine	ACTH; stress	↑ in heavy exercise only
	Aldosterone	Promotes retention of sodium, potassium, and water by kidneys	Angiotensin and plasma potassium concentration; renin	↑ with increasing exercise
Adrenal medulla	Epinephrine Norepinephrine	Facilitates sympathetic activity, increases cardiac output, regulates blood vessels, increases glycogen catabolism and fatty acid release	Stress stimulates hypothalamic sympathetic nerves	Epinephrine: ↑ with heavy exercise; Norepinephrine: ↑ with increasing exercise
Thyroid	Thyroxine (T4) Triiodothyronine (T3)	Stimulates metabolic rate; regulates cell growth and activity	TSH; whole-body metabolism	↑ with increasing exercise
Pancreas	Insulin	Promotes CHO transport into cells; increases CHO catabolism and decreases blood glucose; promotes fatty acid and amino acid transport into cells	Plasma glucose levels	↑ with increasing exercise
	Glucagon	Promotes release of glucose from liver to blood; increases fat metabolism	Plasma glucose levels	↑ with increasing exercise

Table 4.2 Endocrine Glands and Their Hormones (CONT)

HOST	HORMONE	HORMONE FUNCTION	CONTROL OF HORMONE SECRETION	EFFECTS OF EXERCISE ON HORMONE SECRETION
Parathyroid	Parathormone	Raises blood calcium; lowers blood phosphate	Plasma calcium concentration	↑ with long-term exercise
Ovaries	Estrogen Progesterone	Controls menstrual cycle; increases fat deposition; promotes female sex characteristics	FSH, LH	↑ with exercise; depends on menstrual phase
Testes	Testosterone	Controls muscle size; increases number of red blood cells; decreases bodyfat; promotes male sex characteristics	LH	↑ with exercise
Kidneys	Renin	Stimulates aldosterone secretion	Plasma sodium concentration	↑ with increasing exercise

ENDOCRINE GLANDS

Endocrine glands secrete hormones directly into the blood to be transported to their target tissues. Since they circulate, hormones come in contact with nearly every cell in the body. However, hormones are specific in that they can only act on target cells that have receptors on the cell surface specifically for that hormone.

The major glands of the endocrine system include:

Hypothalamus: The main role of this gland is to maintain homeostasis. It either stimulates or inhibits heart rate, blood pressure, body temperature, fluid and **electrolyte** balance, thirst, appetite, body weight, glandular secretions of the stomach and intestines, the release of substances influencing the pituitary gland, and sleep cycles.

ELECTROLYTE:
Minerals in the body that have an electric charge.

Pineal gland: The only hormone this gland is known to secrete is melatonin.

Pituitary gland: Pituitary hormones control other parts of the endocrine system, including the thyroid gland, adrenal glands, ovaries, and testes.

Thyroid: The main function of the thyroid is to regulate metabolism.

Parathyroid: There are four parathyroid glands that help regulate calcium levels in the body.

Thymus: The thymus is only active until puberty. Before puberty, it stimulates the development of T lymphocytes, which play a role in the lymphatic system's defense against illness and infection.

Adrenal: The adrenal glands are attached to the kidneys and are made up of the adrenal cortex and adrenal medulla. Hormones secreted by the adrenal cortex are essential to life. Those secreted by the adrenal medulla are not.

Pancreas: The main role of the pancreas is to maintain blood **glucose** balance.

GLUCOSE:
A simple sugar the body uses for energy production on the cellular level.

Ovaries: The ovaries secrete hormones essential for female reproductive development and fertility.

Testes: The testes are responsible for maintaining male reproductive health.

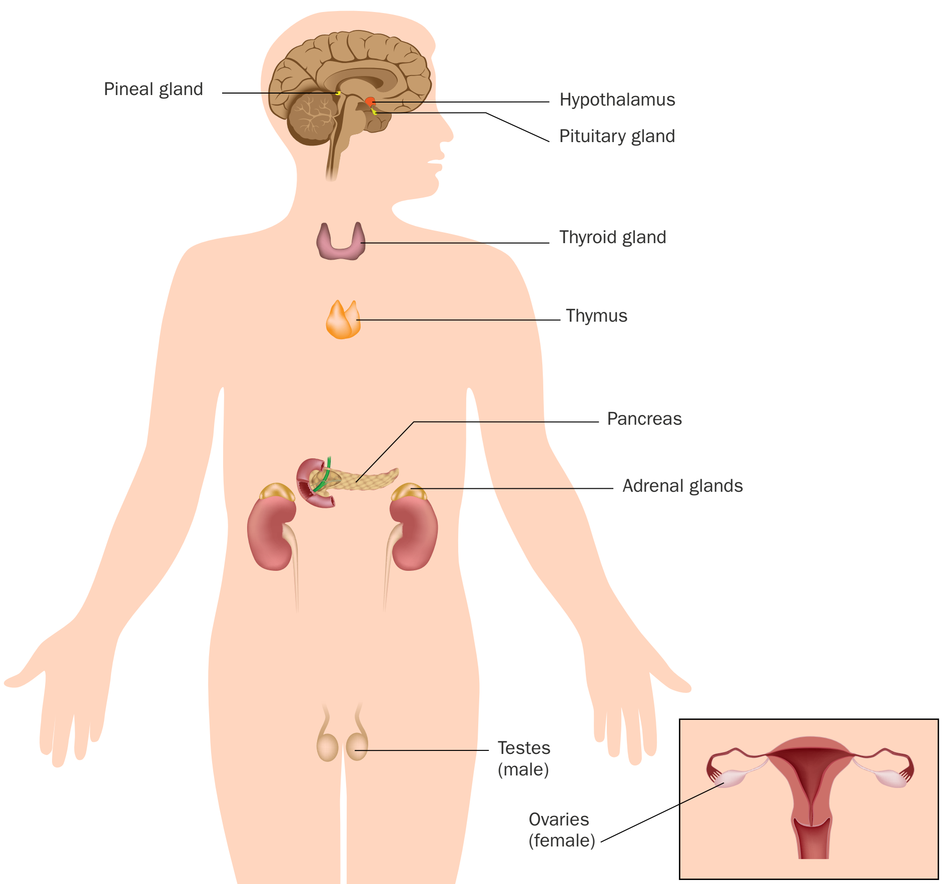


Figure 4.14 Endocrine Glands

HORMONAL RESPONSES TO EXERCISE

Many hormones are sensitive to exercise. These hormones can increase blood glucose (blood sugar) levels, affect the heart rate, and alter muscular force production, contraction rate, and cellular energy production. Some hormones can affect how the muscles repair and grow as well. The primary hormones a fitness professional should be familiar with as they relate to physical activity and exercise include:

INSULIN:
A hormone produced in the pancreas to regulate blood sugar.

TESTOSTERONE:
A steroid hormone found in both males and females.

OSTEOPOROSIS:
A skeletal condition that results in weak or brittle bones.

CATABOLIC:
Metabolic activity involving the breakdown of molecules such as proteins or lipids.

PROTEIN SYNTHESIS:
The process of arranging amino acids into protein structures.

ANABOLIC:
The process of creating larger molecules from smaller units.

GROWTH HORMONE (GH):
A hormone released by the pituitary gland that stimulates growth in animal cells.

INSULIN-LIKE GROWTH FACTORS (IGF):
A protein similar to insulin that stimulates growth of cells.

- Testosterone
- Growth hormone (GH)
- Insulin-like growth factor
- **Insulin**
- Cortisol
- Catecholamines

Testosterone

In mammals, **testosterone** is primarily secreted in the testes of males and the ovaries of females, although small amounts are also secreted by the adrenal glands. It is the principal male sex hormone and is classified as a steroid. In men, testosterone plays a key role in health and well-being as well as in the prevention of **osteoporosis**. On average, an adult human male body produces about 40 to 60 times more testosterone than an adult human female body. However, females are more sensitive to the hormone behaviorally.

Not all exercise protocols elicit increases in the circulating concentrations of hormones in the body. A significant amount of force is required to activate high-threshold motor units not typically stimulated by endurance exercise. Keep in mind, however, high-intensity endurance exercise can have a very dramatic **catabolic** effect. An increase in testosterone may occur to maintain **protein synthesis** to keep up with this protein breakdown. Following an exercise session, remodeling of the muscle tissue begins in the presence of hormonal secretions to stimulate **anabolic** action.

The primary anabolic hormones involved in muscle tissue growth and repair aside from testosterone are **growth hormone (GH)** and **insulin-like growth factors (IGF)**.

Training experience and age of participants also affect testosterone. Research suggests that males under 30 have higher increases in free testosterone as a result of long-term high-intensity training than do females of any age or males over 30.

Growth Hormone (GH)

Secreted from the pituitary gland and made from more than 190 amino acids, growth hormone may:

- Increase protein synthesis
- Increase fat breakdown
- Increase collagen synthesis
- Decrease glucose utilization

Growth hormone secretion is at its peak during adolescence. With good nutrition, sleep, and training, levels of GH can be kept higher later in life. Research suggests that people who maintain higher levels of GH because of exercise in their younger years are more likely to have a healthier body composition later in life.

Many of these hormone actions may be helped by insulin-like growth factor (IGF). Growth hormone stimulates both the release of IGFs and the availability of amino acids for protein synthesis. Without growth hormone, IGF cannot be released by the liver.

The time of day affects the blood secretion levels of GH, with the highest levels observed at night. Like with testosterone, the intensity of training matters regarding the hormonal response of GH in the body. Heavy loads with shorter rest periods are shown to elicit a stronger GH response post-exercise. Growth hormone may have an anti-insulin effect, and research suggests it suppresses the ability of insulin to stimulate the uptake of glucose in tissues and enhances glucose synthesis in the liver.

Insulin-Like Growth Factors

Many of the effects of growth hormone are mediated by insulin-like growth factors from the liver. IGFs travel in the blood attached to binding proteins, then are released as free hormones to interact with receptors on target cells. Fat cells have relatively high levels of IGF in comparison to skeletal muscle, which has very little of its own. With high-intensity training, research suggests that the amount of IGF in the bloodstream and the number of IGF receptors found in the body increase as a prominent training adaptation.

Insulin

Released by the pancreas, insulin increases cellular uptake of glucose-synthesizing muscle glycogen, which in turn decreases blood glucose. Small increases in blood insulin levels will slow or stop the breakdown of fat (adipose tissue) for energy with glucose becoming the primary source. During prolonged workouts, blood glucose reduction along with decreased insulin production can greatly increase the mobilization of fatty tissue for energy production.

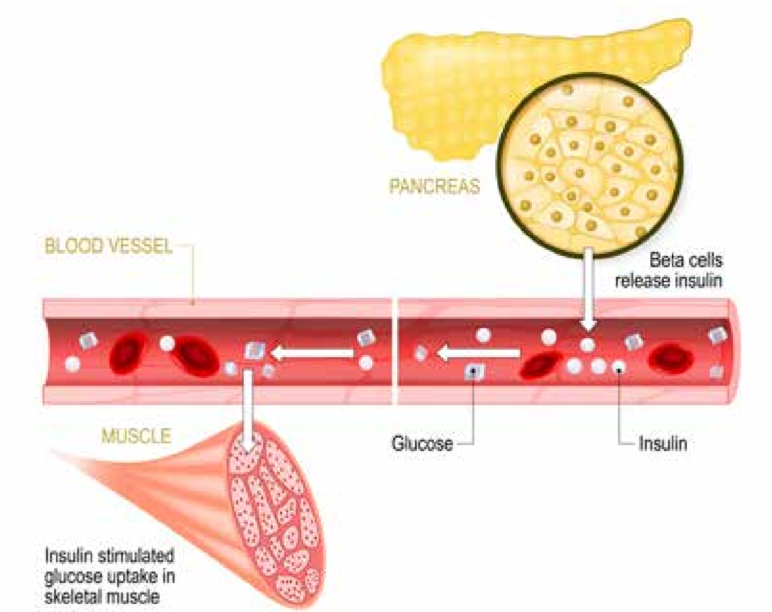


Figure 4.15 How Insulin Works

> **TEST TIP!**
>
> Insulin helps move glucose into the cells. Insulin = IN the cells.

Cortisol

> **CORTISOL:**
> A catabolic hormone released in response to physical and emotional stress.

Secreted by the adrenal gland, **cortisol** is catabolic and causes a breakdown of protein in the muscles. Cortisol is an antagonist that inhibits glucose uptake and utilization. It has been found to be released during high-intensity exercise and as a stress response (emotional and physical). It has a greater catabolic effect in fast-twitch muscle fibers than in slow-twitch muscle fibers.

> **KETONE BODIES:**
> Molecules released by the liver in starvation states for an alternate energy source.

> **KETOSIS:**
> A metabolic process that occurs when the body does not have enough carbohydrates for energy; the liver metabolizes fatty acids to produce ketones as a replacement energy source.

Some research on cortisol and sleep cycles suggests that moderate to low-intensity exercise can reduce blood cortisol levels instead of increasing them. This is largely attributed to the differing levels of physical stress the body undergoes in low intensity versus high-intensity exercise. Also, excess cortisol may cause the body to release **ketone bodies** and bring on a state of **ketosis**. Ketone bodies are typically produced during times of low food intake or starvation to provide an alternate source of cellular energy. However, too many ketone bodies in the blood can cause ketoacidosis, making the blood fatally acidic.

TEST TIP!

Remember that cortisol can be good or bad based on how long it remains elevated.

Short-term cortisol elevation:

- Increases blood sugar (glucose) levels
- Enhances the brain's use of glucose
- Reduces inflammation
- Reduces unnecessary bodily functions during the fight-or-flight response

Extended-duration cortisol elevation:

- Increases appetite
- Increases blood pressure
- Promotes weight gain
- Contributes to type 2 diabetes

Catecholamines

The "fight-or-flight" hormones epinephrine, norepinephrine, and dopamine are released by the adrenal glands in response to stress and are referred to as **catecholamines**. Like with cortisol, epinephrine will increase with heavy resistance training as heavy resistance training is very stressful on the body. Since epinephrine is involved in metabolism, force production, and the rate of response of other hormones such as testosterone and IGFs, the stimulation of catecholamines is likely one of the first hormonal changes in response to resistance exercise.

CATECHOLAMINES: Hormones released by the adrenal glands into the blood as a result of stress.

EXOCRINE GLANDS

Exocrine glands release secretions that are carried to an epithelial or skin surface and secreted via ducts. They allow the body to expel substances that contain mucus, proteins, water, enzymes, and ions. Examples of exocrine glands include the sweat glands, sebaceous glands (secrete oils), mammary glands (secrete milk), and digestive glands producing enzymes and other substances in the digestive tract. Substances secreted from the exocrine glands are non-hormonal in nature, but the production of the secretions is controlled by the release of hormones within the body.

TEST TIP!

Remember that EXOcrine glands secrete substances that EXIT the body, while ENDOcrine glands produce substances that remain within the body.

THE DIGESTIVE SYSTEM

The digestive system collectively breaks down food into smaller molecules for use in energy production at the cellular level. There are six functions the digestive system is responsible for regarding the breakdown of food for energy:

1. **Ingestion:** taking food in through the mouth.
2. **Mechanical digestion:** the process of chewing (mastication) and the churning and mixing actions of the stomach that further break down food.
3. **Chemical digestion:** enzymes released throughout the digestive tract are released to break food into smaller molecules.
4. **Movements:** food moves through the digestive system by the rhythmic contractions of the smooth muscle of the digestive tract—a process known as **peristalsis**.
5. **Absorption:** simple molecules get absorbed by the cell membranes in the lining of the small intestine into blood or lymph capillaries.
6. **Elimination:** the removal of waste products and indigestible particles.

PERISTALSIS:
The muscular contractions of the smooth muscle of the digestive tract, which moves food through the digestive tract.

The digestive tract—beginning at the mouth and ending at the anus—is between four and six meters long in the average adult. Unlike the circulatory system, it is an open system with openings at both ends. Important digestive system components include the:

- Mouth
- Esophagus
- Stomach
- Small intestine
- Large intestine and rectum
- Liver
- Gallbladder
- Pancreas

MOUTH

Food enters the digestive system through the mouth. The mouth has four functions in the digestive process. First, the mouth physically breaks apart food via mastication (chewing) to reduce the size of ingested food pieces. Second, it mixes food with saliva to create a moist mass called a "bolus." Once a bolus is formed, food is ready to be swallowed. Saliva contains digestive enzymes that begin the chemical breakdown of the components of food and provide lubrication as the bolus moves into the esophagus.

Third, the mouth helps to regulate the temperature of food by either cooling it or warming it. This is an important function, as many digestive enzymes function best at certain temperatures. For humans, this range is close to normal body temperature. Finally, the mouth initiates the swallowing of food to move it along the digestive tract.

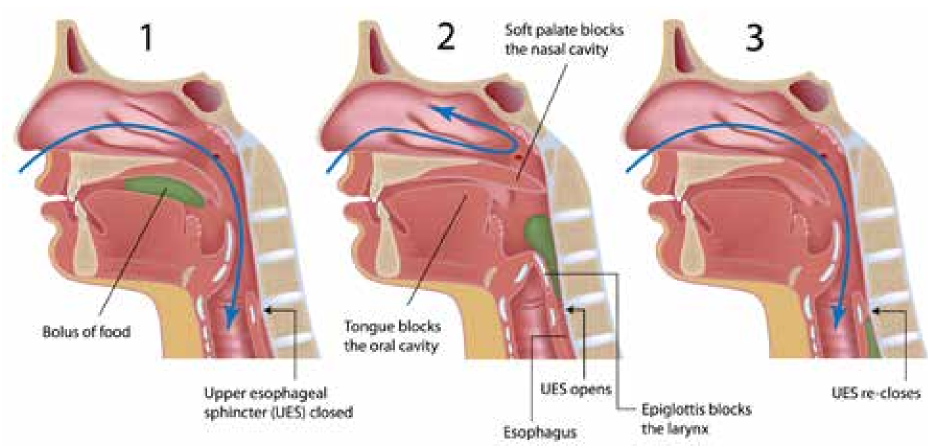


Figure 4.16 Swallowing

ESOPHAGUS

The esophagus extends between the pharynx and stomach and is the transport conduit for food and water traveling to the stomach. When the bolus enters the esophagus, an involuntary wave of muscle contractions is triggered, propelling the food mass down into the stomach. This muscle contraction action is known as "peristalsis." This peristaltic wave travels down the esophagus at the rate of about three inches per second. Once at the base of the esophagus, a ringlike muscle (the esophageal sphincter) is reached, which relaxes to allow the food into the stomach.

STOMACH

The stomach is a muscular sac about two quarts in volume. It is responsible for the storage and gradual release of food into the small intestine, digestion through chemical secretions and the physical activity of churning the digesting food, and transport of ingested food down the gut.

The stomach secretes several types of substances to aid in the breakdown of food. Mucus acts as a protective layer to lubricate the stomach wall and a buffer against acidic secretions. Hydrochloric acid is also secreted in the stomach and helps to keep the stomach relatively free of microorganisms (bacteria) while maintaining the low pH (more acidic) inside the stomach. Hydrochloric acid also acts to catalyze the action of pepsins, which begin the digestion of proteins.

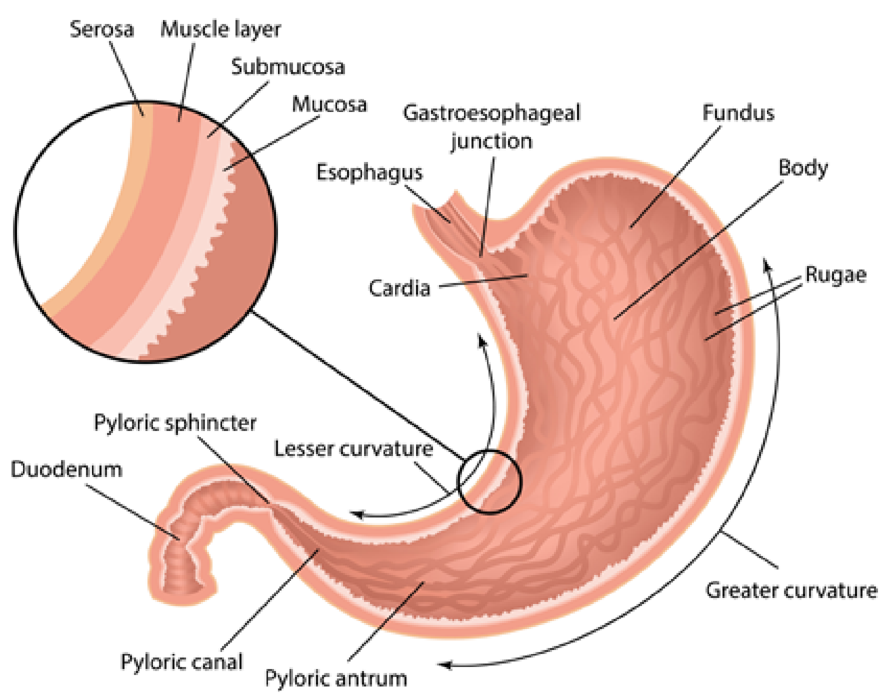


Figure 4.17 The Stomach Anatomy

While the intestines are known as the primary location for absorption, the stomach can absorb some nutrients as well. The stomach can absorb water, glucose, alcohol, aspirin, some other drugs, and certain vitamins such as niacin. The fact that water and glucose can be partially absorbed through the stomach is a benefit for quick replenishment of these nutrients during exercise. Some popular sports drinks take advantage of this fact by including glucose as a main ingredient.

The stomach only begins the process of breaking down complex molecules. Complete digestion of these substances occurs farther along in the digestive tract. Complex molecules are broken down into their smaller components (e.g., proteins into amino acids). This breakdown process, also called "hydrolysis," continues in the intestines when the partially digested material in the stomach enters the small intestine through the pyloric sphincter muscle. At this stage, it is called **chyme**.

CHYME:
A pulpy, acidic fluid that moves from the stomach to the small intestines containing partially digested food and gastric juices.

SMALL INTESTINE

The small intestine stretches about 12 feet long and is divided into three main regions: duodenum, jejunum, and ileum. The duodenum is connected to the stomach and makes up the first part of the small intestine. Some absorption takes place here, but it is primarily a location for the storage and continued breakdown of food. The next regions of the small intestine, the jejunum and ileum, are responsible for most of the nutrient absorption.

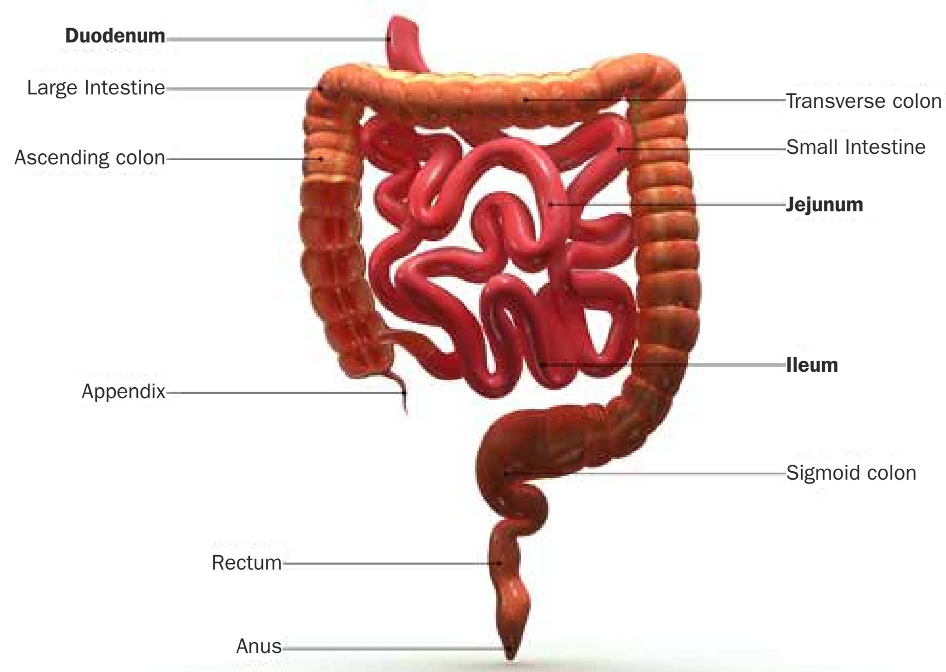


Figure 4.18 Anatomy of the Intestines

To accomplish complete absorption, the inside surface of the small intestine has a unique anatomy. Instead of being a flat surface, like that of the skin, the small intestine is lined with special cells called villi. These villi are very small fingerlike projections that line the entire inner surface of the intestine. The surface area of the intestine is greatly increased by the villi. Each villus is served by blood vessels. When nutrients pass through the cells of the villi, they are transported into the blood vessels and then to the liver.

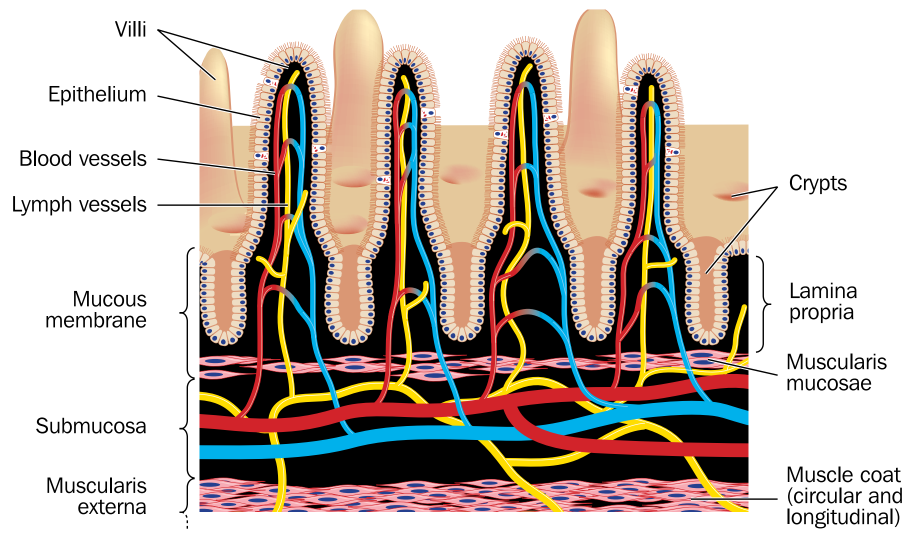


Figure 4.19 Small Intestine Villi

The lymphatic system is also present within the villi and works to transport ingested fats. A small projection called a lacteal extends into the villus and is responsible for about 60 to 70 percent of ingested fat being transported to the liver.

LARGE INTESTINE AND RECTUM

The large intestine is about three feet long. The area where the ileum and large intestine join is called the cecum. The appendix is found at the end of the cecum as well. In the large intestines, some final absorption of water, minerals, and vitamins occurs. Bacteria are present in the large intestine, and through their metabolism, they produce vitamins that are absorbed, such as vitamin K. The large intestine (also called the colon) stores the waste products of digestion.

The further decomposition of fecal matter by bacterial action produces gas. The amount of gas produced varies depending on the nutrient substrate that makes it down to the colon. When the proper stimulus occurs, the colon empties its contents into the rectum, triggering defecation. Normally, the rectum remains empty and rectal filling occurs due to peristalsis. The more fiber in the diet, the softer the feces and the easier it is to eventually defecate.

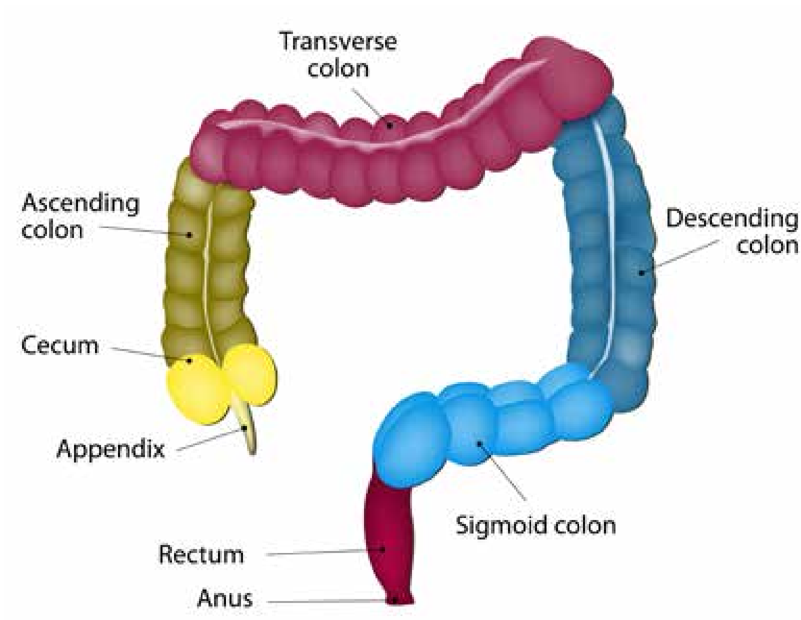


Figure 4.20 Large Intestine Anatomy

LIVER

The liver is the largest gland in the body. It gets oxygenated blood from the hepatic artery (the major blood vessel that carries blood from the liver) and nutrient-rich blood from the digestive tract through the hepatic portal vein (the vein carrying blood to the liver from the stomach, spleen, pancreas, and intestines).

The liver serves many important functions, including:

- Secretion of plasma proteins, carrier proteins, hormones, prohormones, and apolipoprotein
- Making and excreting bile salts
- Storage of fat-soluble vitamins
- Detoxification and filtration
- Carbohydrate, protein, and lipid metabolism

GALLBLADDER

Attached to the liver is the gallbladder. Its primary role is to store **bile** for use in digestion. Bile is made of water, bile salts, bile pigments, and cholesterol, and it helps in the digestion and absorption of fats.

BILE:
A bitter greenish-brown alkaline fluid aiding digestion, secreted by the liver and stored in the gallbladder.

SALIVARY AMYLASE: An enzyme found in saliva that converts starches and glycogen to more simple sugars.

PANCREAS

The pancreas is located behind the stomach. It has both endocrine and exocrine functions in the body and plays a major role in digestion by secreting the digestive enzymes amylase, trypsin, peptidase (protease), and lipase. **Salivary amylase** is an enzyme found in saliva that converts starches and glycogen to more simple sugars, while trypsin acts in the small intestine to break down protein. Peptidase also breaks down proteins, and lipase helps to digest dietary fat. Specialized cells on the pancreas called the islets of Langerhans secrete the endocrine hormones insulin, glucagon, and somatostatin to control blood sugar and regulate the activity of the gastrointestinal tract.

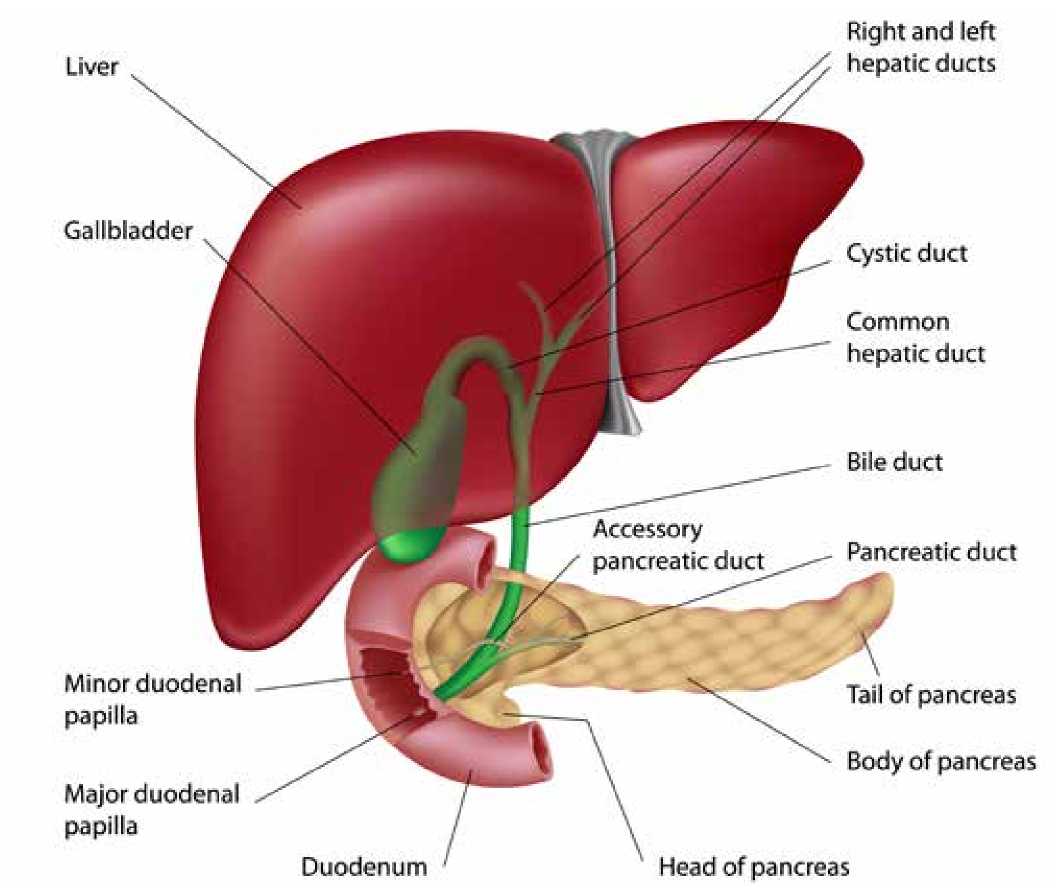


Figure 4.21 Liver, Gallbladder, and Pancreas

THE INTEGUMENTARY SYSTEM

The **integumentary system** is the largest human organ system. It covers the entire human body and is made up of skin, hair, and nails. This system protects the internal organ systems from damage and disease, prevents water and fluid loss, and helps to regulate body temperature. The layers of the skin also include the exocrine glands and sensory nerves.The skin has three layers:

The **epidermis** is the outermost layer of the skin that makes the skin taut and creates a waterproof barrier.

The **dermis** lies beneath the epidermis and is the layer holding blood cells, sweat glands, hair roots (follicles), and connective tissues.

The **hypodermis** is the deepest layer of skin that holds **subcutaneous fat** and connective tissues.

INTEGUMENTARY SYSTEM:
Organ system protecting the body; composed of skin, hair, and nails.

EPIDERMIS:
The outermost layer of the skin.

DERMIS:
Deep to the epidermis; holds blood vessels, sweat glands, and hair follicles.

HYPODERMIS:
The deepest layer of skin housing fat cells and connective tissues.

SUBCUTANEOUS FAT:
Generally harmless fat cells located just beneath the skin.

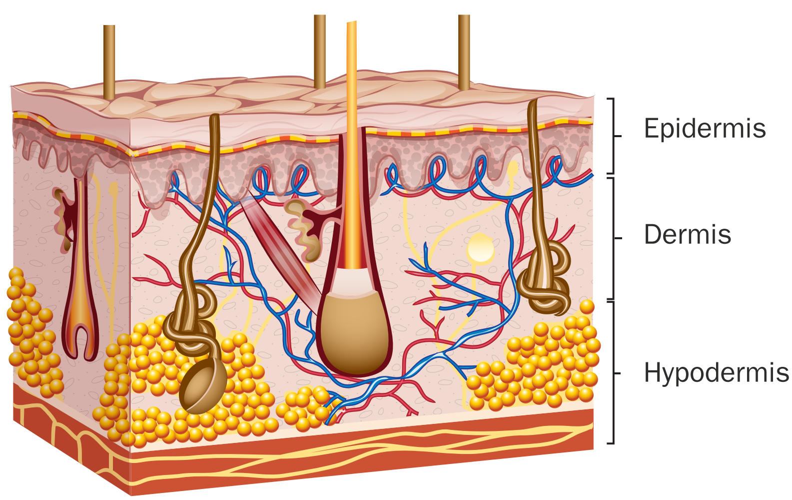


Figure 4.22 Human Skin