

CHAPTER 21

LECTURE OUTLINE

I. INTRODUCTION

- A. One main focus of this chapter considers hemodynamics, the means by which blood flow is altered and distributed and by which blood pressure is regulated.
- B. The histology of blood vessels and anatomy of the primary routes of arterial and venous systems are surveyed.

II. STRUCTURE AND FUNCTION OF BLOOD VESSELS

A. Basic structure of vessels.

1. There are three layers in a generalized blood vessel
2. Tunica interna (intima)
 - a. The tunica interna, closest to the lumen, has direct contact with the blood and is continuous with the endocardium. It consists of an inner endothelium (simple squamous epithelium) and a basement membrane.
3. Tunica Media
 - a. The tunica media consists of smooth muscle and elastic fibers that provide for changes in lumen diameter.
4. Tunica Externa
 - a. The tunica externa, consisting of elastic and collagen fibers, forms a protective layer.
5. Angiogenesis, the formation of new blood vessels, is stimulated by some cancers and a potential form of treatment is to inhibit angiogenesis.(Clinical Connection)
6. The major structural and functional characteristics of blood vessels are describe in Table 21.1

B. Arteries

1. Arteries carry blood away from the heart to the tissues.
 - a. The wall of an artery consists of a tunica interna, tunica media (which maintains elasticity and contractility), and a tunic externa (Figure 21.1).
 - b. The functional properties of arteries are elasticity and contractility.
 - 1) Elasticity, due to the elastic tissue in the tunica internal and media, allows arteries to accept blood under great pressure from the contraction of the ventricles and to send it on through the system.

- 2) Contractility, due to the smooth muscle in the tunica media, allows arteries to increase or decrease lumen size and to limit bleeding from wounds.

- i. Elastic Arteries

2. Large arteries with more elastic fibers and less smooth muscle are called elastic arteries and are able to receive blood under pressure and propel it onward (Figure 21.2).
 - a. They are also called conducting arteries because they conduct blood from the heart to medium sized muscular arteries.
 - b. They function as a pressure reservoir.
3. Muscular arteries have a large amount of smooth muscle in their walls and distribute blood to various parts of the body.

C. Anastomoses

1. Anastomoses are the union of the branches of two or more arteries supplying the same region.
2. They provide alternate routes for blood to reach a tissue or organ.
3. The collateral circulation is the alternate flow of blood to a body part through an anastomosis.
4. Arteries that do not anastomose are known as end arteries. Occlusion of an end artery interrupts the blood supply to a whole segment of an organ, producing necrosis (death) of that segment.
5. Anastomoses can also consist of two veins or a vein and an artery.

D. Arterioles

1. Arterioles are very small, almost microscopic, arteries that regulate the flow of blood to capillaries (Figure 21.3).
2. Through vasoconstriction (decrease in the size of the lumen of a blood vessel) and vasodilation (increase in the size of the lumen of a blood vessel), arterioles assume a key role in regulating blood flow from arteries into capillaries and in altering arterial blood pressure.

E. Capillaries

1. Capillaries are microscopic vessels that usually connect arterioles and venules (Figure 21.3).
2. The flow of blood through the capillaries is called the microcirculation.

3. Capillaries are found near almost every cell in the body, but their distribution varies with the metabolic activity of the tissue.
4. The primary function of capillaries is to permit the exchange of nutrients and wastes between the blood and tissue cells through interstitial fluid.
5. Capillary walls are composed of only a single layer of cells (endothelium) and a basement membrane (Figure 21.1).
6. Capillaries branch to form an extensive capillary network throughout the tissue. This network increases the surface area, allowing a rapid exchange of large quantities of materials.
 - a. The flow of blood through capillaries is regulated by vessels with smooth muscle in their walls (Figure 21.3).
 - b. Rings of smooth muscle fibers (cells) called precapillary sphincters regulate blood flow through true capillaries.
 - c. There are three types of capillaries: continuous, fenestrated, and sinusoids (Figure 21.4).

F. Venules

1. Venules are small vessels that are formed from the union of several capillaries; venules merge to form veins (Figure 21.1)
2. They drain blood from capillaries into veins.

G. Veins

1. Veins consist of the same three tunics as arteries but have a thinner tunica interna and media and a thicker tunica externa; they have less elastic tissue and smooth muscle and are therefore thinner-walled than arteries. They contain valves to prevent the backflow of blood (Figure 21.5).
2. Vascular (venous) sinuses are veins with very thin walls with no smooth muscle to alter their diameters. Examples are the brain's superior sagittal sinus and the coronary sinus of the heart (Figure 20.3c).
3. Weak valves can lead to varicose veins. (Clinical Connection)

H. Blood Distribution

1. At rest, the largest portion of the blood is in systemic veins and venules, collectively called blood reservoirs (Figure 21.6).
 - a. They store blood and, through venous vasoconstriction, can move blood to other parts of the body if the need arises.

- b. In cases of hemorrhage, when blood pressure and volume decrease, vasoconstriction of veins in venous reservoirs helps to compensate for the blood loss.
2. The principal reservoirs are the veins of the abdominal organs (liver and spleen) and skin.

III. CAPILLARY EXCHANGE

- A. Substances enter and leave capillaries by diffusion, transcytosis, and bulk flow (filtration and absorption).
- B. Diffusion
 1. The most important method of capillary exchange is simple diffusion.
 2. Substances such as O₂, CO₂, glucose, amino acids, hormones, and others diffuse down their concentration gradients.
 3. All plasma solutes, except larger proteins, pass freely across most capillary walls.
 4. The prime exception of diffusion of water-soluble materials across capillary walls is in the brain where the blood-brain barrier exists.
- C. Transcytosis
 1. Some materials cross the capillary membrane by transcytosis, the enclosing of substances within tiny vesicles that enter cells by endocytosis.
- D. Bulk Flow: Filtration and Reabsorption
 1. Whereas diffusion is more important for solute exchange between plasma and interstitial fluid, bulk flow is more important for regulation of the relative volumes of blood and interstitial fluid.
 2. The movement of water and dissolved substances (except proteins) through capillaries is dependent upon hydrostatic and osmotic pressures.
 3. The near equilibrium at the arterial and venous ends of a capillary by which fluids exit and enter is called Starling's law of the capillaries (Figure 21.7).
 4. Occasionally, the balance of filtration and reabsorption between interstitial fluid and plasma is disrupted, allowing an abnormal increase in interstitial fluid called edema. Edema may be caused by several factors including increased blood hydrostatic pressure in capillaries due to an increase in venous pressure, decreased concentration of plasma proteins that lower blood colloid osmotic pressure, increased permeability of capillaries which allows greater amounts of plasma proteins to leave the blood and enter tissue fluid, increased extracellular fluid volume as a result of fluid retention,

and blockage of lymphatic vessels postoperatively or due to filarial worm infection (Clinical Connection).

IV. HEMODYNAMICS: FACTORS AFFECTING BLOOD FLOW

- A. The distribution of cardiac output to various tissues depends on the interplay of the factors that drive the blood flow and resist blood flow.
- B. Blood pressure (BP) is the pressure exerted on the walls of a blood vessel; in clinical use, BP refers to pressure in arteries.
 - 1. Cardiac output (CO) equals mean aortic blood pressure (MABP) divided by total resistance (R).
 - 2. Factors that affect blood pressure include cardiac output, blood volume, viscosity, resistance, and elasticity of arteries.
 - 3. As blood leaves the aorta and flows through systemic circulation, its pressure progressively falls to 0 mm Hg by the time it reaches the right atrium (Figure 21.8).
- C. Resistance refers to the opposition to blood flow as a result of friction between blood and the walls of the blood vessels.
 - 1. Vascular resistance depends on the diameter of the blood vessel, blood viscosity, and total blood vessel length.
 - 2. Systemic vascular resistance (also known as total peripheral resistance) refers to all of the vascular resistances offered by systemic blood vessels; most resistance is in arterioles, capillaries, and venules due to their small diameters.
- D. Venous Return**
 - 1. Venous return occurs because of the pressure gradient between the venules and the right atrium.
 - 2. Blood return to the heart is maintained by several factors, including skeletal muscular contractions, valves in veins (especially in the extremities) and pressure changes associated with breathing (Figure 21.9).
- E. Velocity of Blood Flow**
 - 1. The volume that flows through any tissue in a given period of time is blood flow.
 - 2. The velocity of blood flow is inversely related to the cross-sectional area of blood vessels; blood flows most slowly where cross-sectional area is greatest (Figure 21.11).
 - 3. Blood flow decreases from the aorta to arteries to capillaries and increases as it returns to the heart.

- F. Figure 21.10 summarizes the factors that affect blood pressure.
- G. Syncope, or fainting, refers to a sudden, temporary loss of consciousness followed by spontaneous recovery. It is most commonly due to cerebral ischemia but it may occur for several other reasons (Clinical Connection)

V. CONTROL OF BLOOD PRESSURE AND BLOOD FLOW

A. Role of the Cardiovascular Center

1. The cardiovascular center (CV) is a group of neurons in the medulla that regulates heart rate, contractility, and blood vessel diameter.
2. The CV receives input from higher brain regions and sensory receptors (baroreceptors and chemoreceptors) (Figure 21.12).
3. Output from the CV flows along sympathetic and parasympathetic fibers.
 - a. Sympathetic impulses along cardioaccelerator nerves increase heart rate and contractility.
 - b. Parasympathetic impulses along vagus nerves decrease heart rate.
 - c. The sympathetic division also continually sends impulses to smooth muscle in blood vessel walls via vasomotor nerves. The result is a moderate state of tonic contraction or vasoconstriction, called vasomotor tone.

B. Neural Regulation of Blood Pressure

1. Baroreceptors are important pressure-sensitive sensory neurons that monitor stretching of the walls of blood vessels and the atria.
 - a. The cardiac sinus reflex is concerned with maintaining normal blood pressure in the brain and is initiated by baroreceptors in the wall of the carotid sinus (Figure 21.13).
 - b. The aortic reflex is concerned with general systemic blood pressure and is initiated by baroreceptors in the wall of the arch of the aorta or attached to the arch.
 - c. If blood pressure falls, the baroreceptor reflexes accelerate heart rate, increase force of contraction, and promote vasoconstriction (Figure 21.14).
 - d. Carotid sinus massage can slow heart rate in paroxysmal supraventricular tachycardia. (Clinical Connection)
 - e. Receptors sensitive to chemicals are called chemoreceptors.
 - f. These receptors are located close to the baroreceptors of the carotid sinus and arch of the aorta.

- g. They monitor blood levels of oxygen, carbon dioxide, and hydrogen ion concentration.

C. Hormonal Regulation of Blood Pressure

1. Hormones such as angiotensin II, epinephrine, norepinephrine, antidiuretic hormone, and atrial natriuretic peptide affect blood pressure and blood flow by altering cardiac output, changing systemic vascular resistance, or adjusting the total blood volume.
2. Table 21.2 summarizes the relationship between hormones and blood pressure regulation.

D. Autoregulation of Blood Pressure

1. The ability of a tissue to automatically adjust its own blood flow to match its metabolic demand for supply of O₂ and nutrients and removal of wastes is called autoregulation.
2. In most body tissues, oxygen is the principal, though not direct, stimulus for autoregulation.
3. Researchers have identified two general types of stimuli that cause autoregulatory changes in blood flow: physical and chemical.

VI. CHECKING CIRCULATION

A. Pulse

1. Pulse is the alternate expansion and elastic recoil of an artery wall with each heartbeat. It may be felt in any artery that lies near the surface or over a hard tissue and is strongest in the arteries closest to the heart. The radial artery is most commonly used to feel the pulse but Table 21.3 depicts the common pulse points.
2. A normal resting pulse (heart) rate is between 70 to 80 beats per minute.
 - a. Tachycardia means a rapid resting heart or pulse rate (> 100 beats/min).
 - b. Bradycardia indicates a slow resting heart or pulse rate (< 60 beats/min).

B. Measurement of Blood Pressure

1. Blood pressure is the pressure exerted by blood on the wall of an artery when the left ventricle undergoes systole and then diastole. It is measured by the use of a sphygmomanometer, usually in one of the brachial arteries.
2. Systolic blood pressure is the force of blood recorded during ventricular contraction (Figure 21.15).
 - a. Diastolic blood pressure is the force of blood recorded during ventricular relaxation.

- b. The various sounds that are heard while taking blood pressure are called Korotkoff sounds.
 - c. The normal blood pressure of a young adult male is 120/80 mm Hg (8-10 mm Hg less in a young adult female). The range of average values varies with many factors.
3. Pulse pressure is the difference between systolic and diastolic pressure. It normally is about 40 mm Hg and provides information about the condition of the arteries.

VII. SHOCK AND HOMEOSTASIS

A. Shock is an inadequate cardiac output that results in failure of the cardiovascular system to deliver adequate amounts of oxygen and nutrients to meet the metabolic needs of body cells. As a result, cellular membranes dysfunction, cellular metabolism is abnormal, and cellular death may eventually occur without proper treatment.

B. Types of Shock

1. Hypovolemic shock is due to decreased blood volume.
2. Cardiogenic shock is due to poor heart function.
3. Vascular shock is due to inappropriate vasodilation.
4. Obstructive shock is due to obstruction of blood flow.

C. Homeostatic Responses to Shock

1. Homeostatic responses to hypovolemic shock include activation of the renin-angiotensin-aldosterone system, secretion of ADH, activation of the sympathetic division of the ANS, and release of local vasodilators (Figure 21.16).

D. Signs and Symptoms of Shock

1. Signs and symptoms of shock include clammy, cool, pale skin; tachycardia; weak, rapid pulse; sweating; hypotension (systemic pressure < 90 mm HG); altered mental status; decreased urinary output; thirst; and acidosis.

VIII. CIRCULATORY ROUTES

A. Introduction

1. The blood vessels are organized into routes that deliver blood throughout the body. Figure 21.17 shows the circulatory routes for blood flow.
2. The largest circulatory route is the systemic circulation.
3. Other routes include hepatic portal circulation (Figure 21.28), pulmonary circulation (Figure 21.29) and fetal circulation (Figure 21.30).

B. Systemic Circulation

1. The systemic circulation takes oxygenated blood from the left ventricle through the aorta to all parts of the body, including some lung tissue (but does not supply the air sacs of the lungs) and returns the deoxygenated blood to the right atrium.
2. The aorta is divided into the ascending aorta, arch of the aorta, and the descending aorta.
3. Each section gives off arteries that branch to supply the whole body.
4. Blood returns to the heart through the systemic veins. All the veins of the systemic circulation flow into the superior or inferior venae cavae or the coronary sinus, which in turn empty into the right atrium.
5. The principal arteries and veins of the systemic circulation are described and illustrated in Exhibits 21.1-21.12 and Figures 21.18-21.27.
6. Blood vessels are organized in the exhibits according to regions of the body. Figure 21.18 shows the major arteries. Figure 21.23 shows the major veins.
 - a. Exhibit 21.a: The Aorta and its branching
 - b. Exhibit 21.b: Ascending Aorta
 - c. Exhibit 21.c: The arch of the Aorta
 - d. Exhibit 21.d: Thoracic Aorta
 - e. Exhibit 21.e: Abdominal Aorta
 - f. Exhibit 21.f: Arteries of the Pelvis and Lower limbs
 - g. Exhibit 21.g: Veins of the systemic circulation
 - h. Exhibit 21.h: Veins of the head and neck
 - i. Exhibit 21.I: Veins of the upper limbs
 - j. Exhibit 21.J: Veins of the thorax
 - k. Exhibit 21.K: Veins of the Abdomen and pelvis
 - l. Exhibit 21.L: Veins of the lower limbs

C. Hepatic Portal Circulation

1. The hepatic portal circulation collects blood from the veins of the pancreas, spleen, stomach, intestines, and gallbladder and directs it into the hepatic portal vein of the liver before it returns to the heart (Figure 21.28).
2. A portal system carries blood between two capillary networks, in this case from capillaries of the gastrointestinal tract to sinusoids of the liver.
3. This circulation enables nutrient utilization and blood detoxification by the liver.

D. Pulmonary Circulation

1. The pulmonary circulation takes deoxygenated blood from the right ventricle to the air sacs of the lungs and returns oxygenated blood from the lungs to the left atrium (Figure 21.29).
2. The pulmonary and systemic circulations differ from each other in several more ways.
 - a. Blood in the pulmonary circulation is not pumped so far as in the systemic circulation and the pulmonary arteries have a larger diameter, thinner walls, and less elastic tissue. As a result, resistance to blood flow is very low meaning that less pressure is needed to move blood through the lungs.
 - b. Because resistance in the pulmonary circulation is low, normal pulmonary capillary hydrostatic pressure is lower than systemic capillary hydrostatic pressure which tends to prevent pulmonary edema.

E. Fetal Circulation

1. The fetal circulation involves the exchange of materials between fetus and mother.
2. The fetus derives its oxygen and nutrients and eliminates its carbon dioxide and wastes through the maternal blood supply by means of a structure called the placenta.
3. Blood passes from the fetus to the placenta via two umbilical arteries (Figure 21.30) and returns from the placenta via a single umbilical vein.
4. At birth, when pulmonary, digestive, and liver functions are established, the special structures of fetal circulation are no longer needed.
 - a. The ductus arteriosus becomes the ligamentum arteriosum shortly after birth.
 - b. The foramen ovale becomes the fossa ovalis shortly after birth.
 - c. The ductus venosus becomes the ligamentum venosum shortly after birth.
 - d. The umbilical arteries become the medial umbilical ligaments.
 - e. The umbilical vein becomes the ligamentum teres (round ligament).

IX. DEVELOPMENT OF BLOOD VESSELS AND BLOOD

- A. Blood vessels develop from isolated masses of mesenchyme in the mesoderm called blood islands (Figure 21.31).
 1. Spaces soon appear in the islands and become the lumens of the blood vessels.
 2. Some of the mesenchymal cells immediately around the spaces give rise to the endothelial lining of the blood vessels.
- B. Blood plasma and blood cells are produced by the endothelial cells of blood vessels, a function later assumed by the liver, spleen, bone marrow, and lymph nodes.

X. AGING AND THE CARDIOVASCULAR SYSTEM

- A. General changes associated with aging and the cardiovascular system include loss of compliance (extensibility) of the aorta, reduction in cardiac muscle fiber size, progressive loss of cardiac muscular strength, reduced cardiac output, a decline in maximum heart rate, and increased systolic blood pressure.
- B. The incidence of coronary artery disease, congestive heart failure, and arteriosclerosis increases with age.

XI. FOCUS ON HOMEOSTASIS: THE CARDIOVASCULAR

- A. The role of the cardiovascular system in maintaining homeostasis is discussed.

XII. DISORDERS: HOMEOSTATIC IMBALANCES

- A. Hypertension, or persistently high blood pressure, is defined as systolic blood pressure of 140 mm Hg or greater and diastolic blood pressure of 90 mm Hg or greater.
 - 1. Primary hypertension (approximately 90-95% of all hypertension cases) is a persistently elevated blood pressure that cannot be attributed to any particular organic cause.
 - 2. Secondary hypertension (the remaining 5-10% of cases) has a identifiable underlying cause such as obstruction of renal blood flow or disorders that damage renal tissue, hypersecretion of aldosterone, or hypersecretion of epinephrine and norepinephrine by pheochromocytoma, a tumor of the adrenal gland.
- B. High blood pressure can cause considerable damage to the blood vessels, heart, brain, and kidneys before it causes pain or other noticeable symptoms.
- C. Lifestyle changes that can reduce elevated blood pressure include losing weight, limiting alcohol intake, exercising, reducing sodium intake, maintaining recommended dietary intake of potassium, calcium, and magnesium, not smoking, and managing stress.
- D. Various drugs including diuretics, beta blockers, vasodilators, and calcium channel blockers have been used to successfully treat hypertension.

XIII. MEDICAL TERMINOLOGY – Alert students to the medical terms associated with blood vessels.