McCance: Pathophysiology, 6th Edition

Chapter 29: Structure and Function of the Cardiovascular and Lymphatic Systems

Key Points – Print

SUMMARY REVIEW

Circulatory System

1. The circulatory system is the body's transport system. It delivers oxygen, nutrients, metabolites, hormones, neurochemicals, proteins, and blood cells throughout the body and carries metabolic wastes to the kidneys and lungs for excretion.
2. The circulatory system consists of the heart and blood vessels and is made up of two separate, serially connected systems: the pulmonary circulation and the systemic circulation.
3. The pulmonary circulation is driven by the right side of the heart. The function of the pulmonary circulation is to deliver blood to the lungs for oxygenation.
4. The systemic circulation is driven by the left side of the heart, and its function is to move oxygenated blood throughout the body.
5. The lymphatic vessels collect fluids from the interstitium and return the fluids to the circulatory system.

The Heart

1. The heart consists of four chambers (two atria and two ventricles), four valves (two AV valves and two semilunar valves), a muscular wall, a fibrous skeleton, a conduction system, nerve fibers, systemic vessels (the coronary circulation), and openings where the great vessels enter the atria and ventricles.
2. The heart wall, which encloses the heart and divides it into chambers, is made up of three layers: the pericardium (outer layer), the myocardium (muscular layer), and the endocardium (inner lining).
3. The myocardial layer of the two atria, which receive blood entering the heart, is thinner than the myocardial layer of the ventricles, which must be stronger to squeeze blood out of the heart.
4. The right and left sides of the heart are separated by portions of the heart wall called the *interatrial septum* and the *interventricular septum.*
5. Unoxygenated (venous) blood from the systemic circulation enters the right atrium through the superior and inferior venae cavae. From the atrium the blood passes through the right AV (tricuspid) valve into the right ventricle. In the ventricle the blood flows from the inflow tract to the outflow tract and then through the pulmonic semilunar valve (pulmonary valve) into the pulmonary artery, which delivers it to the lungs for oxygenation.

6. Oxygenated blood from the lungs enters the left atrium through the four pulmonary veins (two from the left lung and two from the right lung). From the left atrium the blood passes through the left AV valve (mitral valve) into the left ventricle. In the ventricle the blood flows from the inflow tract to the outflow tract and then through the aortic semilunar valve (aortic valve) into the aorta, which delivers it to systemic arteries of the entire body.
7. The heart valves ensure the one-way flow of blood from atrium to ventricle and from ventricle to artery.
8. Oxygenated blood enters the coronary arteries through an opening in the aorta, and unoxygenated blood from the coronary veins enters the right atrium through the coronary sinus.
9. The pumping action of the heart consists of two phases: diastole, during which the myocardium relaxes and the chambers fill with blood; and systole, during which the myocardium contracts, forcing blood out of the ventricles. A cardiac cycle consists of one systolic contraction and the diastolic relaxation that follows it. Each cardiac cycle makes up one heartbeat.
10. The conduction system of the heart generates and transmits electrical impulses (cardiac action potentials) that stimulate systolic contractions. The autonomic nerves (sympathetic and parasympathetic fibers) can adjust heart rate and systolic force, but they do not stimulate the heart to beat.
11. The normal ECG is the sum of all action potentials. The P wave represents atrial depolarization; the QRS complex is the sum of all ventricular cell depolarizations. The ST interval occurs when the entire ventricular myocardium is depolarized.
12. Cardiac action potentials are generated by the SA node at the rate of about 75 impulses per minute. The impulses can travel through the conduction system of the heart, stimulating myocardial contraction as they go.
13. Cells of the cardiac conduction system possess the properties of automaticity and rhythmicity. Automatic cells return to threshold and depolarize rhythmically without outside stimulus. The cells of the SA node depolarize faster than other automatic cells, making it the natural pacemaker of the heart. If the SA node is disabled, the next fastest pacemaker, the AV node, takes over.
14. Each cardiac action potential travels from the SA node to the AV node to the bundle of His (AV bundle), through the bundle branches, and finally to the Purkinje fibers. There the impulse is stopped. It is prevented from reversing its path by the refractory period of cells that have just been polarized. The refractory period ensures that diastole (relaxation) will occur, thereby completing the cardiac cycle.
15. Adrenergic receptor number, type, and function govern autonomic (sympathetic) regulation of heart rate, contractile force, and dilation or constriction of coronary arteries. The presence of specific receptors (α_1, α_2, β_1, β_2) in the myocardium and coronary vessels determines the effects of the neurotransmitters norepinephrine and epinephrine.
16. Unique features that distinguish myocardial cells from skeletal cells enable myocardial cells to transmit action potentials faster (through intercalated disks), synthesize more ATP (because

of a large number of mitochondria), and have readier access to ions in the interstitium (because of an abundance of transverse tubules). These combined differences enable the myocardium to work constantly, which skeletal muscle is not required to do.

17. Cross-bridges between actin and myosin enable contraction to occur. Calcium and its interaction with the troponin complex facilitate the contraction process. With troponin release of calcium, myocardial relaxation begins.
18. Cardiac performance is affected by preload, afterload, heart rate, and myocardial contractility.
19. Preload, or pressure generated in the ventricles at the end of diastole, depends on the amount of blood in the ventricle. Afterload is the resistance to ejection of the blood from the ventricle. Afterload depends on pressure in the aorta.
20. Heart rate is determined by the SA node and by components of the autonomic nervous system, including cardiovascular control centers in the brain, neuroreceptors in the atria and aorta, hormones, and catecholamines (epinephrine and norepinephrine).
21. Contractility is the potential for myocardial fiber shortening during systole. It is determined by the amount of stretch during diastole (i.e., preload) and by sympathetic stimulation of the ventricles.
22. The Frank-Starling law of the heart states that the myocardial stretch determines the force of myocardial contraction (the greater the stretch, the stronger the contraction).
23. Laplace's law states that the amount of contractile force generated within a chamber depends on the radius of the chamber and the thickness of its wall (the smaller the radius and the thicker the wall, the greater the force of contraction).

Systemic Circulation

1. Blood flows from the left ventricle into the aorta and from the aorta into arteries that eventually branch into arterioles and capillaries, the smallest of the arterial vessels. Oxygen, nutrients, and other substances needed for cellular metabolism pass from the capillaries into the interstitium, where they are available for uptake by the cells. Capillaries also absorb products of cellular metabolism from the interstitium.
2. Venules, the smallest veins, receive capillary blood. From the venules the venous blood flows into larger and larger veins until it reaches the venae cavae, through which it enters the right atrium.
3. Vessel walls consist of three layers: the tunica intima (inner layer), the tunica media (middle layer), and the tunica externa (outer layer).
4. Layers of the vessel wall differ in thickness and composition from vessel to vessel, depending on the vessel's size and location within the circulatory system. In general, the tunica media of arteries close to the heart contains a greater proportion of elastic fibers because these arteries must be able to distend during systole and recoil during diastole. Distributing arteries farther from the heart contain a greater proportion of smooth muscle fibers because these arteries

must be able to constrict and dilate to control blood pressure and volume within specific capillary beds.

5. Blood flow into the capillary beds is controlled by the contraction and relaxation of smooth muscle bands (precapillary sphincters) at junctions between metarterioles and capillaries. The endothelium is probably a source of prostaglandins that control vasomotion.
6. Blood flow through the veins is assisted by the contraction of skeletal muscles (the muscle pump), and backflow in the lower body is prevented by one-way valves, particularly in the deep veins of the legs.
7. Blood flow is affected by blood pressure; resistance to flow within the vessels; blood consistency (which affects velocity); anatomic features that may cause turbulent or laminar flow; and compliance (distensibility) of the vessels.
8. Poiseuille’s law describes the relationship of blood flow, pressure, and resistance as the difference between pressure at the inflow end of the vessel and pressure at the outflow end divided by resistance within the vessel.
9. According to Poiseuille’s formula, resistance depends on the vessel’s length and radius and on the viscosity of the blood. The greater the vessel’s length and the blood’s viscosity and the narrower the radius of the vessel’s lumen, the greater the resistance within the vessel.
10. Total peripheral resistance, or the resistance to flow within the entire systemic circulatory system, depends on the combined lengths and radii of all the vessels within the system and on whether the vessels are arranged in series (greater resistance) or in parallel (lesser resistance).
11. Poiseuille’s law and Poiseuille’s formula are based on physical laws governing the behavior of fluids in a straight tube. In the body, blood flow is influenced also by neural stimulation (of vasoconstriction or vasodilation) and by autonomic features that cause turbulence within the vascular lumen (e.g., protrusions from the vessel wall, twists and turns, bifurcations).
12. Arterial blood pressure is influenced and regulated by factors that affect cardiac output (heart rate and stroke volume), total resistance within the system, and blood volume.
13. Many hormones alter vasomotion including epinephrine, norepinephrine, antidiuretic hormone, renin-angiotensin system, natriuretic peptides adrenomedullin and insulin.
14. Ang II has two subtypes of receptors, AT_1 and AT_2. The majority of Ang II actions are thought to be mediated by AT_1 receptor.
15. Venous blood pressure is influenced by blood volume within the venous system and compliance of the venous walls.
16. Blood flow through the coronary circulation is governed not only by the same principles as flow through other vascular beds but also by adaptations dictated by cardiac dynamics. First, blood flows into the coronary arteries during diastole rather than systole because during systole, the cusps of the aortic semilunar valve block the openings of the coronary arteries. Second, systolic contraction inhibits coronary artery flow by compressing the coronary arteries.

17. Autoregulation enables the coronary vessels to maintain optimal perfusion pressure despite systolic effects, and myoglobin in heart muscle stores oxygen for use during the systolic phase of the cardiac cycle.

Lymphatic System

1. The vessels of the lymphatic system run in the same sheaths in which the arteries and veins run.
2. Lymph (interstitial fluid) is absorbed by lymphatic venules in the capillary beds and travels through ever larger lymphatic veins until it is emptied through the right or left thoracic duct into the right or left subclavian vein.
3. As lymph travels toward the thoracic ducts, it is filtered by thousands of lymph nodes clustered around the lymphatic veins. The lymph nodes are sites of immune function.

Tests of Cardiovascular Function

1. The evaluation of an individual with known or suspected cardiovascular disease must include a careful history and physical examination including assessment of risk factors, symptoms, vital signs, level of consciousness, mucous membrane color, and cardiopulmonary functioning.
2. Important tests for cardiac disorders are ECG and Holter monitoring, which detect disturbances of impulse generation or conduction.
3. Stress tests elicit clinical manifestations of cardiovascular disease that might not be present at rest.
4. The sensitivity of stress testing is improved by the use of radiotracer imaging techniques such as SPECT.
5. Echocardiography detects structural and functional cardiac abnormalities over time.
6. Cardiac catheterization is used to measure the oxygen content and pressure of blood in the heart’s chambers and to inject contrast media for x-ray examination of the size and shape of the chambers and valves. Injection of contrast medium into the coronary arteries (coronary angiography), on the other hand, permits visualization of the coronary circulation and every tissue perfused by the coronary arteries.
7. Evaluation of the systemic vascular system can include pulse tracings, Doppler ultrasonography, venography, and arteriography.

Aging and the Cardiovascular System

1. Much controversy exists regarding the effects of normal aging on the cardiovascular system. Separating the physiologic from the pathologic alterations is difficult because of the presence of arteriosclerosis in a majority of older adults.

2. Studies have documented no change in cardiac output, a slight decrease in heart rate, and a slight increase in stroke volume in healthy (lack of ischemic heart disease) older adults at rest. No changes were noted at rest in ejection fraction. A slight increase in afterload (e.g., as systolic blood pressure) and prolonged left ventricular relaxation was noted.
3. The most relevant age-associated changes in cardiovascular performance are myocardial and blood vessel stiffening, changes in neurogenic control over vascular tone, and left ventricular hypertrophy and fibrosis.
4. With active risk reduction and disease management, older adults can have markedly improved cardiovascular health.