

The Heart

The heart is enclosed within the medial cavity of the thorax called the mediastinum. It extends from the second rib to the 5th intercostal space and rests on the superior surface of the diaphragm. About 2/3 of the heart lies to the left of the midsternal line. It has a flat base (posterior surface) and an apex that points inferiorly toward the left hip.

Coverings

A dense connective tissue covering called the fibrous pericardium protects the heart and anchors it to surrounding structures. Deep to the fibrous pericardium is the thin two-layer serous pericardium. The parietal layer lines the inside of the fibrous pericardium. The visceral layer is attached to the external heart surface and is called the epicardium. Between these two layers is the pericardial cavity containing serous fluid lubricating the outside of the heart. Loss of this fluid creates painful pericarditis. If too much fluid is present it may restrict the heart's activity. This is referred to as cardiac tamponade.

Layers and Chambers

The epicardium is a thin membrane (the visceral pericardium) covering the heart wall. The middle layer, the myocardium, forms the bulk of the heart and consists mostly of cardiac muscle. The endocardium is a thin layer of squamous epithelium and connective tissue that lines the chambers of the heart.

There are four chambers of the heart: the superior right and left atria and the inferior right and left ventricles. The two sides are separated by the interatrial and interventricular septa respectively. Protruding from the atria are small, "ear-like" auricles. On the interior surface are raised bundles of pectinate muscles. Within the interatrial septum is a shallow depression, the fossa ovalis, which in fetal life was the foramen ovale and through which blood passed directly from the right to the left atrium. This opening closes shortly after birth. The atria are relatively small and thin-walled because their function is only to collect blood and pass it to the ventricles.

Blood enters the right atrium from the superior and inferior vena cavae draining the upper and lower parts of the body, and from the coronary sinus that drains the myocardium. The four pulmonary veins (2 right and 2 left) enter the left atrium that makes up most of the heart's base. These veins transport oxygen-rich blood from the lungs back to the heart.

The right (anterior) and left (posteroinferior) ventricles make up most of the heart volume. On the interior surfaces of the ventricles are irregular ridges of muscles called trabeculae carneae. Other cone-like muscles called papillary muscles connect to the valves. The muscular walls of the ventricles are thickened reflecting the amount of work required to pump the blood greater distances. When the ventricles contract, blood is forced into the circulation. The right ventricle forces blood into the pulmonary trunk which quickly divides into the right and left pulmonary arteries. The left ventricle forces blood into the aorta, the largest artery of the body.

Pathway of Blood Through the Heart

The right side of the heart pumps blood through the pulmonary circuit. It collects O₂-poor and CO₂-rich blood from the body and pumps it to the lungs where the CO₂ is unloaded and O₂ is picked up. The left side of the heart pumps blood through the systemic circuit where O₂-rich blood is transported to the tissues and CO₂ is picked up.

The heart picks up almost no O₂ and nutrients from the chambers of the heart but has its own coronary circulation. The right and left coronary arteries arise from the base of the aorta and encircle the heart in the atrioventricular groove (sulcus). The left coronary artery divides into the anterior interventricular artery (also called the Left Anterior Descending Artery) and the circumflex artery. The right coronary artery divides into the marginal artery and the posterior interventricular artery. There is considerable variation among people with regard to the arterial blood supply of the heart. There are many anastomoses among the arterial branches.

After passing through the capillary beds of the myocardium, blood is collected by the cardiac veins. Three large veins, the great cardiac vein, the middle cardiac vein and the small cardiac vein drain into the

coronary sinus which empties into the right atrium. Several anterior cardiac veins also empty into the right atrium.

Arterial blockage in the coronary circulation may lead to a myocardial infarction. Cell death due to oxygen deprivation results in tissue replacement with scar tissue.

Heart Valves

There are two atrioventricular valves: the tricuspid valve regulating flow between the right atrium and right ventricle and the mitral valve (or bicuspid valve) regulating flow between the left atrium and left ventricle. Valve flaps are connected to papillary muscles by collagen cords called chordae tendinae. When the ventricles contract, these two valves close preventing backflow into the atria. The papillary muscles also contract preventing the flaps from everting back into the atria.

There are two semilunar valves: the aortic and the pulmonary that prevent backflow into the left and right ventricles respectively. When the ventricles contract, the SL valves are forced open and when the ventricles are relaxed the backpressure of the aorta and the pulmonary trunk forces the SL valves closed.

Cardiophysiology

Cardiac muscle is striated and contracts by sliding filaments (like skeletal muscle) but has only one or two centrally located nuclei. A greater proportion of the cell is made up of mitochondria since the heart relies almost exclusively on aerobic respiration. Thus, cardiac muscle cannot incur much oxygen debt. At the junctions of cardiac cells are intercalated discs containing anchoring desmosomes which prevent separation during contraction, and gap junctions which allow ions to pass from cell to cell. This electrical coupling allows the entire myocardium to act as a coordinated unit.

Although the heart is well supplied by nerve fibers which can alter the heart rhythm, noncontractile cardiac cells, called autorhythmic cells, are able to initiate action potentials that spread through the heart. This is called the intrinsic cardiac conduction system.

Excitation follows this sequence: Autorhythmic cells are found in the sinoatrial (SA) node located in the right atrial wall just inferior to the entrance of the superior vena cava. This is the heart's pacemaker determining the sinus rhythm. The wave of depolarization spreads via gap junctions throughout the atria to the atrioventricular (AV) node located on the inferior interatrial septum. Here, the impulse is delayed allowing for the complete contraction of the atria. From the AV node the impulse spreads to the bundle of His in the superior part of the interventricular septum. This is the only electrical connection between the atria and the ventricles. The bundle of His splits into right and left bundle branches and the impulse continues through Purkinje fibers which reach down to the apex and then into the ventricular walls where cell to cell transmission via gap junctions occurs between ventricular muscle cells.

Arrhythmias are irregular atrial or ventricular contractions.

Fibrillation is the condition of rapid and irregular or out-of-phase contractions in which contractions are no longer controlled by the SA node. An electrical shock to the heart called defibrillation (which depolarizes the entire myocardium) may allow the SA node to regain control of rhythms.

EKG's

An electrocardiograph records electrical currents generated in the heart and spread through the heart and the body. Voltage determined by leads typically results in three distinguishable waves: the small P wave results from the depolarization wave from the SA node through the atria; The QRS complex results from ventricular depolarization and precedes ventricular contraction; the T wave is caused by ventricular repolarization. Because atrial repolarization occurs at the same as ventricular depolarization, the QRS complex obscures a graphical recording of atrial repolarization.

The size, duration and timing of the deflection waves tend to be consistent in a healthy heart so that changes in patterns may reveal disease or past damage.

Heart Sounds

The “lub-dup” sounds heard upon auscultation of the heart are associated with the closing of heart valves. The first sound occurs when the AV valves close; the second sound when the SL valves close. Thus, the first sound occurs when the ventricles contract, the second when the ventricles relax. Abnormal heart sounds are called murmurs. One fairly common murmur occurs when an incompetent mitral valve fails to completely close causing a swishing sound as the blood backflows into the left atrium.

Cardiac Cycle

Systole refers to the contraction of the chambers. Diastole refers to periods of relaxation. The cardiac cycle of chambers contracting and relaxing is outlined as follows:

- Ventricular filling (mid to late diastole). Blood flows passively from the atria to the ventricles. The SL valves are closed. Atrial systole (P wave) then occurs forcing the remaining atrial blood to the ventricles. Atrial diastole occurs as the ventricles depolarize (QRS complex).
- Ventricular systole. As the ventricles contract, the AV valves are closed and the SL valves are forced open. Blood is forced into the aorta and the pulmonary trunk. Pressure in the aorta generally reaches 120mm Hg.
- Isovolumetric relaxation (early diastole). Following ventricular repolarization, the ventricles relax. Pressure in the aorta and pulmonary trunk causes a backflow resulting in the closure of the SL valves. As the ventricles contract the atria are filling. When blood pressure in the atria exceeds that in the ventricles, the AV valves are forced open.

About half of the cardiac cycle is a period of total heart relaxation called the quiescent period.

Cardiac Output

Cardiac output is the amount of blood pumped by each ventricle in one minute and is calculated by multiplying the heart rate (number of beats per minute) times the stroke volume (the volume of blood pumped out by one ventricle with each beat). Cardiac output varies considerably in response to the oxygen demands of the body.

Regulation of Heart Rate

Besides the intrinsic conduction system there are several extrinsic factors regulating heart rate the most important of which is the autonomic nervous system. Sympathetic nerve fibers release norepinephrine at their cardiac synapses resulting in an increase in heart rate. Sympathetic nerve fibers also enhance Ca^{2+} entry into contractile cells. Under resting conditions both divisions of the autonomic nervous system send impulses to the SA node usually inhibiting the heart rate.

Hormones, especially epinephrine and thyroxine, may both act on the heart increasing the rate. The relationship between intracellular and extracellular ions (Na^+ , K^+ , and Ca^{2+}) must be maintained in a certain balance. Imbalances threaten normal heart function. Hypocalcemia depresses the heart while hypercalcemia may result in too many contractions. Too much Na^+ and K^+ may interfere with the transport of Ca^{2+} into the cardiac muscle cells. The mode of action of a number of cardiac drugs involves the transport of calcium into cardiac cells.

Age, body temperature, gender and exercise also affect the heart rate.

Disorders

Tachycardia is an abnormally elevated heart rate (usually >100 beats per minute). Bradycardia is an abnormally depressed heart rate (usually <60 beats per minute).

When the cardiac output is not enough to meet tissue needs, the heart is said to be in congestive heart failure. Damage to the myocardium may be done by coronary atherosclerosis, chronic hypertension, and multiple myocardial infarcts. Pulmonary congestion occurs with left side failure. The right side continues to pump to the lungs which may become engorged forcing circulation fluid into the lung tissue causing a pulmonary edema. Right side failure often results in edema in the extremities. Diuretics are often given as treatment for edema.