CIRCULATORY PATHWAYS

The circulatory patterns are of two types-open or closed. In open circulatory system, blood pumped by the heart passes through large vessels into open spaces or body cavities called sinuses. This type of system is present in arthropods and molluscs. In closed circulatory system, the blood pumped by the heart is always circulated through a closed network of blood vessels. This system or pattern is considered to be more advantageous as the flow of fluid can be more precisely regulated. The closed circulatory system is present in annelids and most chordates.

In all vertebrates, the heart consists of 1 or 2 atria and 1 or 2 ventricles. The heart of lower vertebrates has additional chambers, namely, sinus venosus and conus arteriosus or truncus arteriosus.

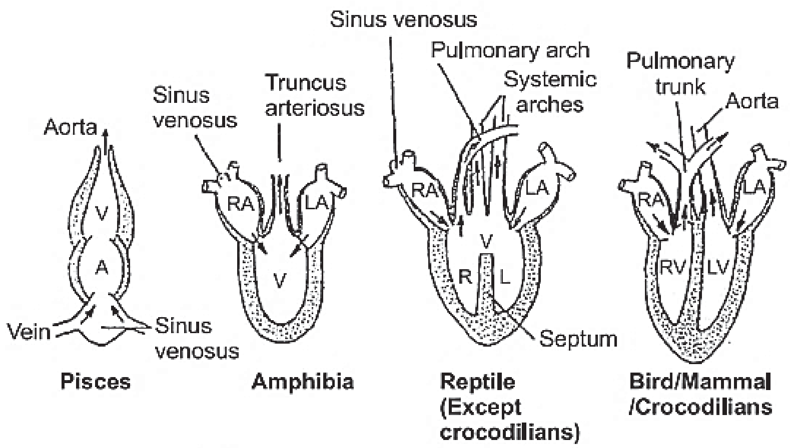

Fig. : Hearts of different vertebrates;
A = Atrium, V = Ventricle, R = Right, L = Left

- All vertebrates have a muscular heart. Fishes have a two-chambered heart with an atrium and a ventricle, while lung fishes have 3 chambered heart. Amphibians and the reptiles (except crocodiles) possess a three-chambered heart with two atria and a single ventricle, whereas crocodiles, birds and mammals possess a four-chambered heart with two atria and two ventricles.
- In fishes, the heart pumps out deoxygenated blood which undergoes oxygenation in the gills. The oxygenated blood is then supplied to the body parts from where deoxygenated blood is returned to the heart. This is known as single circulation.
- In amphibians and reptiles except crocodiles, the left atrium gets oxygenated blood from the gills/lungs/skin and the right atrium receives the deoxygenated blood from other body parts. However, both oxygenated and deoxygenated blood get mixed up in the single ventricle. The heart thus pumps out mixed blood. This is known as incomplete double circulation.
- In crocodiles, birds and mammals, the left and the right atria receive oxygenated and deoxygenated blood, respectively which is passed onto the ventricles of the same sides. Here, there is no mixing of oxygenated and deoxygenated blood. Thus, the ventricles pump it out without any mixing, i.e., two separate circulatory pathways are present in these organisms, hence, these animals have double circulation.

Human Circulatory System

Human circulatory system, also known as the blood vascular system consists of a muscular chambered heart, a network of closed branching blood vessels and blood, the fluid which is circulated.

Structure of Human Heart

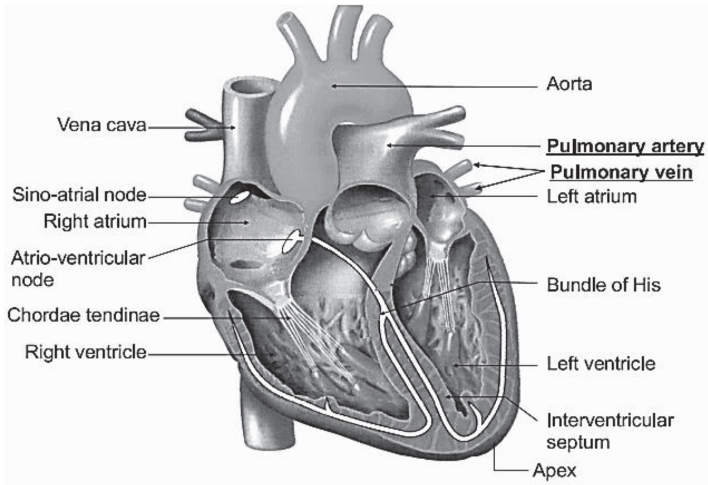

Fig. : Section of a human heart

- Heart is located in the thoracic cavity, in between the two lungs, slightly tilted to the left. It is derived from the mesoderm and has the size of a clenched fist.
- Heart is protected by a double walled membranous bag called pericardium. The pericardium consists of two layers, an outer parietal pericardium and an inner visceral pericardium attached to the heart. A space called pericardial cavity is present between the two layers which is filled with a fluid called pericardial fluid. The pericardium protects the heart from shocks and mechanical injuries.
- Our heart is divided into four chambers, two relatively small upper chambers called atria (singular, atrium) and two larger lower chambers called ventricles. The walls of the ventricles are much thicker than that of the atria. The right and the left atria are separated by a thin, muscular wall called the interatrial septum whereas the right and left ventricles are separated by thick-walled interventricular septum.
- A thick fibrous tissue called the atrio-ventricular septum separates the atrium and the ventricle of the same side. However, both of the atrio-ventricular septa are provided with an opening through which the two chambers of the same side are connected.
- The openings between the atria and the ventricles are guarded by atrioventricular (AV) valves.The AV valve between right atrium and right ventricle has three flaps or cusps and is therefore called the tricuspid valve. The AV valve between the left atrium and left ventricle has two flaps or cusps and is thus called the bicuspid valve or mitral valve.
- Special fibrous cords called the chordae tendinae are attached to the flaps of the bicuspid and tricuspid valves at one end and their other ends are attached to the ventricular wall with the special muscles, the papillary muscles. The chordae tendinae prevent the bicuspid and tricuspid valves from collapsing back into the atria during powerful ventricular contractions.
- Three semilunar valves (half-moon shaped pockets) are found at the points where the pulmonary artery (arising from the right ventricle and carrying deoxygenated blood to the lungs) and aorta (large artery arising from left ventricle and carrying oxygenated blood to all parts of the body) leave the heart. These valves prevent blood from getting back into the ventricles.

- The right atrium receives deoxygenated blood through coronary sinus (discussed later) and two large veins called venae cavae (one superior vena cava and one inferior vena cava). The left atrium receives oxygenated blood from the lungs through two pairs of pulmonary veins.

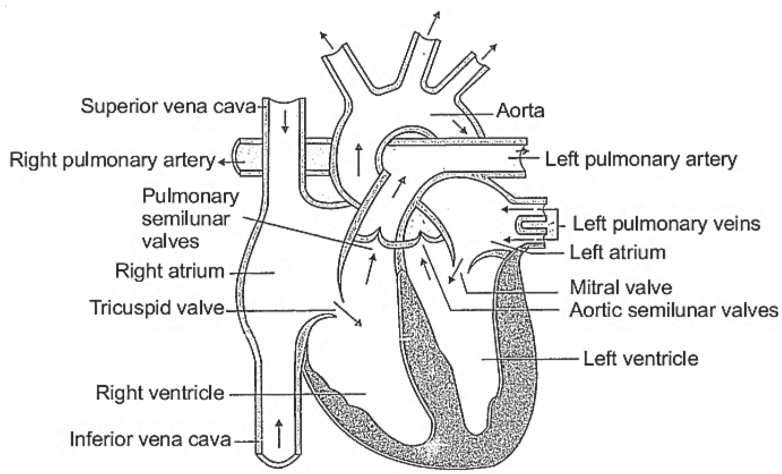

Fig. : Human heart showing the flow of blood

Conducting System in Human Heart

The entire heart is made of cardiac muscles. A specialised cardiac musculature called the nodal tissue is also distributed in the heart. A patch of this tissue called the sino-atrial node (SAN) is present in the upper right corner of the right atrium. Another mass of this tissue called the atrio-ventricular node (AVN) is present in the lower left corner of the right atrium, close to the atrio-ventricular septum.

AV node is continuous with the bundle of His, which gives off a left and right bundle branch at the top of the interventricular septa. These branches give rise to minute fibres called Purkinje fibres throughout the ventricular musculature of the respective sides.

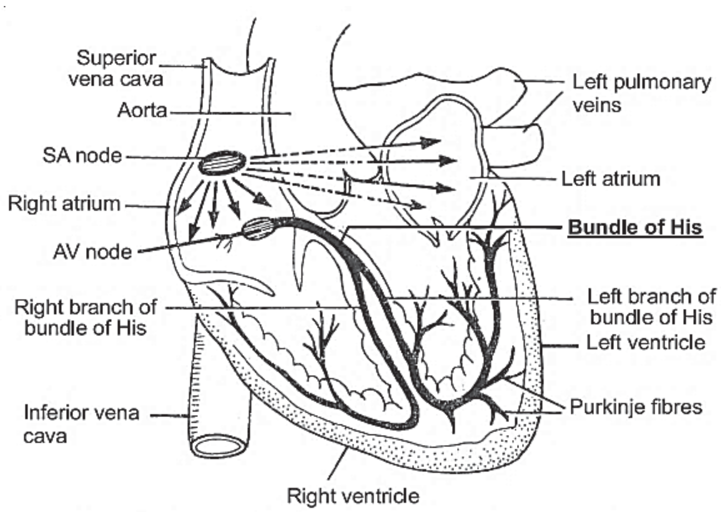

Fig. : Diagram of the conducting system in human heart

The nodal musculature has the ability to generate action potentials without any external stimuli, i.e., it is auto excitable. Action potential is a short-lasting event in which the electrical membrane potential (difference in electrical potential between the interior and the exterior of a biological cell) of a cell rapidly rises and falls. Although all the heart muscle cells have the ability to generate the electrical impulses (or action potentials) that trigger cardiac contraction, the SAN initiates it, simply because it generates the maximum number of action potentials, i.e., 70-75 min-1, and is responsible for initiating and maintaining the rhythmic contractile activity of the heart. Therefore it is called the pacemaker of the heart. Our heart normally beats 70-75 times in a minute (average 72 beats min-1). This is called heart rate.

Cardiac Cycle

- The cardiac cycle refers to the repeating pattern of contraction and relaxation of the heart. The phase of contraction is called systole, and the phase of relaxation is called diastole.
- How does the heart function? Let us take a look. To begin with, all the four chambers of heart are in a relaxed state, i.e., they are in joint diastole. Blood from pulmonary veins and venae cavae, fills the left and right atria, respectively. The buildup of pressure that results, causes the AV valves to open and blood to flow from atria to the ventricles. Nearly 70% of ventricles get filled with blood during joint diastole. At this stage, the semilunar valves are closed. The SAN now generates an action potential which stimulates both the atria to undergo a simultaneous contraction known as atrial systole. It results in increase of blood flow into the ventricles by about 30 percent.

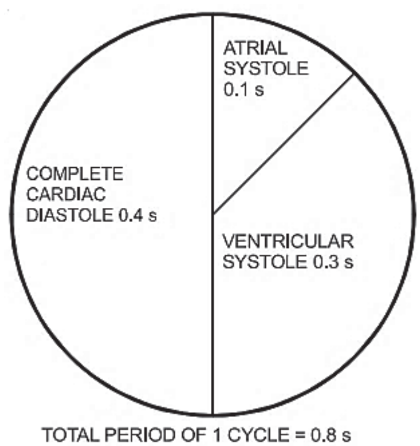

Fig. : Stages of cardiac cycle

- The action potential generated by the SAN is conducted to the ventricular side by the AVN and AV bundle from where the bundle of His transmits it through the entire ventricular musculature. This causes contraction of the ventricular muscles known as ventricular systole. The atria now undergo relaxation called atrial diastole which coincides with ventricular systole. As the ventricles begin their contraction, the intraventricular pressure rises, causing the closure of tricuspid and bicuspid valves (AV valves) to prevent backflow of blood into the atria.
- When the pressure in the left and right ventricles becomes greater than the pressure in aorta and pulmonary artery respectively, the semilunar valves are forced open. Opening of semilunar valves, guarding the pulmonary artery (right side) and the aorta (left side) allow the blood in ventricles to flow through these vessels into the circulatory pathways. Now the ventricles relax, i.e., ventricular diastole occurs and the ventricular pressure falls, causing the closure of semilunar valves. It prevents the backflow of blood into the ventricles.
- The ventricular pressure declines further and the AV valves are pushed open due to the pressure in the atria exerted by the blood which was being emptied into them by the veins. Once again the blood moves freely into the ventricles.
- The ventricles and atria are again in joint diastole (relaxed state) as earlier. Soon a new action potential is generated by SAN and the events described above are repeated in that sequence and the process continues.

- This sequential event which is cyclically repeated in the heart constitute the cardiac cycle which consists of systole and diastole of both the atria and ventricles.
- Our heart beats 72 times per minute, i.e., 72 cardiac cycles are performed per minute. Now, if 72 cardiac cycles are performed in 60 seconds (1 min) then one cardiac cycle would occur in 0.8 second.
- During a cardiac cycle, each ventricle pumps out approximately 70 mL of blood. This is called the stroke volume. The stroke volume multiplied by the number of beats per minute (heart rate) gives the cardiac output. The cardiac output is 72 x 70 or 5040 mL per minute, i.e., about 5 litres per minute. Therefore, the volume of blood pumped out by each ventricle per minute is known as the cardiac output.
- The body is able to alter the stroke volume as well as the heart rate and thereby the cardiac output. For example, the cardiac output of an athlete will be much higher than that of an ordinary man.
- During exercise, the cardiac output can increase upto five folds - from about 5 L per minute to about 25 L per minute. This is primarily due to an increase in heart rate which increases the blood flow to skeletal muscles. The heart rate, can however increase only upto a maximum value, which is determined mainly by a person's age. In well-trained athletes, the stroke volume can also increase significantly, allowing these individuals to achieve cardiac output during strenous exercise upto six-seven times greater than their resting values. This high cardiac output results in increased oxygen delivery to the exercising muscles. This is the major reason for the much higher than average maximal oxygen uptake of elite athletes.

Heart Sounds

During each cardiac cycle two prominent sounds are produced which can be easily heard through a stethoscope. These sounds are of clinical diagnostic significance.

First Heart Sound (LUB)	Second Heart Sound (DUB)
1. It is produced by closing of AV valves (tricuspid and bicuspid valves) during ventricular systole.	1. It is produced by closing of semilunar valves at the beginning of ventricular diastole.
2. It is low pitched and of long duration.	2. It is higher pitched and of short duration.

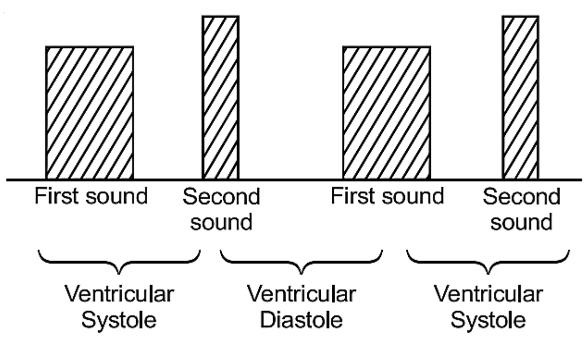

Fig. : Heart Sounds

Electrocardiogram (ECG)

The pacemaker region of the heart (SA node) exhibits a spontaneous depolarisation that causes action potentials, resulting in the automatic beating of the heart. Impulses which travel through cardiac muscles during the cardiac cycle produce electrical currents. The electrical currents are conducted through the body fluids to the body surface, where the amplified currents can be detected by placing electrodes on the skin and recorded as an electrocardiogram (ECG). Einthoven recorded the first ECG in the world in 1903.

Electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart during a cardiac cycle. The machine used to obtain an electrocardiogram is known as electrocardiograph and this technique is called electrocardiography.

To obtain a standard ECG, a patient is connected to the machine with three electrical leads (one to each wrist and one to the left ankle).

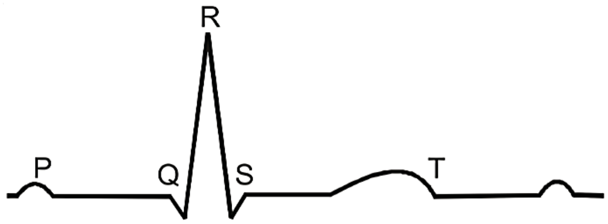

Fig. : Diagrammatic presentation of a standard ECG

- The P wave is a small upward wave that represents electrical excitation (or depolarisation) of the atria which leads to contraction of both the atria.
- The QRS (wave) complex represents the depolarisation of the ventricles, which initiates the ventricular contraction (ventricular systole). The contraction of the ventricles starts shortly after Q and marks the beginning of the systole.
- The T-wave represents the return of the ventricles from excited (depolarised) to normal state (i.e., repolarisation). The end of the T-wave marks the end of systole.
- Thus, by counting the number of QRS complexes that occur in a given time period, the heart beat rate or pulse of an individual can be determined. ECGs obtained from different individuals have roughly the same shape for a given lead configuration. ECG is of great clinical significance as any deviation from this shape indicates a possible abnormality or disease.
- Enlargement of P-wave indicates enlargement of the atria.
- The enlarged Q and R waves indicate myocardial infarction (heart attack).
- The S-T segment is elevated in myocardial infarction and depressed when the heart muscles receive insufficient oxygen.
- T-wave is flat when the heart muscles receive insufficient oxygen as in atherosclerotic heart disease.