Body Fluids and Circulation - Part 4

Objectives

After going through this lesson, the learners will be able to understand the following:

- Blood vessels
- Single and double circulation
- Electrocardiograph (ECG)
- Regulation of cardiac activity
- Disorders of circulatory system

Content Outline

- Introduction
- Blood Vessels
- Single and Double Circulation
- Electrocardiograph (ECG)
- Regulation of Cardiac Activity
- Disorders of Circulatory System
- Summary

Introduction

The circulatory system is often seen to comprise two separate systems: the cardiovascular system, which distributes blood, and the lymphatic system, which circulates lymph. The passage of lymph for example takes much longer than that of blood. Blood is a fluid consisting of plasma, red blood cells, white blood cells, and platelets that is circulated by the heart through the vertebrate vascular system, carrying oxygen and nutrients to and waste materials away from all body tissues. Lymph is essentially recycled excess blood plasma after it has been filtered from the interstitial fluid (between cells) and returned to the lymphatic system. The cardiovascular (from Latin words meaning "heart" and "vessel") system comprises the blood, heart, and blood vessels. The lymph, lymph nodes, and lymph vessels form the lymphatic system, which returns filtered blood plasma from the interstitial fluid (between cells) as lymph.

While humans, as well as other vertebrates, have a closed cardiovascular system (meaning that the blood never leaves the network of arteries, veins and capillaries), some invertebrate groups have an open cardiovascular system. The lymphatic system, on the other hand, is an open system providing an accessory route for excess interstitial fluid to be returned to the blood.The heart powers the pulmonary and the systemic circulations. In the pulmonary circulation, deoxygenated blood travels to the lungs, where it absorbs oxygen before returning to the heart. This oxygenated blood is pumped around the body in the systemic circulation. Body tissues absorb oxygen, and deoxygenated blood returns to the heart to be pumped to the lungs again.

Blood Vessels

The **blood vessels** are the part of the circulatory system that transports blood throughout the human body. There are three major types of blood vessels: the arteries, which carry the blood away from the heart; the capillaries, which enable the actual exchange of water, gasses and chemicals between the blood and the tissues; and the veins, which carry blood from the capillaries back toward the heart. A few structures (such as cartilage and the lens of the eye) do not contain blood vessels.

There are various kinds of blood vessels:

- Arteries
- Elastic arteries
- Distributing arteries
- Arterioles
- Capillaries (the smallest blood vessels)
- Venules
- Veins
- Venae cavae (the two largest veins, carry blood into the heart).
- Large collecting vessels, such as the subclavian vein, the jugular vein, the renal vein and the iliac vein.

They are roughly grouped as ***arterial*** and ***venous***, determined by whether the blood in it is flowing *away from* (arterial) or *toward* (venous) the heart. The term "arterial blood" is nevertheless used to indicate blood high in oxygen, although the pulmonary artery carries "venous blood" and blood flowing in the pulmonary vein is rich in oxygen. This is because they are carrying the blood to and from the lungs, respectively, to be oxygenated.

Arteries

An artery is a blood vessel that conducts blood away from the heart. All arteries have relatively thick walls that can withstand the high pressure of blood ejected from the heart. However, those close to the heart have the thickest walls, containing a high percentage of elastic fibers. This type of artery is known as an elastic artery. Vessels larger than 10 mm in diameter are typically elastic. Their abundant elastic fibers allow them to expand, as blood pumped from the ventricles passes through them, and then to recoil after the surge has passed. If artery walls were rigid and unable to expand and recoil, their resistance to blood flow would greatly increase and blood pressure would rise to even higher levels, which would in turn require the heart to pump harder to increase the volume of blood expelled by each pump and maintain adequate pressure and flow. Artery walls would have to become even thicker in response to this increased pressure. Farther from the heart the percentage of elastic fibers in an artery decreases. The artery at this point is described as a muscular artery. The diameter of muscular arteries typically ranges from 0.1 mm to 10 mm. The thick walls of muscular arteries allow them to play a leading role in vasoconstriction. In contrast, their decreased quantity of elastic fibers limits their ability to expand.

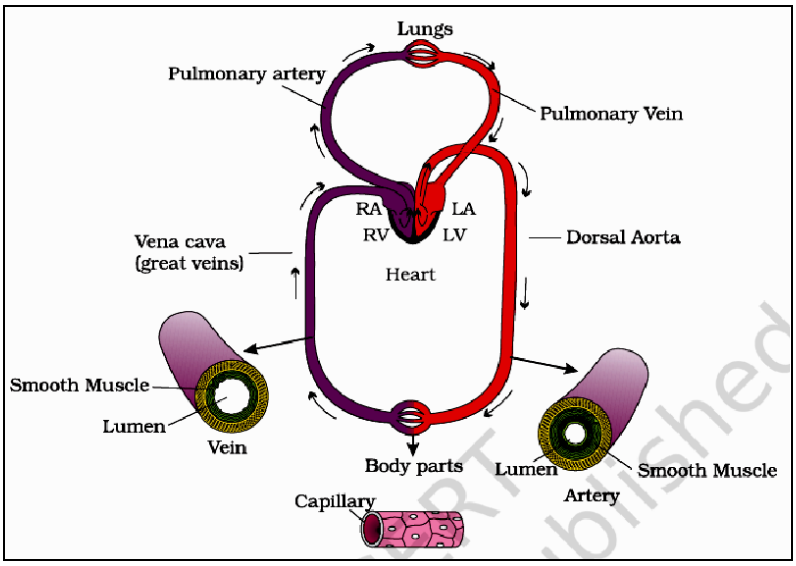


Fig 1: Arteries

Arterioles

An **arteriole** is a very small artery that leads to a capillary. Arterioles have the same three tunics as the larger vessels, but the thickness of each is greatly diminished.

The importance of the arterioles is that they will be the primary site of both resistance and regulation of blood pressure.

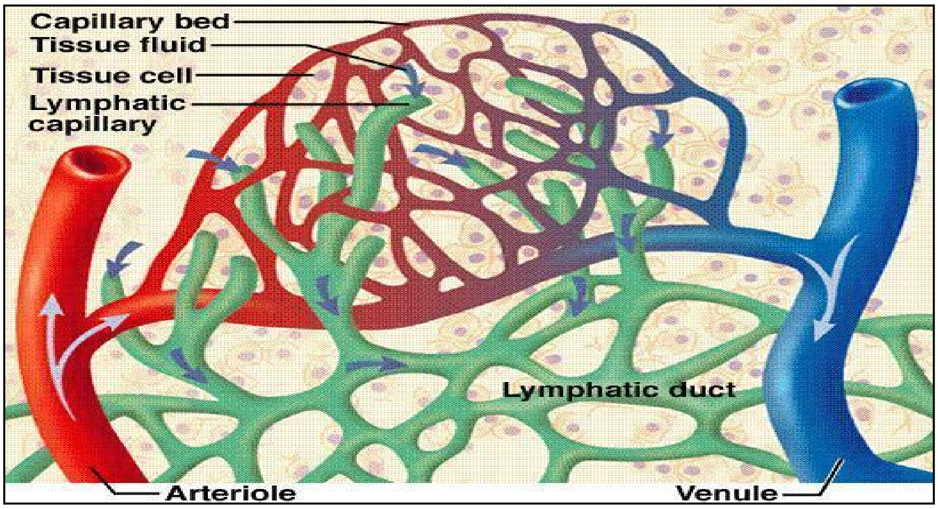


Fig 2: Arteriole

Capillaries

Arteries branch into smaller passages called arterioles and then into the capillaries. The capillaries merge to bring blood into the venous system. A **capillary** is a microscopic channel that supplies blood to the tissues themselves, a process called **perfusion**. Exchange of gases and other substances occurs in the capillaries between the blood and the surrounding cells and their tissue fluid (interstitial fluid). The diameter of a capillary lumen ranges from 5-10 micrometers; the smallest are just barely wide enough for an erythrocyte to squeeze through. The wall of a capillary consists of the endothelial layer surrounded by a basement membrane with occasional smooth muscle fibers. For capillaries to function, their walls must be leaky, allowing substances to pass through.

After their passage through body tissues, capillaries merge once again into venules, which continue to merge into veins. The venous system finally coalesces into two major veins: the superior vena cava (roughly speaking draining the areas above the heart) and the inferior vena cava (roughly speaking from areas below the heart). These two great vessels empty into the right atrium of the heart.

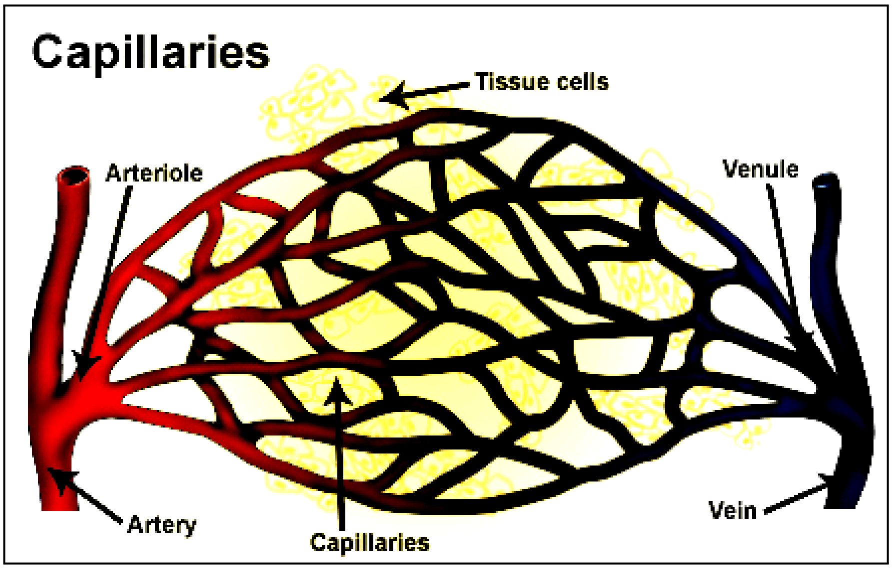


Fig 3: Capillaries

Venules

A **venule** is an extremely small vein, generally 8-100 micrometers in diameter. Post capillary venules join multiple capillaries exiting from a capillary bed. Multiple venules join to form veins.

Veins

A vein is a blood vessel that conducts blood toward the heart. Compared to arteries, veins are thin-walled vessels with large and irregular lumens. Because they are low-pressure vessels, larger veins are commonly equipped with valves that promote the unidirectional flow of blood toward the heart and prevent backflow toward the capillaries caused by the inherent low blood pressure in veins as well as the pull of gravity.

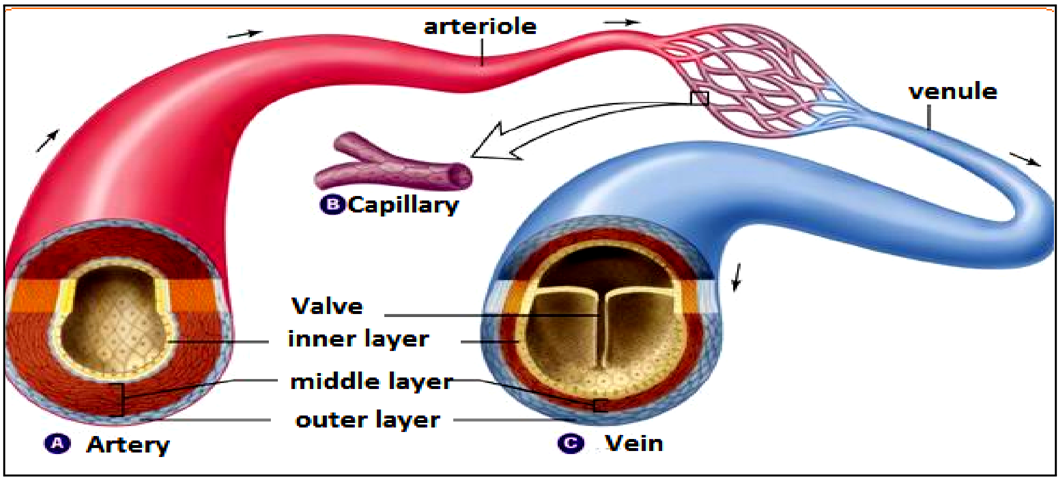
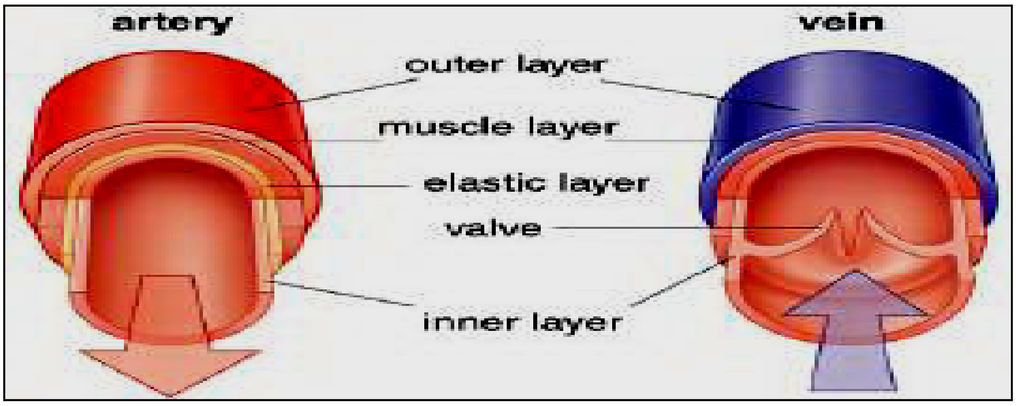


Fig 4: Venule and Vein

In addition to their primary function of returning blood to the heart, veins may be considered blood reservoirs, since systemic veins contain approximately 65 percent of the blood volume at any given time. At any given moment arteries contain about 30 percent of blood while capillaries contain only 5 percent of blood of our systemic circulation. The large lumens and relatively thin walls of veins make them far more distensible than arteries; thus, they are said to be capacitance vessels.

This vast system of blood vessels – arteries, veins, and capillaries – is over 96600 km long. That's long enough to go around the world more than twice!

Property	Arteries	Veins
Direction of blood flow	Conducts blood away from the heart	Conducts blood toward the heart
General appearance	Rounded	Irregular, often collapsed
Pressure	High	Low
Wall thickness	Thick	Thin
Relative oxygen concentration	Higher in systemic arteries Lower in pulmonary arteries	Lower in systemic veins Higher in pulmonary veins
Valves	Not present	Present most commonly in limbs and in veins inferior to the heart



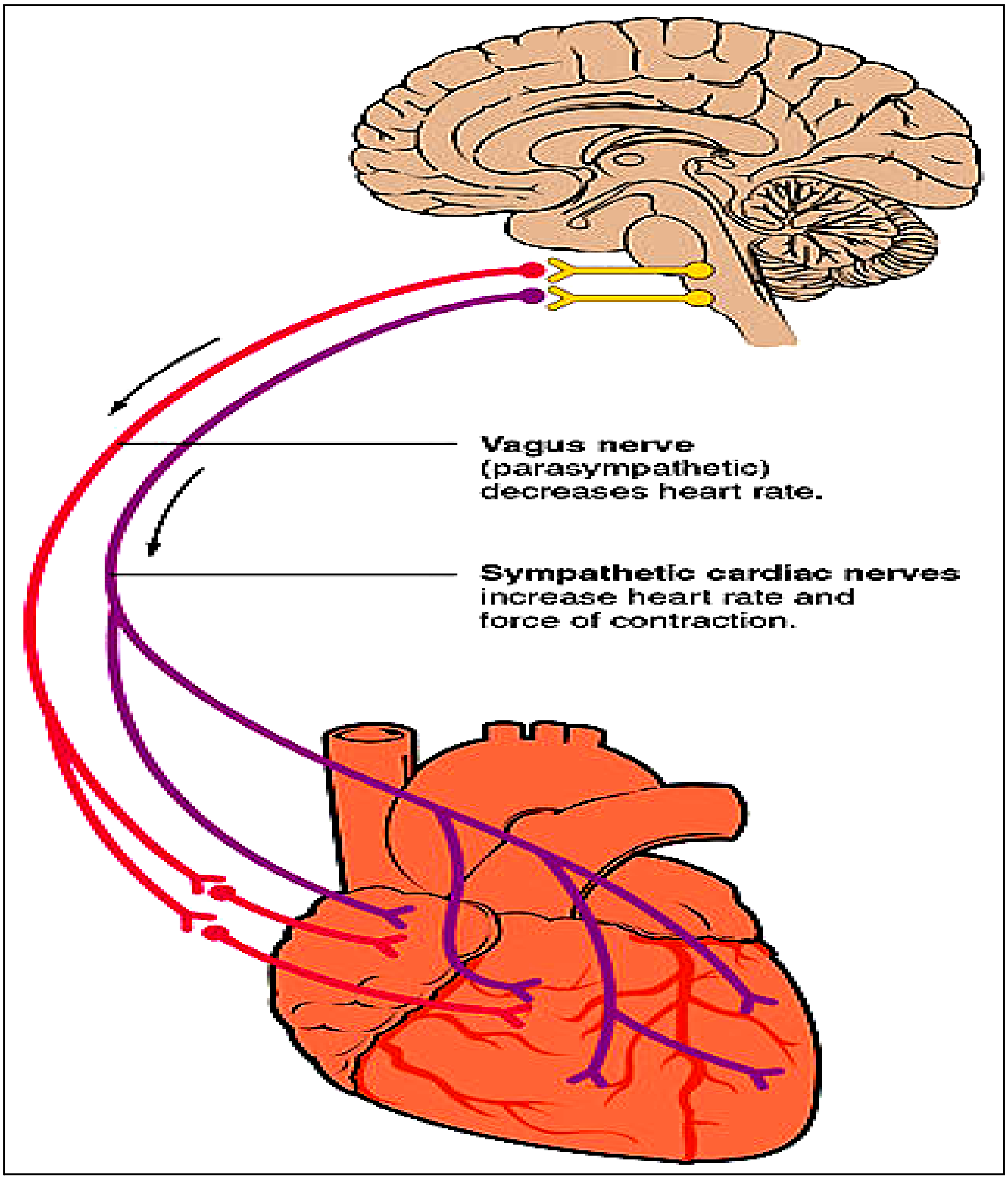


Fig 5: Properties of Arteries and Veins

Single and Double Circulation

Single Circulation

In a single circulatory system, the blood will pass through the heart to gills then after purification, blood will be distributed to different parts of the body. Only one cardiac cycle is completed, hence the name single circulation. In the circulatory system of a fish, the blood travels from the heart to the gills where it absorbs oxygen and releases carbon dioxide. It then flows from the gills to the organs and tissues in the rest of the body, and back to the heart. There is just one circuit from the heart.In single Circulatory System the blood flows:

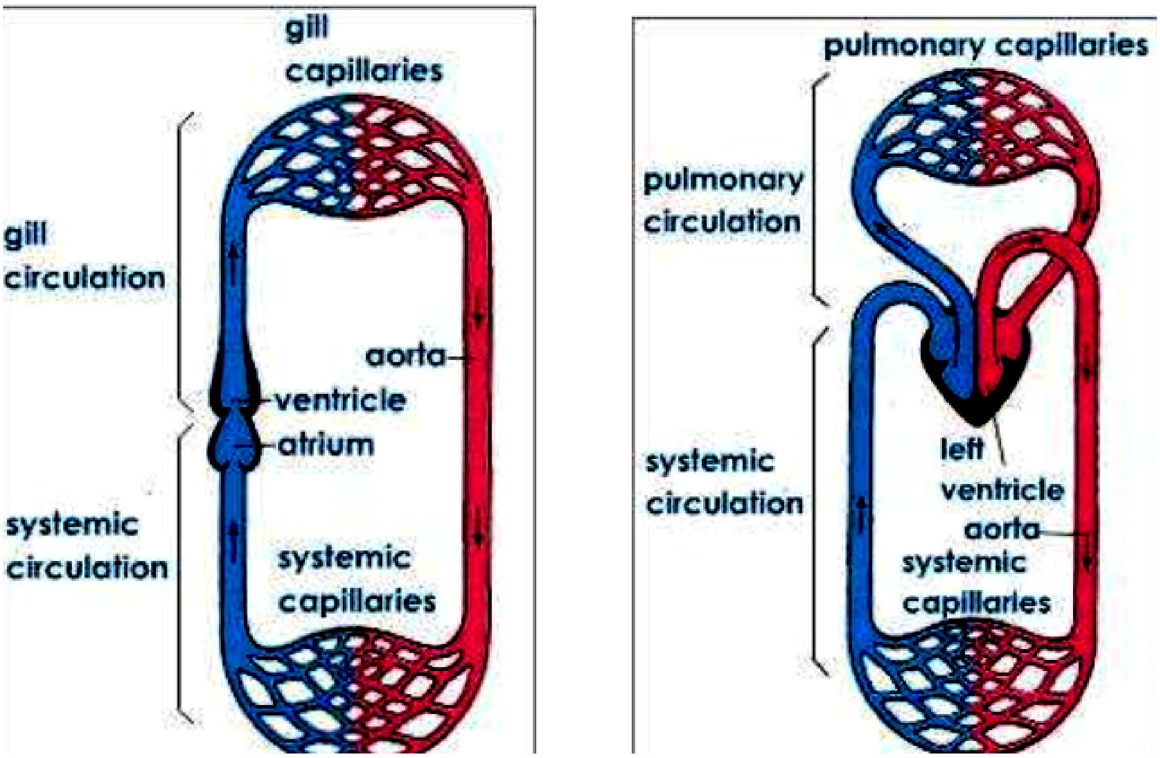
Heart → Gills → Body → Heart

Double Circulation

Most mammals follow double circulation which provides an efficient way of circulation. Heart is the key organ for blood circulation. In the case of humans, the heart is divided into four chambers: left and right atria and left and right ventricles. Further, the heart is connected to the lungs through pulmonary artery and vein.

Double circulation is the circulation of blood through the heart twice while supplying the blood to the whole body. In double circulation, there are two loops or circuits where the blood travels to heart; In Double Circulatory System the blood flows:

Heart → Lungs → Heart → Body → Heart



Single Circulation **Double Circulation**

Fig 6: Single and Double Circulation

Electrocardiography

Electrocardiography (**ECG** or **EKG**) is the process of recording the electrical activity of the heart over a period of time using electrodes placed on the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle's electrophysiological pattern of depolarizing and repolarizing during each heartbeat. It is a very commonly performed cardiology test.

You are probably familiar with this scene from a typical hospital television show: A patient is hooked up to a monitoring machine that shows voltage traces on a screen and makes the sound "... pip... pip... pip.....peeeeeeeeeeeeeeeeeeeeee" as the patient goes into cardiac arrest. This type of machine (electro-cardiograph) is used to obtain an electrocardiogram
(ECG). ECG is a graphical representation of the electrical activity of the heart during a cardiac cycle.

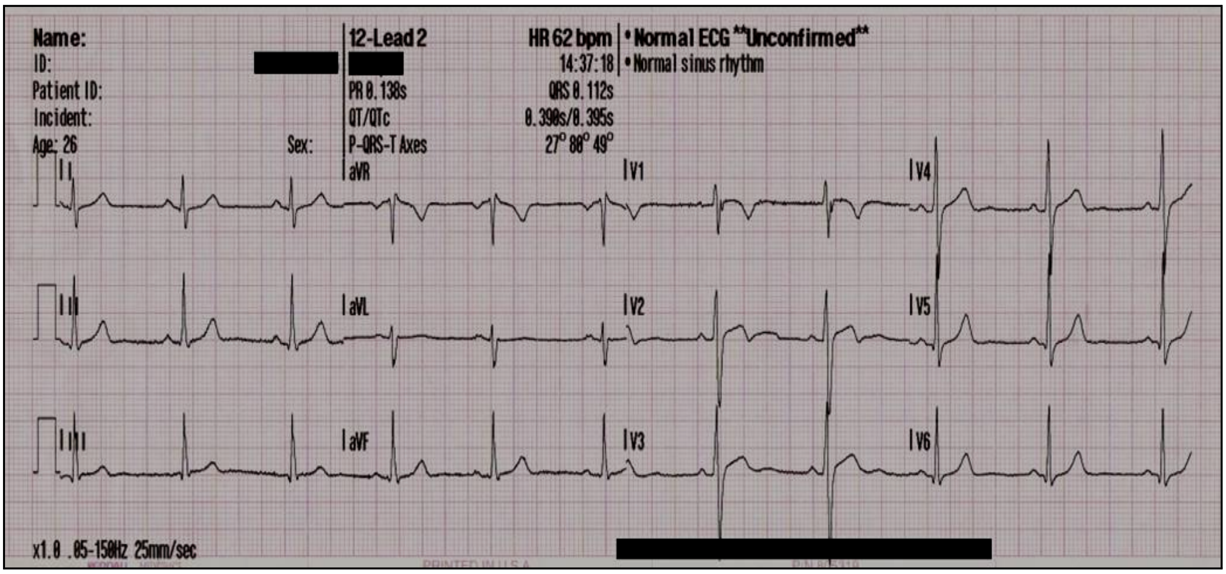


Fig 7: Electrocardiograph

In a conventional ECG, 10 electrodes are placed on the patient's limbs and on the surface of the chest. The overall magnitude of the heart's electrical potential is then measured from 12 different angles ("leads") and is recorded over a period of time (usually 10 seconds). In this way, the overall magnitude and direction of the heart's electrical depolarization is captured at each moment throughout the cardiac cycle. The graph of voltage versus time produced by this noninvasive medical procedure is referred to as an **electrocardiogram**.In a standard ECG, the P-wave represents the electrical **excitation (or depolarisation) of the atria**, which leads to the contraction of both the atria.

The QRS complex represents the **depolarisation of the ventricles**, which initiates the ventricular contraction. The contraction starts shortly after Q and marks the beginning of the systole.

The T-wave represents the return of the ventricles from excited to normal state (**repolarisation**). The end of the T-wave marks the end of the systole.

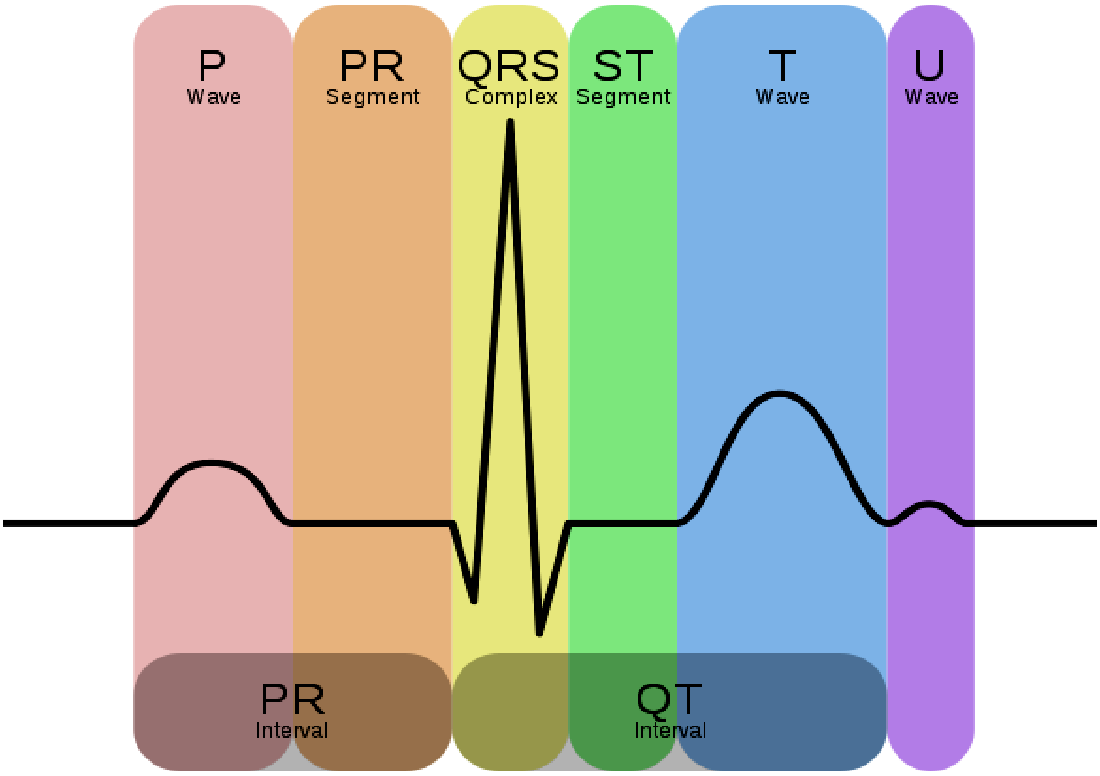


Fig 8: Waves of Electrocardiogram

Obviously, by counting the number of QRS complexes that occur in a given time period, one can determine the heart beat rate of an individual.

Since the ECGs obtained from different individuals have roughly the same shape for a given lead configuration, any deviation from this shape indicates a possible abnormality or disease. To the trained clinician, an ECG conveys a large amount of information about the structure of the heart and the function of its electrical conduction system. Among other things, an ECG can be used to measure the rate and rhythm of heartbeats, the size and position of the heart chambers, the presence of any damage to the heart's muscle cells or conduction system, the effects of cardiac drugs, and the function of implanted pacemakers. Hence, it is of a great clinical significance.

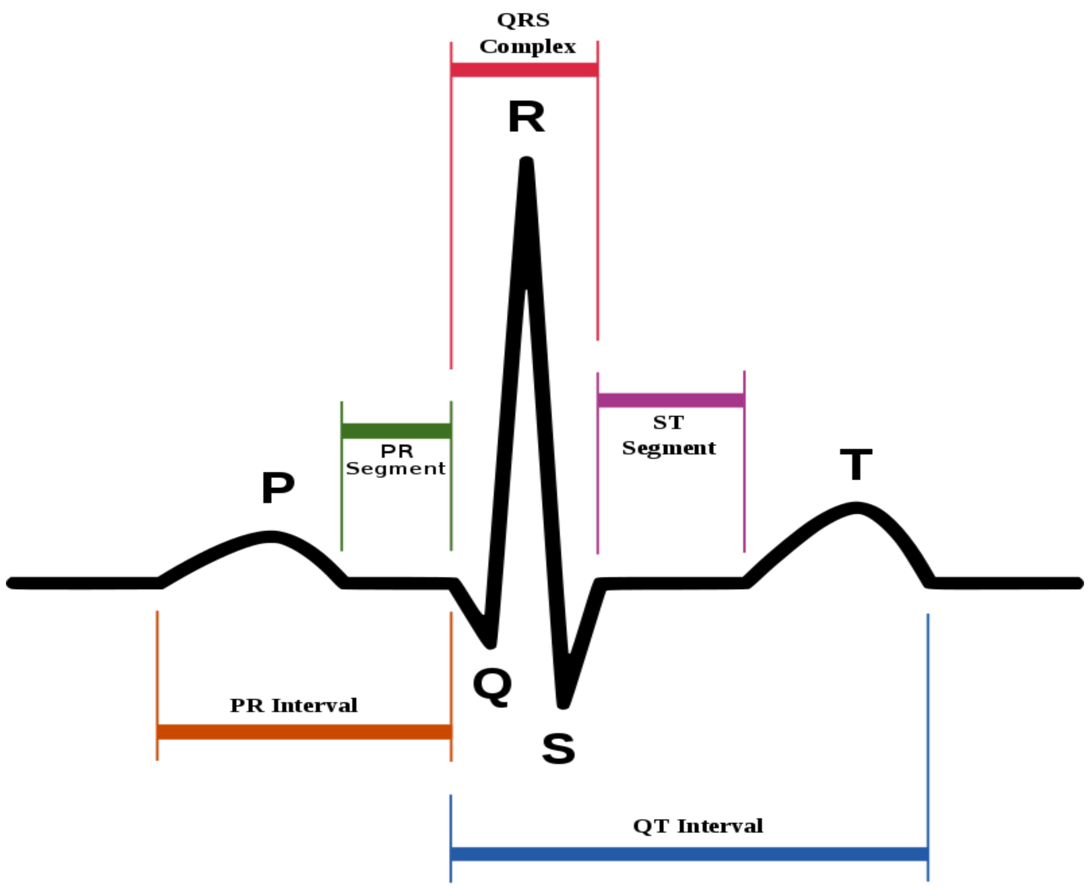


Fig 9: Regulation of Cardiac Activity

How Does the Heart Beat?

The atria and ventricles work together, alternately contracting and relaxing to make the heart beat and pump blood. The electrical system of our heart is the power source that makes this possible.

Our heartbeat is triggered by electrical impulses that travel down a special pathway through our heart.

- The impulse starts in a small bundle of specialized cells called the SA node (sinoatrial node), located in the right atrium. This node is known as the heart's natural pacemaker. The electrical activity spreads through the walls of the atria and causes them to contract.
- A cluster of cells in the center of the heart between the atria and ventricles, the AV node (atrioventricular node) is like a gate that slows the electrical signal before it enters the ventricles. This delay gives the atria time to contract before the ventricles do.

- The His-Purkinje network is a pathway of fibers that sends the impulse to the muscular walls of the ventricles, causing them to contract.

Normal activities of the heart are regulated intrinsically, i.e., auto regulated by specialised muscles (nodal tissue), hence the heart is called myogenic. A special neural centre in the medulla oblongata can moderate the cardiac function through autonomic nervous system (ANS). Neural signals through the sympathetic nerves (part of ANS) can increase the rate of heart beat, the strength of ventricular contraction and thereby the cardiac output. On the other hand, parasympathetic neural signals (another component of ANS) decrease the rate of heart beat, speed of conduction of action potential and thereby the cardiac output.

Cardiac output is a term used in cardiac physiology that describes the volume of blood being pumped by the heart, in particular by the left or right ventricle, per unit time. Cardiac output is the product of the heart rate (HR), which is the number of heart beats per minute, and the stroke volume (SV), which is the volume of blood pumped from the ventricle per beat; thus, CO = HR × SV. Cardiac output values can be represented using many physical units, such as dm^3/min, but is usually denoted as L/min. In a subject weighing 70 kg, the cardiac output at rest would be around 5 L/min; assuming a heart rate of 70 beats/min, the stroke volume would be approximately 70 mL.

Because cardiac output is related to the quantity of blood delivered to various parts of the body, it can be used as an important indicator of how efficiently the heart can meet the body's demands for perfusion. For instance, exercise requires a higher level of CO to support increased muscle activity. In heart failure, CO may be insufficient to even support simple activities of daily living and cannot increase sufficiently to match the higher metabolic demands stemming from even moderate exercise.Medullary hormones can also increase cardiac output.

Disorders of Circulatory System

Diseases affecting the cardiovascular system are called cardiovascular disease. Many of these diseases are called "lifestyle diseases" because they develop over time and are related to a person's exercise habits, diet, whether they smoke, and other lifestyle choices a person makes. Atherosclerosis is the precursor to many of these diseases.

Coronary Artery Disease (CAD): Coronary Artery Disease, often referred to as **atherosclerosis**, affects the vessels that supply blood to the heart muscle. It is caused by deposits of calcium, fat, cholesterol and fibrous tissues, which makes the lumen of arteries narrower. These small plaques build up in the walls of medium and large arteries. This may eventually grow or rupture to occlude the arteries. It is also a risk factor for acute coronary syndromes, which are diseases which are characterised by a sudden deficit of oxygenated blood to the heart tissue.

High Blood Pressure (Hypertension): Hypertension is the term for blood pressure that is higher than normal (120/80). In this measurement 120 mm Hg (millimetres of mercury pressure) is the systolic, or pumping, pressure and 80 mm Hg is the diastolic, or resting, pressure. If repeated checks of blood pressure of an individual is 140/90 (140 over 90) or higher, it shows hypertension. High blood pressure leads to heart diseases and also affects vital organs like the brain and kidney.

Angina: It is also called 'angina pectoris'. A symptom of acute chest pain appears when not enough oxygen is reaching the heart muscle. Angina can occur in men and women of any age but it is more common among the middle-aged and elderly. It occurs due to conditions that affect the blood flow.

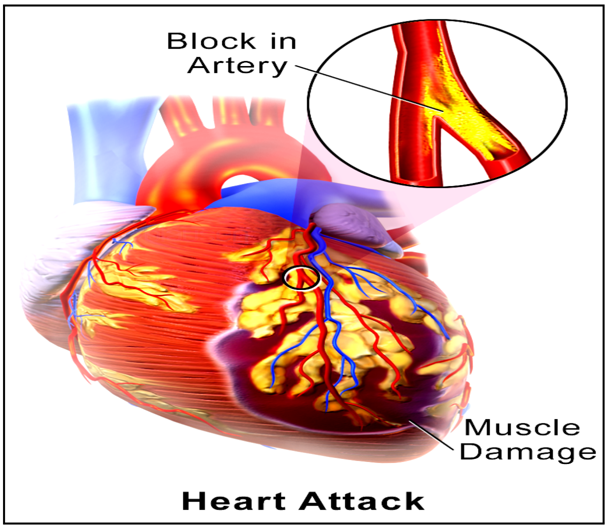


Fig 10: Heart Attack

Heart Failure: Heart failure means the state of heart when it is not pumping blood effectively enough to meet the needs of the body. It is sometimes called congestive heart failure because congestion of the lungs is one of the main symptoms of this disease. Heart failure is not the same as cardiac arrest (when the heart stops beating) or a heart attack (when the heart muscle is suddenly damaged by an inadequate blood supply).

Another major cardiovascular disease involves the creation of a clot, called a "thrombus". These can originate in veins or arteries. Deep venous thrombosis, which mostly occurs in the legs, is one cause of clots in the veins of the legs, particularly when a person has been stationary for a long time. These clots may embolise, meaning travel to another location in the body. The results of this may include pulmonary embolus or stroke.

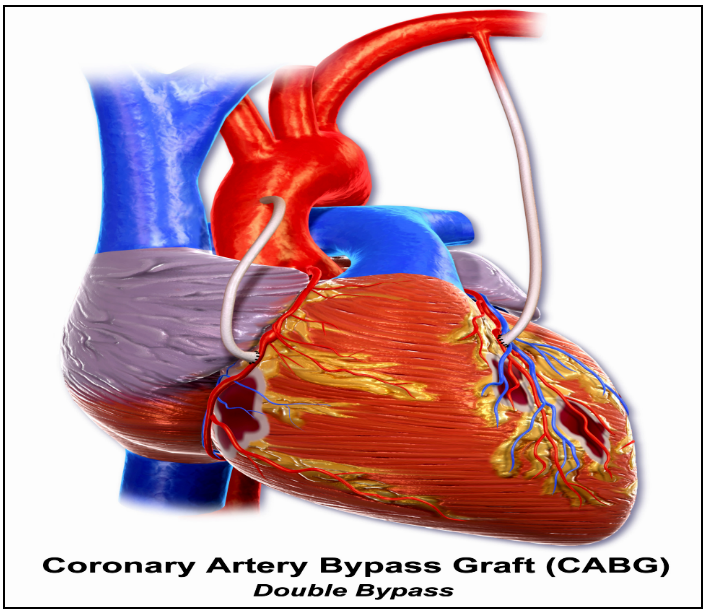


Fig 11: Coronary Artery Bypass Graft

Here is a list of some more heart disorders in brief:

- **Enlarged heart (cardiomegaly):** An enlarged heart can have various causes. But it's usually caused by high blood pressure (hypertension) or coronary artery disease.
- **Irregular Heart Rhythm:** Irregular heart rhythm – arrhythmia – is when our heart doesn't keep up a good beat.
- **Atrial Fibrillation:** It's the most common kind of irregular heartbeat. Irregular heart rhythms can cause the pumping function of the heart to fail.
- **Heart Valve Disease:** We may not know what a heart valve is – until it stops working right. It's a common form of heart disease.
- **Sudden Cardiac Death**:This is the cause of half of all heart disease deaths.
- **Congenital Heart Disease:** Not everyone gets heart disease. Some are born with it.

- **Heart Muscle Disease (Cardiomyopathy):** Heart muscle disease – what doctors call cardiomyopathy – is as serious as it sounds.
- **Heart Murmurs:** Most heart murmurs are innocent: They are caused by blood flowing through healthy valves in a healthy heart and do not require treatment. However, heart murmurs can be caused by blood flowing through a damaged or overworked heart valve.

Cardiovascular diseases may also be congenital in nature, such as heart defects or persistent fetal circulation, where the circulatory changes that are supposed to happen after birth do not. Not all congenital changes to the circulatory system are associated with diseases, a large number are anatomical variations.

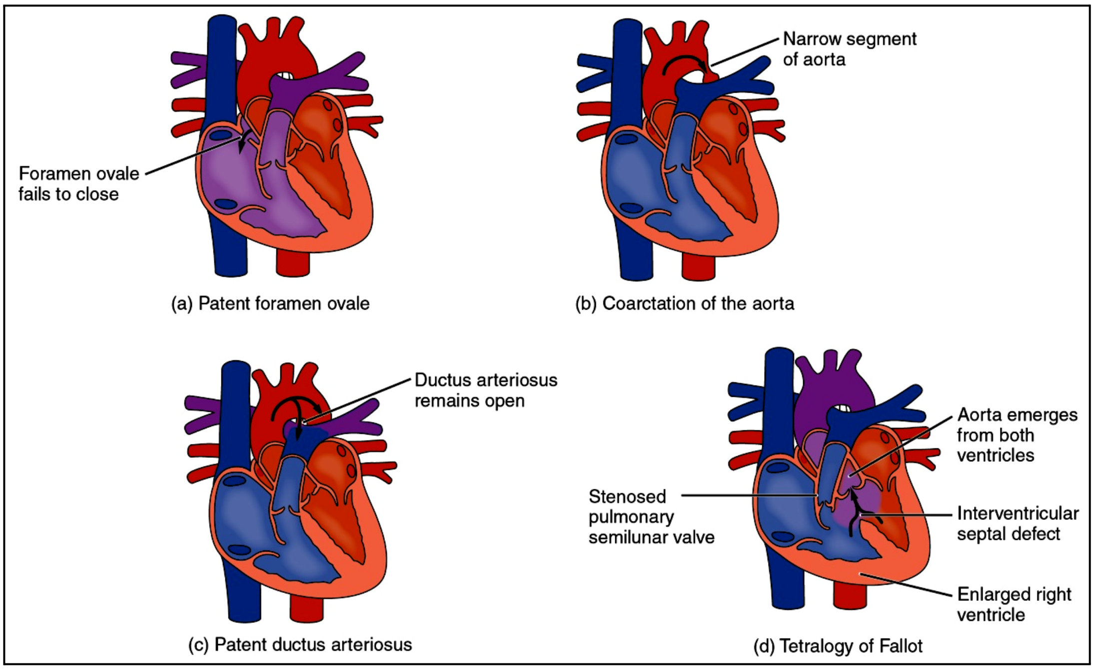


Fig 12: Congenital Heart Defect

Summary

All vertebrates and a few invertebrates have a closed circulatory system. Our circulatory system consists of a muscular pumping organ, heart, a network of vessels and a fluid, blood. Cardiac musculature is auto-excitable. Sino-atrial node (SAN) generates the maximum number of action potentials per minute (70-75/min) and therefore, it sets the pace of the activities of the heart. Hence, it is called the Pacemaker. The action potential causes the atria and then the ventricles to undergo contraction (systole) followed by their relaxation (diastole). The systole forces the blood to move from the atria to the ventricles and to the pulmonary artery and the aorta. The cardiac cycle is formed by sequential events in the heart which are cyclically repeated and is called the cardiac cycle. A healthy person shows 72 such cycles per minute. About 70 mL of blood is pumped out by each ventricle during a cardiac cycle and it is called the stroke or beat volume. Volume of blood pumped out by each ventricle of the heart per minute is called the cardiac output and it is equal to the product of stroke volume and heart rate (approx 5 litres). The electrical activity of the heart can be recorded from the body surface by using electrocardiograph and the recording is called electrocardiogram (ECG) which is of clinical importance. Though the heart is auto-excitable, its functions can be moderated by neural and hormonal mechanisms.