

# BODY FLUIDS AND CIRCULATION

**Circulation** is the transport of nutrients, oxygen, CO<sub>2</sub> and excretory products to the concerned tissues or organs.

For circulation, simple organisms (**sponges, coelenterates etc.**) use water from their surroundings. Complex organisms use body fluids (**blood & lymph**) for circulation.

## CIRCULATORY PATHWAYS

Circulatory system is 2 types- **Open** and **Closed**.

- **Open circulatory system:** Here, the blood pumped by the heart passes through large vessels into open spaces or cavities called **sinuses**. E.g. Arthropods and molluscs.
- **Closed circulatory system:** Here, the blood pumped by the heart is always circulated through blood vessels. This system is more advantageous as the flow of fluid can be more precisely regulated. E.g. Annelids and chordates.

All vertebrates have a muscular chambered heart.

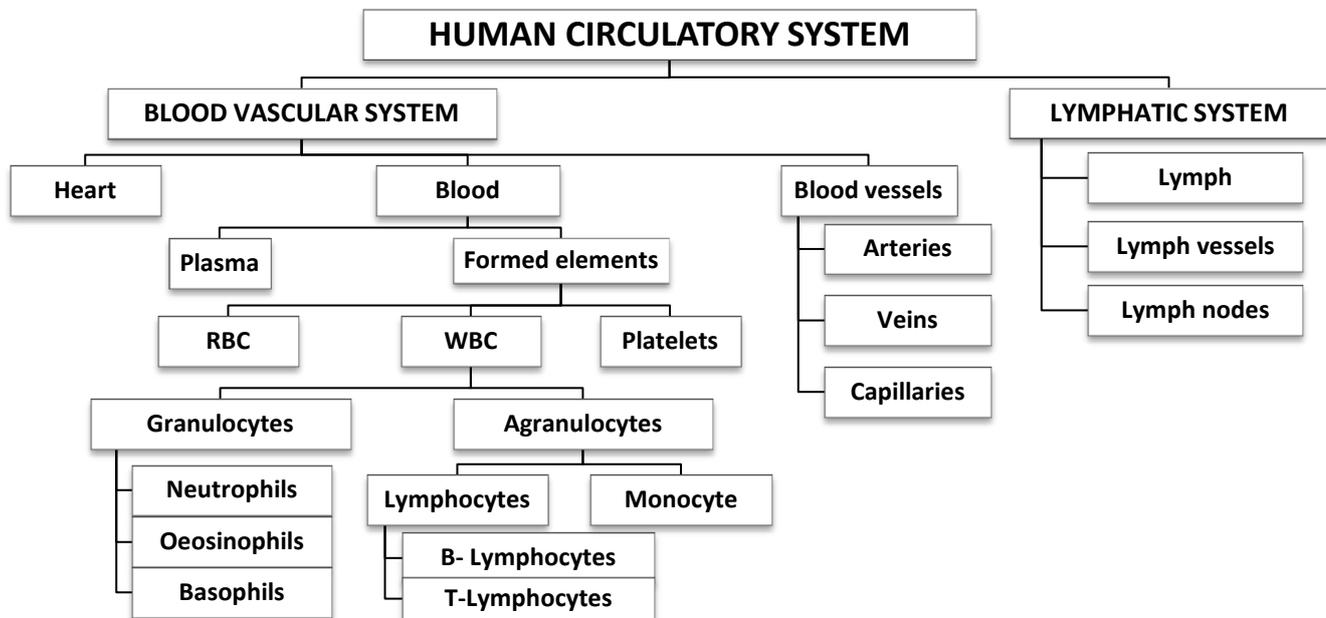
- **Fishes:** 2-chambered heart (an atrium + a ventricle).
- **Amphibians:** 3-chambered heart (2 atria + a ventricle).
- **Reptiles (except crocodiles):** 3-chambered heart (2 atria + a ventricle). Ventricle is incompletely partitioned.
- **Crocodiles, birds & mammals:** 4-chambered heart.

➤ **Single circulation in fish:** In fishes, heart receives impure blood only (*venous heart*).

Deoxygenated blood from heart → oxygenated by gills → supplied to body parts → deoxygenated blood → to heart.

➤ **Incomplete double circulation in amphibians & reptiles:** Left atrium receives oxygenated blood from the gills/lungs/skin and right atrium gets the deoxygenated blood from other body parts. However, they get mixed up in the single ventricle which pumps out mixed blood.

➤ **Double circulation in birds & mammals:** Oxygenated and deoxygenated blood received by the left and right atria respectively passes on to ventricles of the same sides. The ventricles pump it out separately without any mixing up.



## BLOOD VASCULAR SYSTEM

It includes Heart, Blood vessels & Blood.

### BLOOD

Formed of **plasma** (55%) & **formed elements** (45%).

#### a. Plasma

Straw-coloured, slightly alkaline (pH 7.4) viscous fluid.

#### Constituents of plasma

- **Water (90-92%):** It is a good solvent.
- **Plasma proteins (6-8 %):** Include
  - **Fibrinogen:** For blood coagulation.
  - **Globulins:** Act as antibodies (for defense of the body).
  - **Albumins:** For osmotic balance. Regulate blood pressure.
- **Glucose, amino acids, lipids & cholesterol**
- **Inorganic constituents:** Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup> etc.
- **Gases** like CO<sub>2</sub>, O<sub>2</sub>, N<sub>2</sub> etc.

Plasma without clotting factors is known as **Serum**.

#### b. Formed elements (RBC, WBC & platelets)

##### ▪ Red Blood Cells (RBC) or Erythrocytes:

- Biconcave non-nucleated cells. No mitochondria, Golgi complex etc. Red colour is due to **Haemoglobin** (iron containing protein). Normal Hb level is 12-16 g/ 100 ml.
- **Count:** 5 - 5.5 millions/ mm<sup>3</sup>.
- **Formed in:** Red Bone marrow.
- **Average lifespan:** 120 days. Worn-out RBCs are destroyed in **spleen** (graveyard of RBCs).
- **Function:** CO<sub>2</sub> and O<sub>2</sub> transports.

##### ▪ White Blood Cells (WBC) or Leucocytes:

- Colourless nucleated cells. Different types.
- **Count:** 6000-8000 /mm<sup>3</sup>.
- **Formed in:** Bone marrow, lymph glands, spleen.
- **Average lifespan:** Generally short lived (1- 15 days).
- **Function:** Part of immune system.

## Types of WBC: Granulocytes & Agranulocytes

### 1. Granulocytes

They are 3 types:

- Neutrophils (Heterophils):** 60-65%. Soldier of the body.  
Function: Phagocytosis.
- Eosinophils (Acidophils):** 2-3%. Resist infections.  
Cause allergic reactions.
- Basophils (Cyanophils):** 0.5-1%. Secrete histamine, serotonin, heparin etc. Cause inflammatory reactions.

### 2. Agranulocytes

They are 2 types:

- Lymphocytes (20-25%):** Smallest WBC with largest nucleus. Includes **B- lymphocytes & T- lymphocytes**.  
Cause immune responses. Secrete antibodies.
- Monocytes (6-8%):** Largest WBC.  
Function: Phagocytosis.

## BLOOD GROUPS (ABO grouping & Rh Grouping)

Blood groups were discovered by **Carl Land Steiner**.

### 1. ABO grouping

It is based on presence or absence of 2 surface **antigens** (chemicals that induce immune response) on **RBCs** namely **A & B**. Similarly, **plasma** contains 2 **antibodies** (proteins produced in response to antigens) namely **anti-A & anti-B**.

Blood group	Antigens	Antibodies	Can donate blood to	Can receive blood from (Donor's group)
A	A	Anti-B	A & AB	A, O
B	B	Anti-A	B & AB	B, O
AB	A, B	Nil	AB only	A, B, AB & O
O	Nil	Anti-A & Anti-B	A, B, AB & O	O only

- Antigen A reacts with anti-A. Antigen B reacts with anti-B.
- If bloods with interactive antigens & antibodies are mixed together, it causes **clumping (agglutination)** of RBCs.
- Persons with **O Group** are called **Universal donors** because they can donate blood to persons with any other blood group. Persons with **AB group** are called **Universal recipients** because they can accept blood from all groups.

### 2. Rh grouping

- **Rhesus (Rh)** factor is another antigen found on RBC.

### ▪ Platelets (Thrombocytes):

- Colourless non-nucleated cell fragments.
- **Count:** 1.5 - 3.5 lakhs /mm<sup>3</sup>.
- **Formed in:** Megakaryocytes in Bone marrow.
- **Average lifespan:** 7 days.
- **Function:** Blood clotting.

## BLOOD COAGULATION

It is a mechanism for **haemostasis** (prevention of blood loss through injuries). It involves the following events:

Clumped **platelets & tissues** at the site of injury release **thromboplastin** → It forms an enzyme, **thrombokinase (Prothrombinase)** → **Thrombokinase** hydrolyses **prothrombin** to **thrombin** in presence of **Ca<sup>2+</sup>** → **Thrombin** converts soluble **fibrinogen** to insoluble **fibrin** → **Fibrin** traps dead & damaged formed elements to form **clot (coagulum)**.

- **Rh+ve** means the presence of Rh factor and **Rh-ve** means absence of Rh factor. Nearly **80%** of humans are Rh+ve.
- **Anti-Rh antibodies** are not naturally found. So Rh-ve person can receive Rh+ve blood only once but it causes the development of anti-Rh antibodies in his blood. So a second transfusion of Rh+ve blood causes **agglutination**. Therefore, Rh-group should be matched before transfusion.

## Erythroblastosis foetalis

- It is an **Rh incompatibility** between the Rh-ve blood of a pregnant mother and Rh+ve blood of the foetus.
- Rh antigens do not get mixed with maternal blood in first pregnancy because placenta separates the two bloods.
- But during first delivery, the maternal blood may be exposed to small amount of foetal blood (Rh+ve). This induces the formation of Rh antibodies in maternal blood.
- In case of her subsequent pregnancies, the Rh antibodies from the mother leak into the foetal blood (Rh+ve) and destroy the foetal RBCs. This is fatal to the foetus or cause severe **anaemia** and **jaundice** to the baby. This condition is called **Erythroblastosis foetalis**.
- It can be avoided by administering **anti-Rh antibodies** to the mother immediately after the first delivery.

## BLOOD VESSELS

Blood vessels are 3 types: Arteries, Veins & Capillaries.

- **Arteries:** They carry blood from heart to other tissues. They contain oxygenated blood (except pulmonary artery). Their smaller branches are called **arterioles**. Arteries are 3-layered- inner **tunica intima** (squamous endothelium), middle **tunica media** (smooth muscles & elastic fibres) and outer **tunica externa** (fibrous connective tissue).

- **Veins:** They carry blood towards heart. They contain deoxygenated blood (except pulmonary vein). Their smaller branches are called **venules**. Veins are also 3-layered but tunica media is comparatively thin.
- **Capillaries:** In tissues, arterioles divide into thin walled and single layered vessels. They are called capillaries. They unite into venules.

## STRUCTURE OF HEART

- Heart is a **mesodermally** derived organ located in **mediastinum** and protected by double-layered **pericardium**.
- The **pericardial space** (between pericardial membranes) is filled with **pericardial fluid**. It reduces the friction between the heart walls, and surrounding tissues.

- The heart is 4 chambered, two upper **atria (auricles)** and two lower **ventricles**. The walls (**cardiac muscles**) of the **ventricles** are much **thicker** than that of the atria.
- The atria are separated by an **inter-atrial septum** and the ventricles are separated by **inter-ventricular septum**.

- In between atrium and ventricle there is a thick fibrous **atrio-ventricular septum** with an opening.
- A **tricuspid valve** (3 muscular flaps or cusps) guards the opening between right atrium and right ventricle. A **bicuspid (mitral) valve** guards the opening between left atrium and left ventricle. These valves allow the flow of blood only in one direction, i.e. from atria to ventricles.
- The openings of right and left ventricles into **pulmonary artery** and **aorta** respectively are provided with the **semilunar valves**. They prevent backwards flow of blood.

### CONDUCTING SYSTEM OF HEART

- Human heart is **myogenic**, i.e. normal activities of heart are auto regulated by **nodal tissues** (a specialized cardiac musculature present in heart wall). It consists of

- o **Sino-atrial node (SAN)** in the right upper corner of the right atrium.
- o **Atrio-ventricular node (AVN)** in the lower left corner of the right atrium close to the **atrio-ventricular septum**.
- From the AVN, a bundle of fibrous **atrio-ventricular bundle (AV bundle)** passes through **atrio-ventricular septa** and divides into a right & left branches. Each branch passes through the ventricular walls of its side. In the ventricular wall, it breaks up into minute fibres (**Purkinje fibres**). These fibres along with the bundles are known as **bundle of His**.
- **Nodal tissues** generate **action potential** without any external stimuli, i.e. it is **autoexcitable**. SAN initiates and maintains contraction of heart by generating action potentials (**70-75/min**). So it is called the **pacemaker**.

### CARDIAC CYCLE

- **Joint diastole:** It is the relaxed state of all chambers of heart. When the **tricuspid** and **bicuspid valves** open, blood from **pulmonary vein** and **vena cava** flows into **left & right ventricles** respectively through **left** and **right atria**. **Semilunar valves** are **closed** at this stage.
- **Atrial (Auricular) systole:** SAN generates an **action potential**. As a result both the atria contract. It is called **atrial systole**. This increases the flow of blood into the ventricles by about **30%**.
- **Ventricular systole:** The action potential is conducted to ventricular side by **AVN & AV bundle** from where **bundle of His** transmits it through the **ventricular musculature**. As a result, ventricles contract. It is called ventricular systole. During this, the atria undergo diastole. **Ventricular systole** increases the **ventricular pressure** causing
  - \* Closure of **tricuspid** and **bicuspid valves** due to attempted backflow of blood into the atria.
  - \* Semilunar valves open. So deoxygenated blood enters the **pulmonary artery** from **right ventricle** and oxygenated blood enters the **aorta** from **left ventricle**.

The ventricles now relax (**ventricular diastole**) and the **ventricular pressure** falls causing

- \* The closure of the **semilunar valves** which prevents the backflow of blood into the ventricles.
- \* The **tricuspid** and **bicuspid valves** are opened by the pressure in the atria.

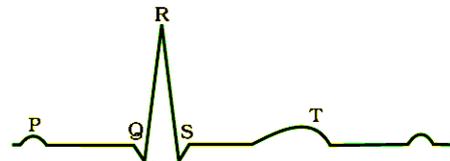
The ventricles and atria again undergo joint diastole and the above processes are repeated. This is called **cardiac cycle**. A cardiac cycle (atrial systole + ventricular systole + diastole) is completed in **0.8 seconds**.

- **One heartbeat = a cardiac cycle.** So number of normal heartbeat: **70-75 times/min (average: 72/min)**.
- **Stroke volume:** It is the volume of blood pumped out by each ventricle during a cardiac cycle. It is about **70 ml**.
- **Cardiac output:** It is the volume of blood pumped out by each ventricle per minute, i.e. **stroke volume x heart rate (70 x 72)**. It is about **5000 ml (5 litres)**.  
Cardiac output of an athlete is very high.

- **Heart sounds:** During each cardiac cycle, 2 sounds are produced. The first sound (**lub**) is due to the closure of **tricuspid** and **bicuspid valves**. The second sound (**dub**) is due to the closure of the **semilunar valves**.  
*One heartbeat = a lub + a dub.*

### ELECTROCARDIOGRAPH (ECG)

- It is an instrument used to obtain **electrocardiogram** (*graphical representation* of the *electrical activity* of the heart during a cardiac cycle).
- To get an ECG, a patient is connected to the machine with **3 electrical leads** (one to each wrist and to left ankle) that monitor heart activity. For a detailed evaluation of heart's function, multiple leads are attached to the chest region.
- An ECG consists of the following waves:
  - o **P-wave:** Represents the excitation (**depolarization**) of atria which causes **atrial systole**.
  - o **QRS-complex:** Represents **depolarization** of ventricles (**Ventricular systole**).
  - o **T-wave:** Represents the **repolarisation** of ventricles.



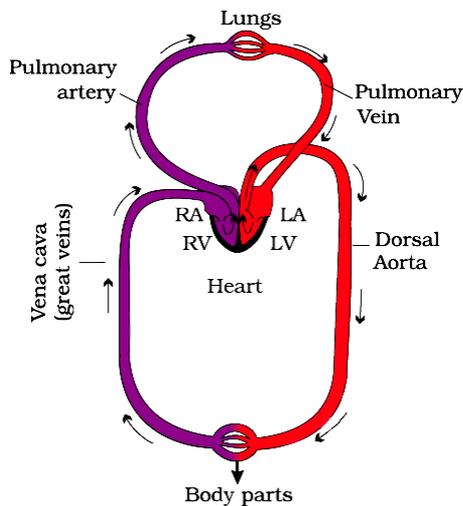
Deviation in the **ECG** indicates the abnormality or disease. So ECG has great clinical significance.

### DOUBLE CIRCULATION

In man, blood flows through the heart twice for completing its circuit. This is called **double circulation**. It includes,

1. **Pulmonary circulation:** Circulation b/w lungs and heart. The **deoxygenated blood** pumped into the **pulmonary artery** is passed on to **lungs** from where **oxygenated blood** is carried by **pulmonary veins** into the **left atrium**.
2. **Systemic circulation:** Circulation b/w heart and various body parts. The **oxygenated blood** is passed through **aorta, arteries, arterioles** and **capillaries** and is reached the **tissues**. The **deoxygenated blood** collected from the tissues by **venules, veins** and **vena cava** is carried to the **right atrium**. The systemic circulation provides nutrients,

O<sub>2</sub> and other essential substances to the tissues and takes CO<sub>2</sub> and other harmful substances away for elimination.



- **Hepatic portal system:** It is a system which includes the *hepatic portal vein* that carries blood from *intestine* to the *liver* before it is delivered to the systemic circulation.
- **Coronary circulatory system:** It is a system of *coronary vessels* that circulate blood to and from the *cardiac musculature*.

### REGULATION OF CARDIAC ACTIVITY

- Normal activities of heart are auto-regulated by *nodal tissues*. So it is called **myogenic heart**.
- *Medulla oblongata* regulates cardiac activity through ANS.
- *Sympathetic nerves* of ANS increase the rate of heartbeat, the strength of ventricular contraction and cardiac output.
- *Parasympathetic nerves* of ANS decrease the heartbeat, conduction of action potential and the cardiac output.
- *Adrenal medullary hormones* increase the cardiac output.

### LYMPHATIC SYSTEM

- It includes **Lymph, Lymph vessels & Lymph nodes**.
- As the blood passes through the capillaries in tissues, some water and soluble substances are filtered out from plasma to the intercellular spaces, to form **tissue fluid**. It has same mineral distribution as that in plasma.
- Exchange of nutrients, gases, etc. between the blood and the cells occur through tissue (interstitial) fluid.
- Some tissue fluid enters **lymphatic system** (a system of **lymph vessels** and **lymph glands**) and the tissue fluid in them is called **lymph**. It drains back to the major veins.

- Lymph is a colourless fluid containing lymphocytes.

#### Functions of lymph

- It is the middleman between blood and tissues.
- It carries plasma proteins synthesized in liver to the blood.
- Transports digested fats (through lacteals in the intestinal villi), fat soluble vitamins, hormones etc.
- Filtration of bacteria and foreign particles.
- Lymph nodes produce WBC (lymphocytes) & antibodies.
- It helps in the defensive mechanism of the body.

### DISORDERS OF CIRCULATORY SYSTEM

- **Hypertension (High Blood Pressure):** Here, the blood pressure is higher than normal *systolic (pumping) pressure* (120 mm Hg) and normal *diastolic (resting) pressure* (80 mm Hg), i.e. above **120/80 mm Hg**. If the BP is **140/90 or above**, it is *hypertension*. It leads to *heart diseases* and also affects *vital organs* (brain, kidney etc).
- **Coronary Artery Disease (CAD) or Atherosclerosis:** Here, **Ca, fat, cholesterol** and **fibrous tissue** are deposited in **coronary arteries**. It makes the lumen of arteries narrower and thereby affects the blood supply.

- **Angina (angina pectoris):** An *acute chest pain* due to *O<sub>2</sub> deficiency* to heart muscles. It occurs due to improper blood flow. It is common among middle-aged and elderly.
- **Heart Failure (congestive heart failure):** It is the condition in which heart is not pumping blood enough to meet the needs of the body. Congestion of the lungs is the main symptom. Heart failure is not same as **cardiac arrest** (heart stops beating) or a **heart attack** (sudden damage of heart muscle due to inadequate blood supply).