VASCULAR SYSTEMS IN ANIMALS

Vascular systems in animals share the following basic features

1. A circulatory fluid: most common one is blood though higher organisms contain lymph as an addition
2. A pump organ: the heart
3. A system of tubes through which the circulatory fluid can move

Functions of circulatory system

The circulatory system may differ in various animals but carries out the same basic functions.

1. Transport of nutrients. It transports all soluble food compounds from the area of absorption to different parts of the body for storage, assimilation or synthesis of new components.
2. Transport of waste products: it transports all the excretory products produced as a result of cellular activities from all over the body to the organs of excretion (like kidney in man)
3. Transport of intermediate metabolites: it transports all the byproducts or intermediate products from the tissues they are produced to the organs where they can be metabolized (like lactic acid produced in muscles is transported to the live for oxidation.
4. Transport of hormones: since hormones are produced by ductless glands, they are transported through the circulatory fluid to their target organs.
5. Uniform distribution of heat: since circulatory fluid connects to all parts of the body it picks up heat from one part and dissipates it on the surface bringing about the uniform distribution.
6. Transport of water, inorganic ions and various chemicals is also done by the circulatory fluid so as to maintain a uniform distribution
7. Defense against diseases: the circulating fluid contains blood cells responsible for body defense
8. Transport of respiratory gases: in some animals the circulatory fluid contains respiratory pigments which may be dissolved in plasma like in snails, crustaceans or cephalopods or present in cells like in all vertebrates including man. The oxygen is transported from respiratory organs to respiring tissues while carbon dioxide is carried from tissues to respiratory organs. Some animals like insects have tracheal system for respiration and circulatory system is not directly associated with respiration. More so it lacks any respiratory pigment

Types of circulatory systems in animals

1. Water circulation system: it exists in lower animals like sponges and hydra where water from the surrounding medium acts as a circulatory a circulatory fluid.
   (a) Canal system: it exists in poriferans like sponges. They have a system of tubes called canal system which could be simple or complex depending on the organization of the sponge. All canals ultimately communicate to the exterior through the numerous pores called Ostia. The body of the sponge is in form of a cylinder enclosing a cavity called spongocoel with a large opening called osculum.

   The beating of flagella lining the canals causes the current of water to enter through Ostia which are like inhalant siphon. The current of water bring in food and oxygen for the sponge. The current of water brings in food and oxygen for the sponge. As the water moves through the various canals, food is taken in and wastes are given out and finally the water leaves the sponge through the osculum i.e. exhalent siphon.

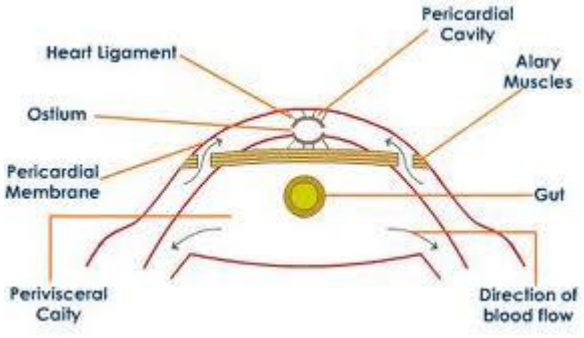
   Water in → ostia → canals → spongocoel → osculum → water out

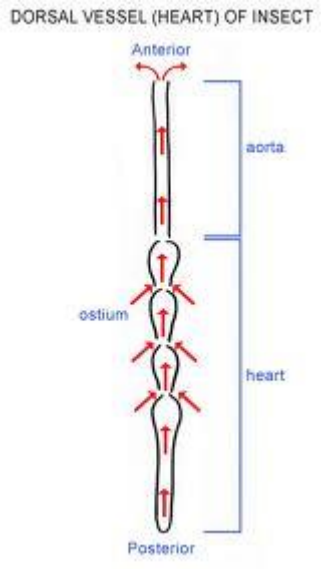
   (b) coelenterons water filled cavity: all coelenterates posses a single large cavity called coelonteron lined by endodermal cells. This cavity has a single opening through which water enters and leaves the animal.
   The water carrying food and oxygen passes in through the mouth and circulates through the coelenteron. After collecting the wastes and carbon dioxide the water leaves the coelenteron through the same mouth opening. The flagellated cells of the endoderm direct the movement of water.

2. **Blood vascular system**
   It exists in all higher animals where the heart and blood vessels together with the circulatory fluid (blood) constitutes a blood vascular system.
   The heart Pumps and conducts the circulatory fluid to various tissues. Arteries take blood away from the heart and veins bring blood back to the heart.
   The higher invertebrates and vertebrates have two types of circulatory systems
   (i) Open circulatory system and (ii) closed circulatory system

   The open circulatory system: this is a system where blood is not confined to blood vessels through the course of its circulation in the body. It fills in open spaces known as the **haemocoel.** The blood is pumped at relatively low pressure from the heart into the main body cavity called the haemocoel. The blood bathes the cells directly and only slowly percolates through the tissues

The open vascular system of an insect





As shown above the only blood vessel is the heart which is tubular and is perforated by tiny holes called Ostia. It is suspended by slender ligaments attached to the pericardial membranes on one and body wall on the other. It extends from the abdomen to the thorax and it is expanded to form a small chamber in each segment. At positions corresponding to these chambers of the heart in the pericardial membrane are muscles known as **alary muscles**. These muscles are responsible for aiding expansion of the heart after its contraction. During systole (contraction) waves of contraction take place in the heart and when it reaches the anterior chambers. This propels blood forward in the heart and when it reaches the anterior

Functions of the circulatory system of insects;

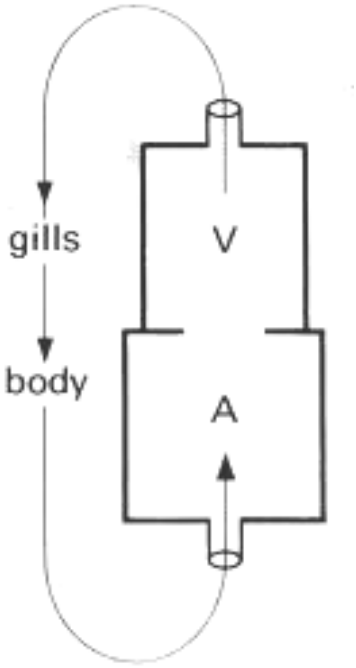
1. Transport of nutrients
2. To transport nitrogenous wastes to organs of elimination i.e. the malphigian tubules
3. To defend the body against disease causing organisms using phagocytes they contain.

Closed circulatory system

A closed circulatory system is one where blood is confined to blood vessels throughout its course of circulation in the body. Blood is moved by a muscular pump organ to the tissues of the body and back again. It is entirely through blood vessels and does not into contact with blood vessels and does not get in contact with the body cells. The body cells are instead directly in contact with a fluid derived from the blood at a higher pressure. This is present in vertebrates and higher invertebrates like annelids.
There are two types of closed circulatory systems;

(a) The single circulatory system: in this case the blood flows through the heart once in each complete circulation.
(b) The double circulatory system. In this case the blood flows twice in each complete circulation to the lungs.

Single circulation in fish



Deoxygenated blood flows the heart to a capillary network in the gills then to the tissues of the body and finally back to the heart. The heart in fish has a single atrium and ventricle.
The functions of the circulatory system in fish are similar to those of earthworms.

The single circulation of the earthworm

In the earthworm the circulatory fluid blood consists mainly of water in which are dissolved gases, sugars, amino acids, salts and many other molecules and ions taking part

in metabolism. The blood also has haemoglobin and this makes it able to carry oxygen. However this haemoglobin is not confined in blood cells but is dispersed in the blood. The circulatory system here consists of a system of large longitudinal blood vessels on both the dorsal and ventral parts of the body which end in capillaries where exchange of materials between the blood and organs like the skin, intestines, nephridia and other tissues takes place. In addition to these blood vessels there is a "heart" which in essence consists of five pairs of aortic loops whose walls are capable of muscular contraction. Blood is propelled from the aortic loops when muscles contract. Blood flows through vessels to organs and tissues where they terminate into capillaries. Once through the capillaries the blood is collected by a branching network of blood vessels leading into the dorsal blood vessel. This vessel contracts rhythmically forcing blood to flow forward to the anterior of the animal until it reaches the aortic loops and the cycle is repeated.

The functions of blood circulatory system of earthworm are;

1. Transport of; nutritive molecules, respiratory gases, nitrogenous wastes
2. Defence against diseases. The blood has amoebocytes which engulf any disease causing organisms in the blood.

Double circulatory system

This is one where blood passes through the heart twice in one complete circulation. This is a characteristic of all members of the vertebrata with the exception of the fish.
Blood entering the heart first flows to the lungs and back to the heart which is known as pulmonary circulation after which it is then pumped to the rest of the body. This is known as systemic circulation. For this reason higher blood pressure can be attained than in single circulation.

Double circulation in amphibians

The heart is three chambered with two atria and a single ventricle. The mixing of blood which would otherwise have occurred in the ventricle is prevented by the presence of spiral valve in the conus arteriosus. The extensive blood supply to the lungs and the skin via pulmocutanous blood vessels greatly increases the efficiency in transporting gases in addition to the presence of haemoglobin in the RBC. Again this is greatly enhanced by the structural arrangement of the circulatory system which ensures that blood is pumped to the skin and lungs where gas exchange occurs from the ventricles at the same pressure with that to the rest of the body.

Double circulation in mammals

Mammals have a complete double circulation. The heart is divided into a left and right section there ensuring complete separation of deoxygenated and oxygenated blood. The heart is therefore two pumps in one and this is why it is able to send out different

volumes of blood to different organs at different pressure. Both these pumps work simultaneously.

Advantages of a double closed circulatory system over open one

1. Relatively high pressure required for fast flow of blood is acquired than in open circulation
2. Since the blood is returned rapidly to the heart for pumping, more rapid circulation can be attained
3. The separation of oxygenated and deoxygenated blood in it improves efficiency of oxygen distribution and therefore sustain the high metabolic rate required by such animals
4. The blood is piped directly to where it is needed
5. The amount flowing to certain organ can be regulated by changing the diameter of the blood vessels.
6. blood cells and large molecules remain within vessels
7. can support higher levels of metabolic activity

Differences between open d closed circulatory system

Open circulatory system	**Closed circulatory system**
i) blood flows through large open spaces and channels called lacunae and sinuses among the tissues	i) blood flows through a system of closed chambers and tubes called the heart and blood vessels
ii) tissues are in direct contact with the blood	ii)..there is no direct communication with any tissue, open body cavity or space
iii) blood flows under very low pressure and moves slowly through the tissues	iii). By strong pumping action of the heart blood flows with great pressure in the arteries
iv) heart pumps oxygenated blood into an aorta which branches into number of arteries, which open into series of blood spaces and lacunae collectively known as haemocoel	iv). Heart pumps oxygenated blood to aorta which branches into a number of arteries, then to arterioles and finally to a network of capillaries all over the body.
v) Blood takes comparatively longer time to circulate through the whole body	v). blood takes a much shorter time to circulate through the body.

vi) Blood seeps out of the sinuses and is poured back into the heart through the open ended vein.	vi). Blood is collected by veins and is poured back into the heart through a tissue or organ can be regulated by contraction and relaxation of the smooth muscles of the arteries.
vii) Exchange of gases takes place directly between blood and tissues	vii). Nutrients and gases pass through the capillary wall to the tissues
viii) Volume of blood flowing through a tissue can not be controlled as blood flows out in open spaces	viii). Volume of blood flowing through a tissue or organ can be regulated by contraction and relaxation of the smooth muscles of the areries
ix) It is present in higher invertebrates like most arthropods, prawns, insects ec	ix). It is present in echinoderms, some mollusks, annelids and all vertebrates

Internal structure of the heart

The internal structure of the heart shows that the heart has two sides, the left side and right side. These are separated by a muscular wall known as septum.

The heart has the artria which collects blood from the body and pumps it to the lower chambers known as ventricles. The ventricles pump blood to the arteries and this is the reason why they have thick walls. The left ventricle which pumps blood to the rest of the body has a thicker and stronger wall than the right ventricle which pumps blood to the lungs which are a shorter distance away. The atria and ventricles are separated by valves. The valve on left side consists of two flaps and is known as bicuspid valve (mitral valve) while that on the right is known as tricuspid but collectively both are known as atrio ventricular valves. These valves are supported by strands of strong inelastic tissues known as tenderone chords or chordate tendinae. These prevent the valves from being turned inside out by the high pressure generated when ventricles contract. The bases of the arteries in the heart also have valves shaped like crescents and are commonly known as the semi lunar valves. However to be more specific the valves at the base of the aorta are known as aortic valves while those at the base of the pulmonary artery are known as pulmonary valves. All valves serve to prevent blood flowing in the wrong direction.

CARDIAC CYCLE

Rhythmic contraction and relaxation of the cardiac chambers i.e. the auricles and the ventricles in a specific manner during one heart beat constitutes a cardiac cycle.

Heart beats continuously without pause in life. Auricles and ventricles show rhythmic contractions and relaxations. On average heart beats 72 times per minute. Heart pumps about 5 litres of blood per minute.

Both auricles contract simultaneously and the blood flows into the ventricles and both ventricles contract together forcing the blood into pulmonary artery and aorta.

Terms

Systole. Refers to the contraction of the cardiac chambers and as a result the heart contracts forcing the blood into the pulmonary artery and the aorta.

Diastole. This refers to the relaxation of the cardiac chambers hence enabling the heart to refill

Joint diastole. This refers to the relaxed state of both atria and ventricles

Sequence of changes in cardiac chambers during one cardiac cycle

Atrial filling and joint diastole

i) Atrial filling and joint diastole.

- Filling of right atrium (RA) with deoxygenated blood from the great veins and left atrium (LA) with oxygenated blood from pulmonary vein.
- As the pressure increases in the atria, the bicuspid and tricuspid valves open and blood flows into the respective relaxed ventricles
- The semilunar valves remain closed because of the low pressure and blood does not flow out of the ventricles.

ii) Atrial systole and ventricular diastole

- At the end of joint diastole, next heart beat begins.
- The two atria contract, forcing most of the blood into the ventricles
- Simultaneous closing of great great vein roots (superior and inferior vena cava) by compression occurs
- Bicuspid and tricuspid valves are open
- It lasts for about 0.15 seconds

iii) Ventricular systole (VS) and atrial diastole (AD)

- Sharp closing of A.V valves to stop backflow of blood to ventricles. this produces the first heart sound lubb.
- Rise of the ventricular pressure but it is still lower than the pressure in the great arteries- the pulmonary artery and aorta and hence the semi lunar valves are still closed.
- Ventricles contract as closed chambers and then the ventricular pressure exceeds the pressure in the pulmonary artery and aorta forcing the opening of valves.
- Blood flows from ventricles to great arteries
- It lasts for about 0.25 seconds

iv) Ventricular diastole and atrial diastole (beginning of joint diastole)

- Ventricles relax and the pressure falls below to that in the great arteries

- Closing of the semilunar in the pulmonary artery and aorta produces the second heart sound- **dub.**
- This prevents backflow of blood into ventricles.
- As the low ventricular pressure is still greater than the atrial pressure , the AV valves remain closed
- Continued ventricular diastole decreases the pressure trmndously and now both atria and ventricles are in joint diatole.
- This lasts for about 0.4 seconds

One complete systole and diastole (described above) forms a cardiac cycle which takes about 0.8 seconds. The new cardiac cycle begins with the atrial systole.
In each cardiac cycle there is a louder lubb heart sound during ventricular systole and a fainter dub sound during ventricular diastole.

Check in functional approach

Comparison of atrial and ventricular systole

Atrial systole	**Ventricular systole**
(i) Contraction of atria and relaxation of ventricles	Contraction of ventricles and relaxation of atria
(ii) Bicuspid and tricuspid valves open	Bicuspid and tricuspid valve are closed
(iii) Closing of great vein roots and no sound is produced. AV valves are open	Closing of AV valves produces the first heat sound lubb
(iv)Blood is poured into ventricles	Blood is pumped out in great arteries
(v) Lasts for about 0.15 seconds	Lasts for about 0.25 seconds

Mitral valve	Semilunar valve
- Also referred as bicuspid since it consists of 2 flaps.	(i) Valves consist of 3 flaps.
(ii) Guards the opening of left auriculo-ventricular	(ii) Present at the base of pulmonary and aorta and at regular intervals in veins.
(iii) Allows the blood to move from left to left ventricle.	(iii) In the heart they allow the blood to from ventricles to great arteries and in the veins allow the blood to flow the heart.
(iv) Valves are attached to chordae which prevent them from being out.	(iv) Valves are attached to the wall of the blood vessel. No chordae tendinae are present.

Control of the heart beat

All vertebrates hearts are myogenic in nature, meaning their heart beat is initiated from within the heart muscles. In insects it is initiated by the nerves outside the heart and is known as neurogenic.

The initial stimulus for a heart beat originates from a group of cardiac muscles known as the Sino Atrial node (SA node). This is located in the wall of of the right atrium near where the venae cavae enter. The SA node determines the basic rate of heart beat and is therefore known as the pacemaker. In humans, this basic rate is 70 beats/minute but can be adjusted according to demand by stimulation from autonomic nervous system.

A wave of excitation spreads out from the SA node across the atria, causing them to contract more or less at the same time.

The wave of excitation reaches a similar group of cells known as the Atrio-ventricular node (AV node) which lies between the two atria. To allow blood to be forced upwards into the arteries, the ventricles need to contract from the apex upwards. To achieve this, the new wave of excitation from the AV node is conducted along purkyne fibres, which collectively make a bundle of His. These fibres lead along the interventricular septum to the apex of the ventricles, from where they radiate upwards.

Heart Rate, Arterial Pulse and Blood Pressure

(i) **Heart rate** - It refers to the number of times the heart beats per minute.

Heart rate of humans	68-72 times/min. at rest.
Heart rate of elephant	25 times/min.
Heart rate of rat	300 times/min.

As is clear from the figures given above, heart rate varies in animals. The smaller animals have high metabolic rates and hence need greater action of heart to pump more oxygen and nutrients to tissues. This is the reason why smaller animals have much higher heart beat rate than the larger animals.

Smaller the animal	- Higher metabolic rate	- Higher heart beat rate/min.
Larger the animal	- Lower metabolic rate	- Lower heart beat rate/min

Higher the activity (exercise) - Higher the heart beat rate/min.

Trachycardia. It refers to the abnormal increase in heart beat rate. It could be due to many factors like emotional stress, anxiety, anger, exicitement etc. It can also be due to over activity of thyroid gland.

Bradycardia. It refers to the abnormal decrease in heart beat rate. Athletes who generally have a high heart rate may suffer low heart rates during rest. It can also be due to under activity of thyroid gland.

(ii) **Arterial Pulse or Pulse wave**. It is a wave of distension followed by constriction experienced in the arteries as a result of ventricular systole and diastole.

Pulse rate per minute = Heart beat rate/minute.

As the ventricles contract, blood is pumped out into arteries with force. It causes distension of the elastic wall of arteries and is felt as a pulse when a finger is placed on an artery near the wrist. This pulse becomes fainter and fainter as the blood moves further away and becomes so low in capillaries that it cannot be felt.

As the ventricles relax, there is a drop in the pressure in the arteries and the distended portion comes back to normal.

(iii) **Blood Pressure**. It is the pressure or the force exerted by the blood against the walls of the arteries.

As the arteries already contain blood, the pressure in them increases due to sudden flow of blood during ventricular systole and falls slightly as the ventricles relax. The blood pressure is measured as two values, for example for a normal healthy man, it is equal to 120 by 80 m.m of Hg. It means that the person has a systolic pressure of 120 m.m of Hg and diastolic pressure of 80 m.m of Hg.

Systolic pressure. It is the pressure experienced in the arteries as a result of contractions in the ventricles. - There is distension in the elastic walls of arteries due to sudden rise of blood in them. - It is equal to 120 m.m of Hg for a normal healthy person.

Diastolic pressure. It is the pressure in the arteries when the ventricles relax.

- As the ventricles fill with blood, there is a slight drop in the pressure in the arteries.

The distended arteries recoil back due to elastic walls.

- It is equivalent to 90 m.m of Hg for a normal healthy person.

The values of blood pressure change with age, sex or health of a person.

Sphygmomanometer. It is an instrument used for the measurement of blood pressure in the brachial artery.

The blood pressure can also be affected by other conditions like arteriosclerosis where due to hardening of arteries, their lumens become narrower and so the blood pressure increases.