SANATAN DHARM COLLEGE MUZAFFARNAGAR
(Affiliated to Maa Shakumbhari University, Saharanpur)

Insect Anatomy and Physiology

Topic: Circulatory System

For

Subject Zoology

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The circulatory system concern with transport of nutrients, gases, hormones, blood cells towards and away from cells in the body to protect, stabilize body temperature and pH to maintain internal body environment i.e., homeostasis. This system includes cardiovascular system which distributes blood and the lymphatic system which distributes lymph. It includes dorsal vessel, heart, ostia, pulsatile organs and haemolymph. The flow is unidirectional from posterior to anterior region and having open spaces or cavities called haemocoel as the insects consists of open circulatory system.

Circulatory organs in insects

Insects are deficient of veins or arteries but they do have separate system to circulate fluids. As blood moves in large spaces instead of vessels, the organism is known to possess an open type of circulatory system. It differs from closed circulatory system found in vertebrates and higher invertebrates both in structure and function.

In an open circulatory system, blood/haemolymph lies in large and opened body cavities called haemocoel and thus blood makes direct contact with all internal tissues and organs. The thoraco-abdominal body cavity is divided into three major compartments with the help of two partitions. These partitions are called dorsal diaphragm placed dorsally and ventral diaphragm placed ventrally. Due to these diaphragms the insect body cavity is divided into following three cavities-

1. Pericardial cavity that surrounds the dorsal aorta.

2. Perivisceral cavity that surrounds the alimentary canal.

3. Perineural cavity that surrounds the nerve cord.

Difference between open and closed circulatory system:

During the evolution of animals, the lower animal phyla like porifera, coelenterata and platyhelminthes do not have definite circulatory system. As the complexity started from lower to higher animal phyla the arthropods and mollusca are having efficient circulatory system with open type as the blood flowing in vessels opens into open spaces called sinus or body cavities called hemocoel. All the organs and tissues are bathed in blood and remain in direct contact with the blood. Due to the open channels low blood pressure is maintained in insects. As far as closed type of circulatory system is concerned blood flows in arteries divide and redivide into capillaries reach to the organ and come back to heart via veins as in annelid and vertebrates.

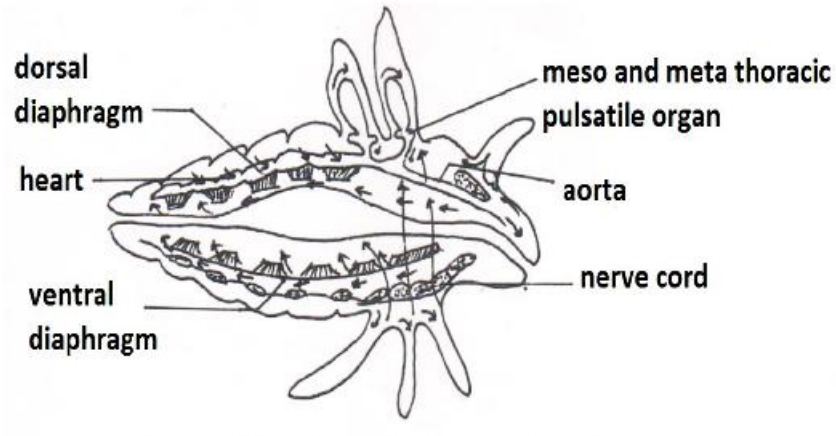

FIG 4.1: Direction of circulation in L.S. of insect.

Circulatory organs

1. Dorsal Vessel/dorsal aorta/heart

Dorsal aorta as the name suggests lie in the dorsal region of the body below the body wall. It is a longitudinal tube runs from thorax and abdomen and constitute major structural component of an insect's circulatory system. It is further divided and often constricted into 5 to 6 heart chambers separated by valves (ostia) to ensure unidirectional flow of hemolymph.

In *Nymphalid* butterfly only larva has both forward and backward peristaltic movements exceptionally. It is a fragile simple tube without ostia and sometimes connected with vertical diverticulum associated with pulsatile organs.

In most insects, hemolymph flows in a direction from posterior to anterior end of the body that is from abdomen to the head. It consists of aortic valve near heart and divides into 2-3 cephalic arteries which again further divides into smaller vessels.

2. Ostia

In heart, incurrent and excurrent both types of ostia are present.

1. **Incurrent ostia** consist of 9 pairs in abdomen and 3 pairs in thorax. The ostia are valvular in generalized insects like cockroach. Numbers of incurrent ostia are variable like in wasp 5 pairs and in housefly 3 pairs are present.

2. **Excurrent ostia** are non-valvular, in grasshoppers, silverfishes 2 thoracic and 5 abdominal pairs are present. In cockroaches where excurrent ostia are absent certain lateral segmental vessels are associated with heart. During each diastolic phase/relaxation, the ostia open to allow inflow of hemolymph from the body cavity and during contraction of heart these ostia closes and the hemolymph move forward.

3. Alary/ Aliform muscles

Many pairs of alary muscles are attached laterally to the walls of each chamber of heart so as to keep them in position.

Alary muscles are 2 thoracic and 10 abdominal in grasshoppers and 4-7 pairs in bugs. It is due to these muscles; peristaltic contractions occur which force the hemolymph forward from one chamber to another.

4. Accessory pulsatile organs

These organs are there in mesothorax or sometimes in metathorax which are concerned with circulation of hemolymph into legs/ wings/ antenna.

In some insects, pulsatile organs are located on the base of the wings, appendages or antenna in grasshoppers and cockroaches.

Pulsatile organs do not usually contract on a regular basis, but they force hemolymph out into the extremities. There are two diaphragm dorsal and ventral which separates the haemocoel into three compartments or sinuses perineural, perivisceral and pericardial.

Heart beat

The rate of pulse is 30-200 beats/minutes. As the temperature falls or rises the heart beat vary. In larva of stag beetle heart beat is 14 beats/minutes and in flies it is 150 beats/minutes. Heart-beat of larva is slower as compared to adult, and in older pupa no heart beat is found. Younger larva sometimes stops beating.

Control of heart

Insect's heart is myogenic and it lacks pacemaker. In cockroach neurogenic nerves supplied from corpora cardiac and motor fibres of segmental ganglia controls heart. Cardioaccelerator neuropeptide proctolin acts as myotropins and regulate heart. Indolalkylamine in insects is equivalent to adrenaline of higher organisms that accelerate the heart-beat.

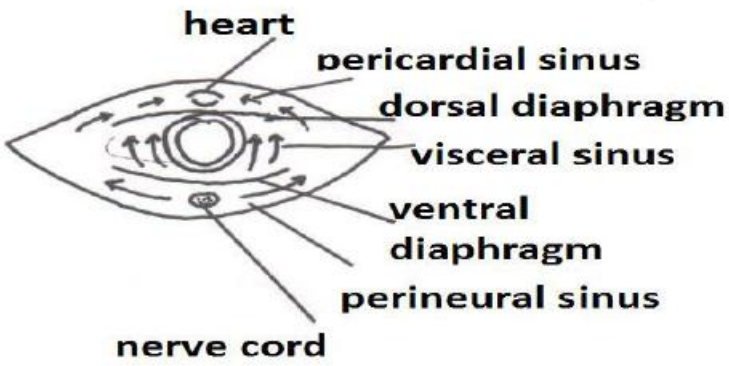

FIG 4.2: Direction of circulation in T.S.

Composition and function of hemolymph

Hemolymph or blood flows in aorta, small vessels in open channels in insects. The body cavity/blood sinus is divided into three compartments pericardial surrounding heart, perivisceral surrounding alimentary canal and perineural sinus around nervous system by two thin sheets of muscles or membrane known as the dorsal and ventral diaphragms.

The dorsal diaphragm is formed by alary muscles of the heart and related structures separating the pericardial sinus from the perivisceral sinus.

The ventral diaphragm separates the perivisceral sinus from the perineural sinus in the same way. Hemolymph is composed of plasma and haemocytes. In insects 170 µl of hemolymph contains 7-20 millions of circulating cells.

Plasma

Major portion about 90% of insect hemolymph is plasma and carries 5-40% of total body weight. It is a watery fluid containing 85% water, usually clear colorless fluid, but sometimes green, yellow or brown in color.

It is slightly acidic in pH and consist of almost all amino acids. In comparison to vertebrate blood, insects have high concentrations of amino acids, proteins, sugars (glucose in honeybees), uric acid, pigments and inorganic ions.

Haemolyph is a dynamic fluid that changes with diet, environmental factors or life stages. For example; In carnivores they have high concentration of Mg^{+} and K^{+}, In herbivores high Na^{+}, and in terrestrial insects' high protein, amino acids and uric acids. In aquatic insects high allantion, allantoic acid, NH_3, urea are there.

Trehalose is a major blood sugar in most insects which is a non-reducing dimer of glucose. In certain insect's blood sugar may be glucose, fructose or ribose depending upon their food sources.

Hemolymph also contains sorbitol or glycerol which is a cryoprotectants or antifreezing agents in the plasma to prevent it from freezing during the winters and fight against cold stress.

Lipophorin is a lipoprotein that functions to transport fatty acids, cholestrol, carotenoids, xenobiotics and hydrocarbons.

Tyrosin plays important role in sclerotization of cuticle previously explained and proline acts as a flight energy source.

Haemocytes

Left 10% of hemolymph volume is made up of various cell collectively known as hemocytes. All types of cells occurs in haemopioetic organs present in developing stages and adults in exopterygotes and these organs are absent in endoterygotes adult. Different types of cells are as follows;

1. Prohaemocytes are like archaeocytes of sponges that give rise to all other cells. They are spherical in shape having large nucleus and quite RNA rich.

2. Plasmatocytes are of variable shapes with vacuolated cytoplasm. It is most abundant of all and phagocytic in nature.

3. Granulocytes are the largest and phagocytic in nature like plasmatocytes. They have granulated and acidophilic cytoplasm.

4. Oenocytoids are special cells present in some Coleopterans, Dipterans, Lepidopterans and Hemipterans having large and rounded nucleus eccentric in position, but they are not derived from prohaemocytes.

5. Coagulocytes/cystocytes having scattered granules and helps in coagulation.

6. Spherules may be spherical, oval or spindle shaped with spherules present in cytoplasm. They are present in only Diptera and Lepidoptera.

Porhaemocytes, plasmatocytes and granulocytes are present in all types of insects. Total number of cells varies and depends upon species, developmental stage and physiological state of insect (in following figure). Number of haemocytes increases with instars development, decreases first in early pupal stage and increases in later pupal stage, then decreased in adult stage. The hydraulic (liquid) properties of blood are important. The hydrostatic pressure generated internally by muscle contraction is used to facilitate hatching, moulting, expansion of body and wings after moulting, physical movements (especially in soft-bodied larvae), reproduction (e.g. insemination and oviposition), and evagination of certain types of exocrine glands. In some insects, the blood aids in thermoregulation: it can help cool the body by conducting excess heat away from active flight muscles or it can warm the body by collecting and circulating heat absorbed while basking in the sun.

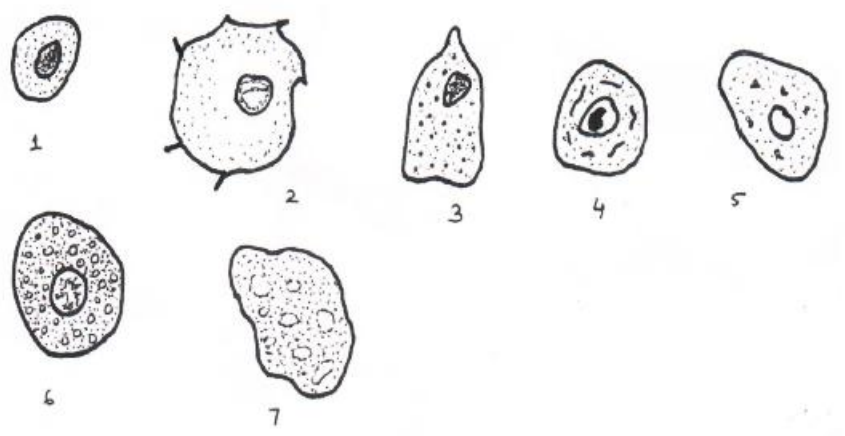

FIG 4.3: Different types of haemocytes 1. Prohaemocytes 2. Plasmatocyte 3. Granular haemocyte 4. Oenocyte 5. Cytocyte 6. Spherule 7. adipocyte

Function of hemolymph

1. Haemolymph creates hydrostatic pressure generated due to muscle contraction that helps the insect to circulate many things.

2. It also facilitates hatching, moulting and expansion of body.

3. Physical movements especially in soft-bodied larvae.

4. It also helps in reproduction like insemination and oviposition.

5. In some insects, the haemolymph aids in thermoregulation, it cool the body by conducting excess heat away from active flight muscles or it can warm the body by collecting and circulating heat absorbed while basking in the sun.

6. It seals off wounds through a clotting reaction.

7. The main function of hemolymph, is to transports hormones, nutrients and waste products.

8. It is important for osmoregulation, temperature control, immunity and storage.

9. It also plays an essential part in predatory defence by having chemicals that deter predators.

Insect immunity against pathogens

Immunity can be innate/ natural and acquired/ induced.

Innate comprises mainly of cell mediated phenomenon like phagocytosis and encapsulation which is performed by the haemocytes. Acquired comes in function when any antigen enters the host. They are different from vertebrate immunity as the antigen antibody reaction is non-specific, does not have memory cells and immunogens are not proteins.

Two types of humeral immunity are found non inducible and inducible.

Non inducible is one which does not require synthesis of RNA and protein like lectins (haemoagglutinin), phenyloxidases. Other is inducible immunity which requires synthesis of RNA and protein like lyzozymes, cercopins, attacins etc.

It encapsulates and destroys internal parasites and produces distasteful compounds that provide a degree of protection against predators. Example; hairy caterpillar contains poison in hemolymph.