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College of Agriculture, Jabalpur (M.P.)

Course No. : ENT- 502 3(2+1)

Course Title: Insect anatomy, physiology and nutrition

Assignment On

Structure, Modification and physiology of CIRCULATORY SYSTEM

SUBMITTED TO

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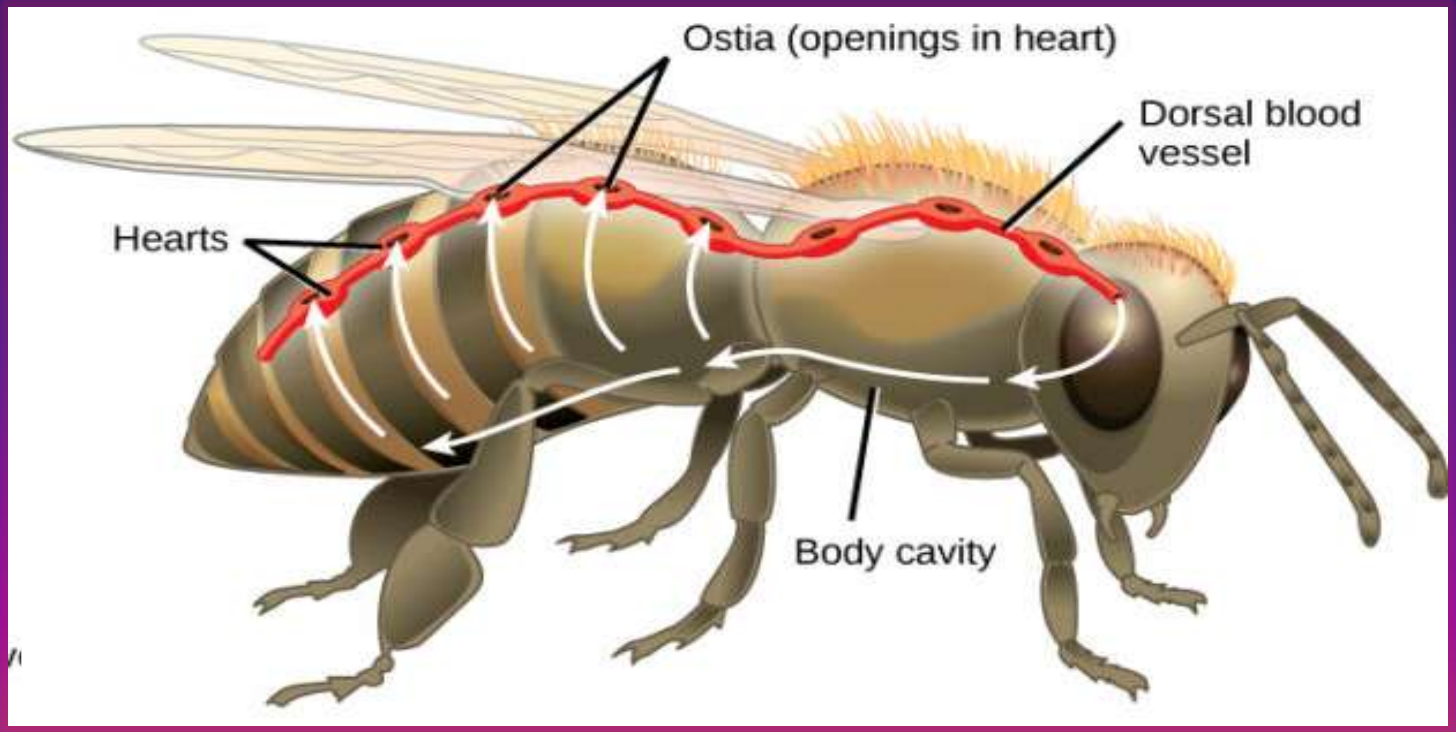
WELCOME

CIRCULATORY SYSTEM IN INSECTS



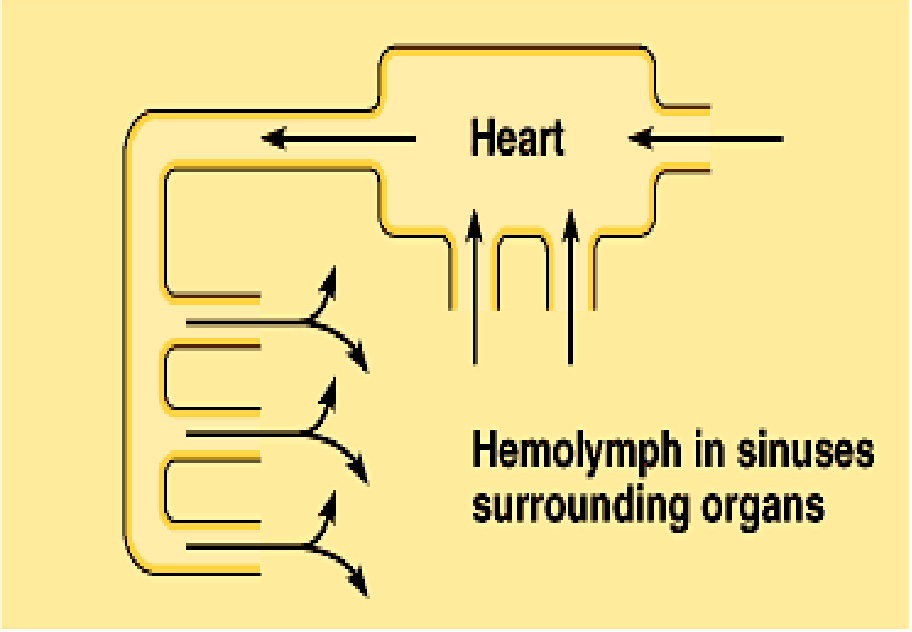
What is Circulatory system?

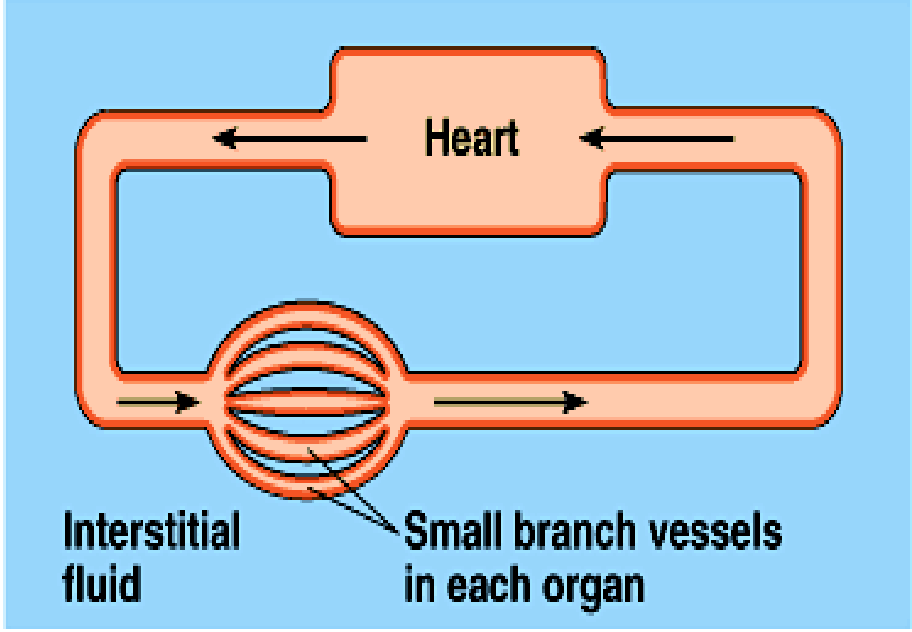
- The cells of all animals, including insects, are bathed in an extracellular fluid(ECF) or interstitial fluid.
- Most of the cells of the animals exchange solutes with the ECF which is facilitated by the bulk flow of ECF, powered by one-to-many pumps (including hearts).
- ***The physiological system mediating bulk flow is known as the circulatory system.***

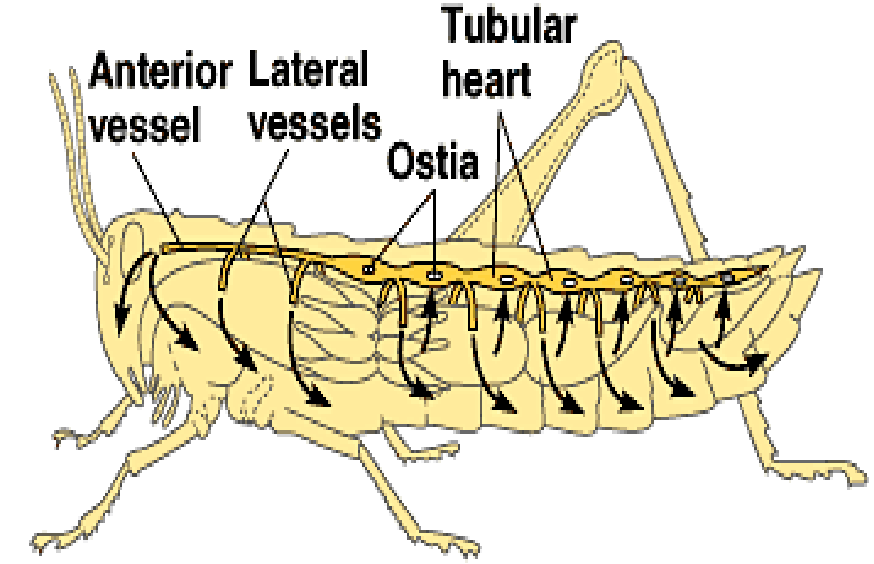
Types of Circulatory systems

1. Open Circulatory System
2. Closed Circulatory System

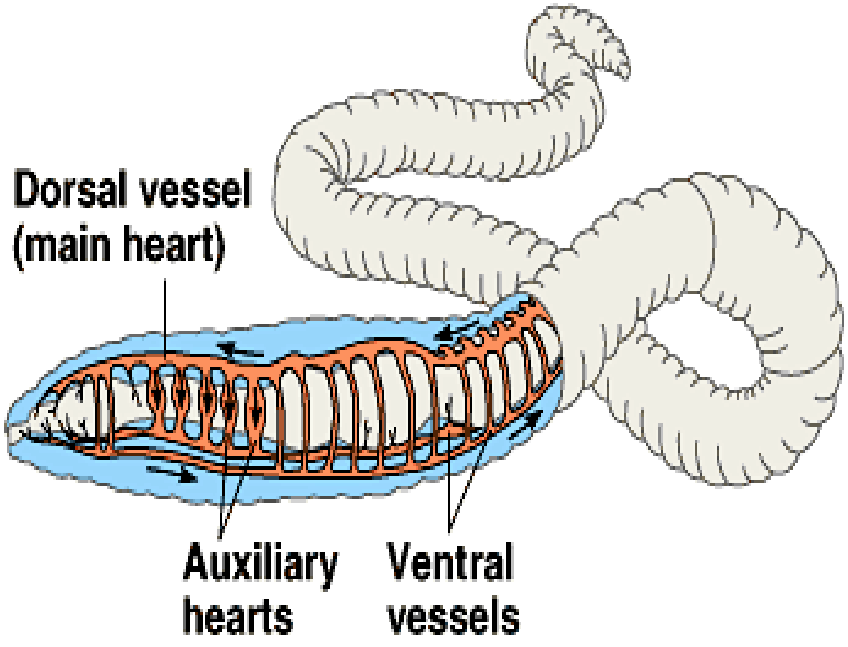
OPEN Circulatory System	CLOSED Circulatory System
There is no distinction between blood and ECF, collectively called as **haemolymph**.	There is a difference between blood and ECF
haemolymph is pumped by **dorsal blood vessel(DBV)** with one or more heart(s) that opens into sinuses.	Blood is pumped by the **heart** into closed blood vessels.
haemolymph is direct contact with tissue cells.	Blood does not come in direct contact with the tissue cells.
Transportation of nutrients, hormones etc **but not oxygen**.	Transportation of oxygen along with nutrients etc.







(a) Open circulatory system

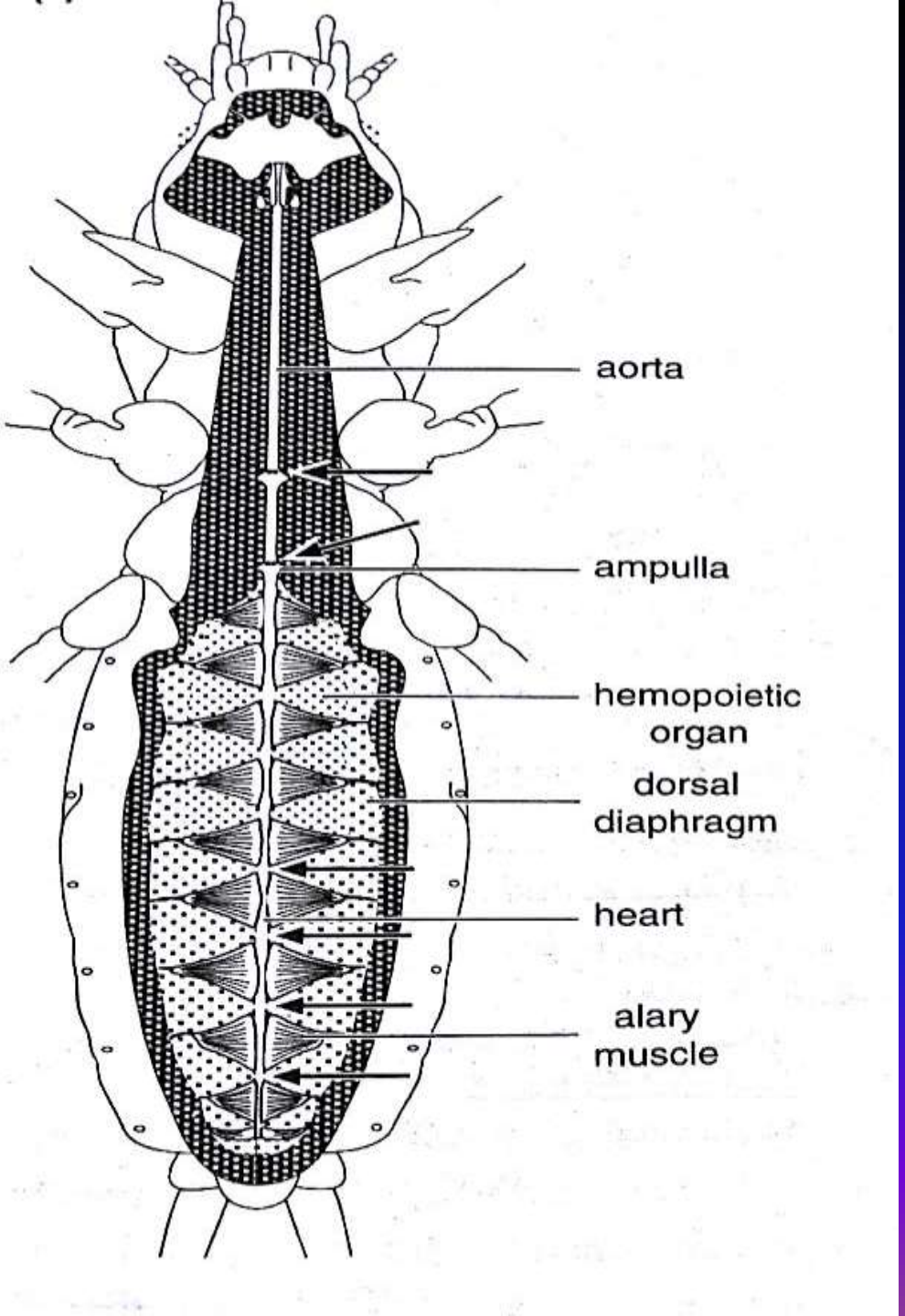


(b) Closed circulatory system

Circulatory system of Insects

Insects are characterized by possessing an OPEN type of blood vascular system in which the blood flows freely within the body cavity.

- The body cavity is called **Haemocoel**.
- The blood is called **haemolymph**.


aorta
ampulla
hemopoietic organ
dorsal diaphragm
heart
alary muscle

Organs of Circulatory system

1. Sinuses and diaphragms.

2. Dorsal blood vessel.

3. Accessory pulsatile organs (Auxiliary hearts).

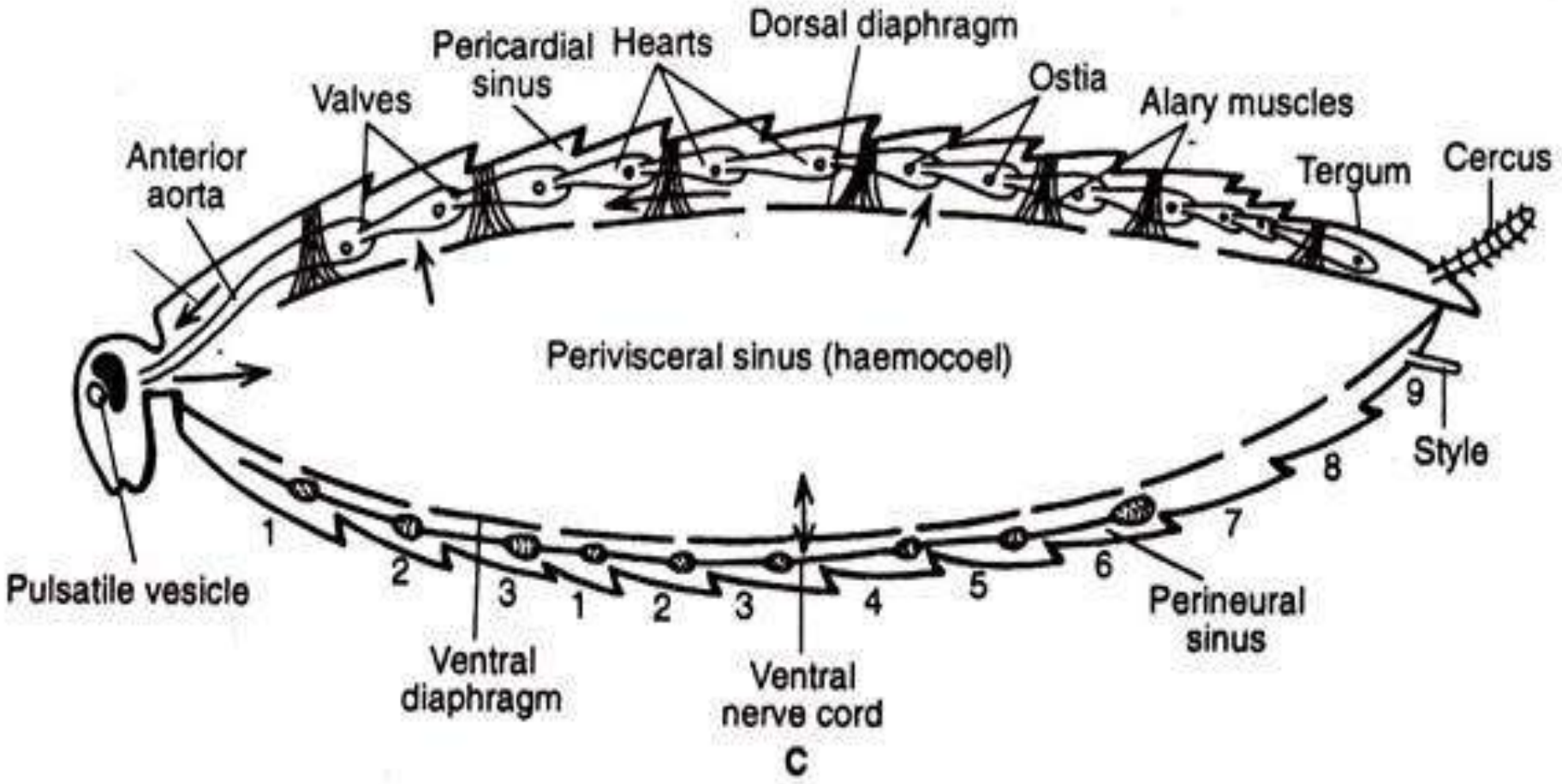


Fig. 18.57C: Blood vascular system of *Periplaneta*.

1. Sinuses and Diaphragms

- The haemocoel of many insects is divided into three major sinuses.
  i. Pericardial Sinus- Dorsal
  ii. Perivisceral Sinus- Middle
  iii. Perineural Sinus- Ventral
- The three sinuses are separated by Two diaphragms.

A)Dorsal diaphragm- b/w PC&PV sinuses
B)Ventral diaphragm- b/w PV&PN sinuses

i. Dorsal Pericardial Sinus

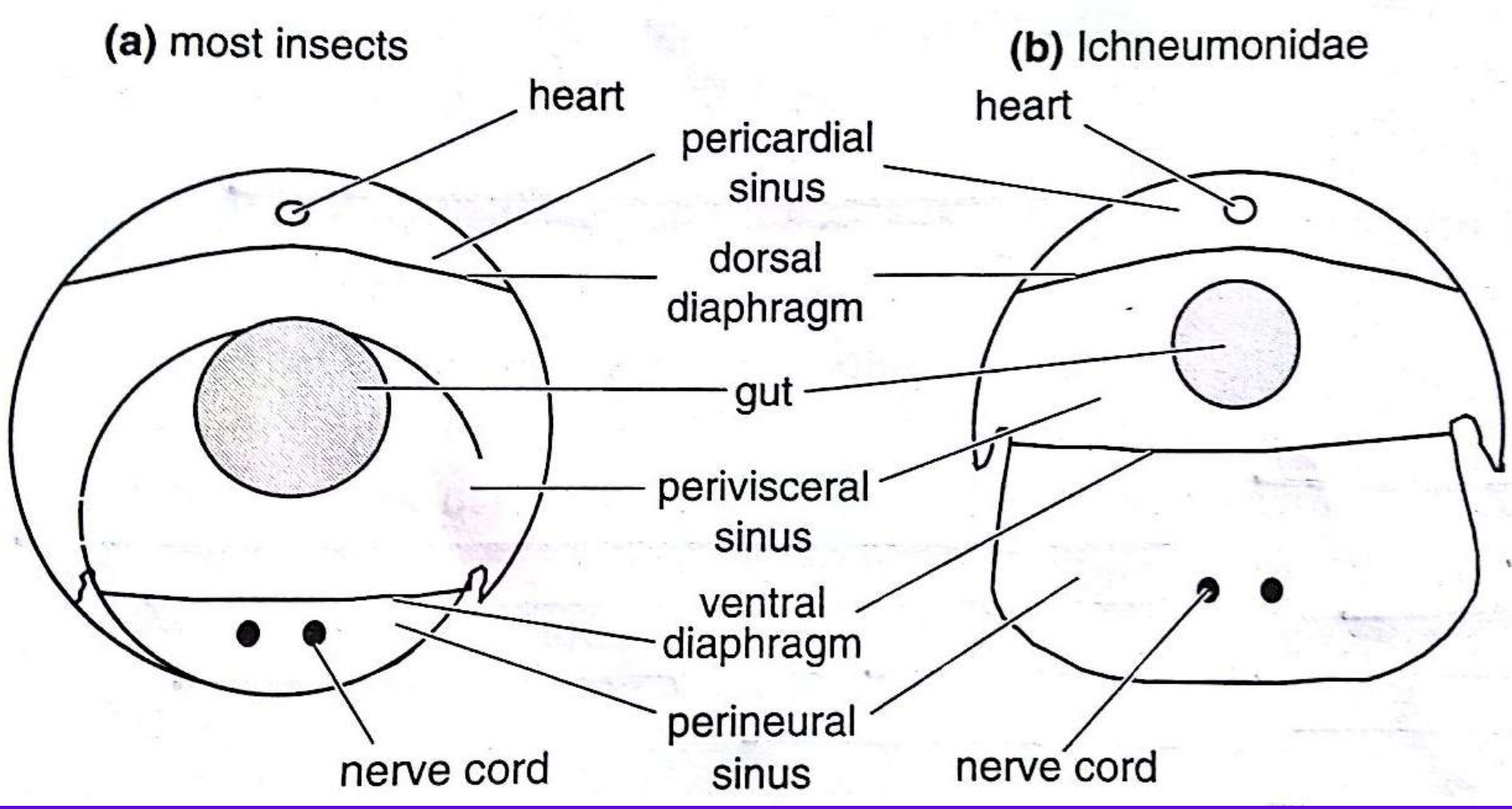
- It is separated by dorsal diaphragm from the middle perivisceral sinus.
- It contains dorsal blood vessel.

ii. Middle Perivisceral Sinus

- It is present in between dorsal and vental diaphragms and is largest sinus.
- It contains alimentary canal (gut).

iii. Ventral Perineural Sinus

- It is separated by ventral diaphragm from the middle perivisceral sinus.
- It contains ventral nerve cord.
- In Ichneumonids, it is enlarged.


(a) most insects
(b) Ichneumonidae
heart
heart
pericardial sinus
dorsal diaphragm
gut
perivisceral sinus
ventral diaphragm
perineural sinus
nerve cord
nerve cord

A. Dorsal diaphragm

- It is a fenestrated connective tissue membrane also called pericardial septum.
- It is usually incomplete laterally, so that it is continuous with the perivisceral sinus below.
- The lateral limits are indefinite and are determined by the presence of tracheae and alary muscles which form an integral part of the diaphragm.
- In Orthopteroids 10P of abdominal, 2P of thoracic **alary muscles**(visceral muscles with 10-12 thin filaments to every thick filament) are present, but in other insects the number is reduced.

B. Ventral diaphragm

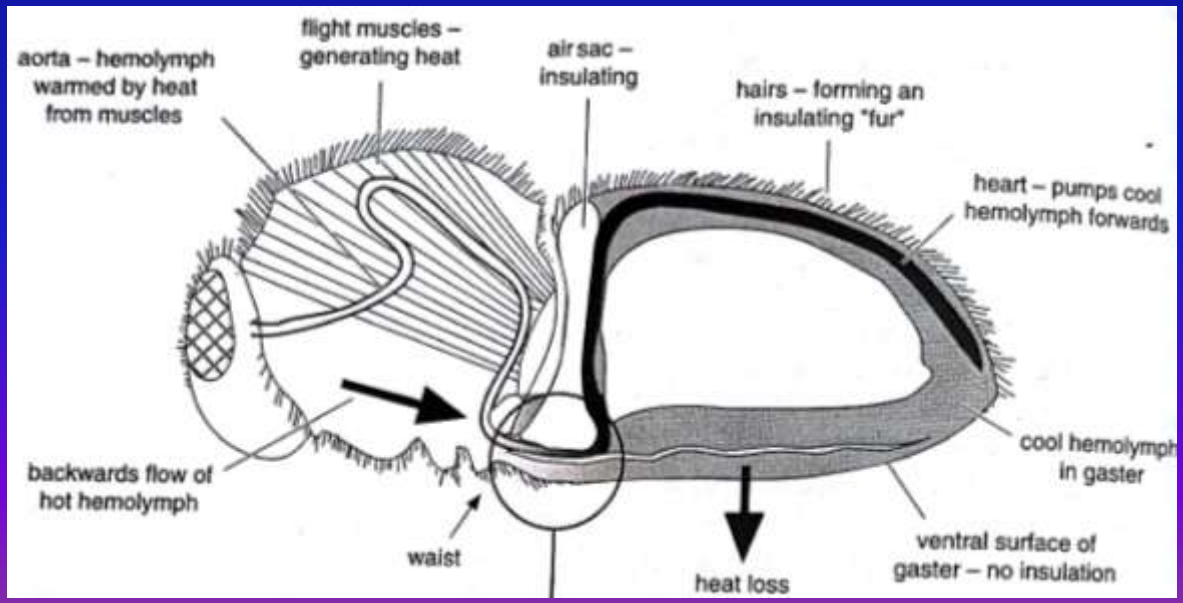
- It is a horizontal septum and it is like solid sheet in larva but a fenestrated membrane in adult.
  Eg: in *Corydalis*(Neuroptera).
- Laterally it is attached to the sternites, usually at one point in each segment, resulting in broad gaps along the margins where perivisceral and perineural sinuses are continuous.
- It contracts myogenically.
- It extends as a septum which divides the cavity of each leg into 2 sinuses.

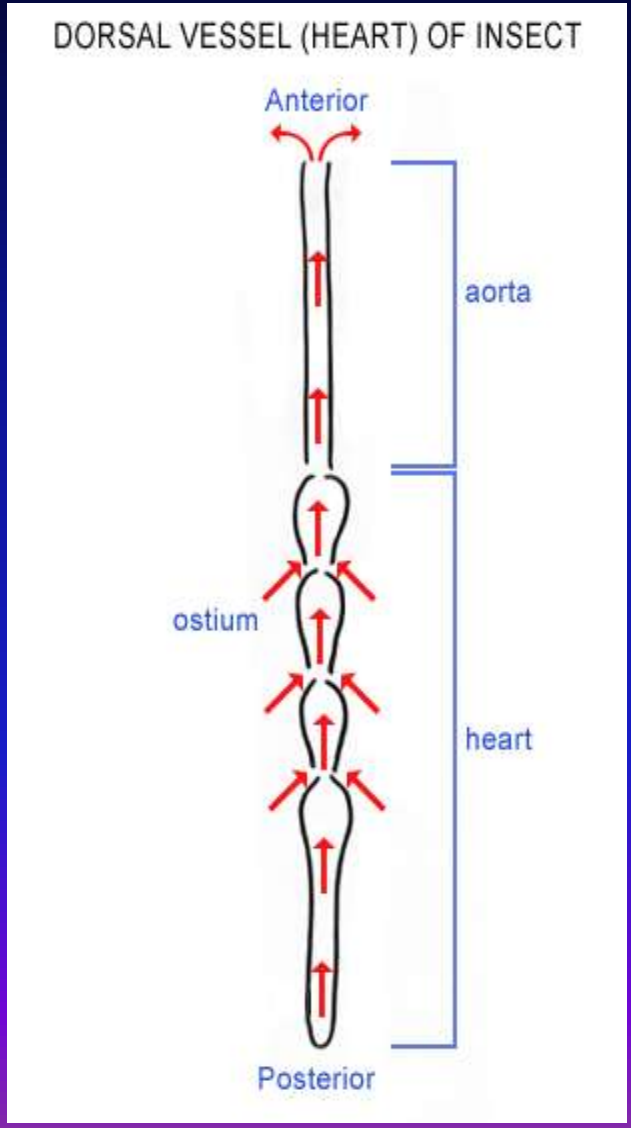
2. Dorsal Blood Vessel

- It has the primary role in the circulation of haemolymph around the body.
  - In most insects it runs along the dorsal mid line, just below the terga.
  - It may be bound to the dorsal wall of the gut in cephalic region above the oesophagous.
  - In adults of Lepidoptera and some Hymenoptera, it loops down between the longitudinal flight muscles in thorax region.
  - It opens anteriorly and closed posteriorly (except in larvae of may flies, 3 vessels diverge to the caudal filaments from posterior side of DBV).

DORSAL BLOOD VESSEL

- It is divided into two regions.
  i. Anterior AORTA.
  ii. Posterior HEART.





i. Aorta

- It is simple, straight, un perforated tube (without any ostia or valves).
- It opens anteriorly into cephalic cavity. (Or)
- It terminates anteriorly blindly into dorsal diverticulae (Eg: Odonata, Orthoptera, Coleoptera, Lepidoptera etc.) (Or)
- It may produce a sac which extends vessels to the antennae, eyes and maxillae.
- These terminal structures act as **accessory pulsatile organs**.
- It is innervated by axons of neuro secretory cells or nerves from the **corpora cardiaca**.

ii. Heart

- It is perforated tube with openings called **ostia** (Incurrent and sometimes excurrent also).
- It is restricted to the abdomen, but in cockroaches it is extended up to prothorax.
- It is divided into a series of dilations or chambers which are separated from each other by distinct constrictions.
- The number of chambers varies among different groups of insects from 12 in Cockroaches **(single pair of ostia/chamber)** to a Single in Mallophaga, Anoplura and Hemiptera **(2-3 pairs of ostia/chamber)**.
- Alary muscles are inserted into the heart.
- It is innervated by segmental nerves arising from thoracic and abdominal ganglia.

Ostia:

- They are of TWO types

  a) Incurrent Ostia

  b) Excurrent Ostia

a) Incurrent Ostia:

- These are vertical, slit like openings in the lateral wall of the heart.
- The maximum number found in any insect is 12 pairs.(9 pairs in abdomen, 3 pairs in thorax).
  Eg: Cockroaches.
- In Lepidoptera- 7 or 8 P
- In Hymenoptera(Bees, Wasps & Ants)- 5P
- In Housefly- 4P
- In Lice and many Heteroptera- 2 or 3P
- In all of these, heart is restricted to posterior abdominal segments.
- The valves are present in each ostium, which prevents the back flow and out flow of the haemolymph from the heart and permits only forward flow.

b) Excurrent Ostia:

- These are reported in Thysanura, Orthoptera, Plecoptera and Embioptera insects.
- In Orthoptera, they are paired (5P in abdomen & 2P in thorax) ventro- lateral openings in the heart wall and lack internal valves.
- In remaining orders they are unpaired.

Lateral vessels:

- In some insects, the heart bears the lateral vessels arising from the excurrent ostia.
- The heart of cockroach contains **6P of lateral vessels** (2P thoracic and 4P abdominal).
- In most of the insects the terminal end of blood vessel is blind, but it is branched into **three slender branches** entering the **cerci** and a **median caudal filament** in the Ephemerid Larvae.

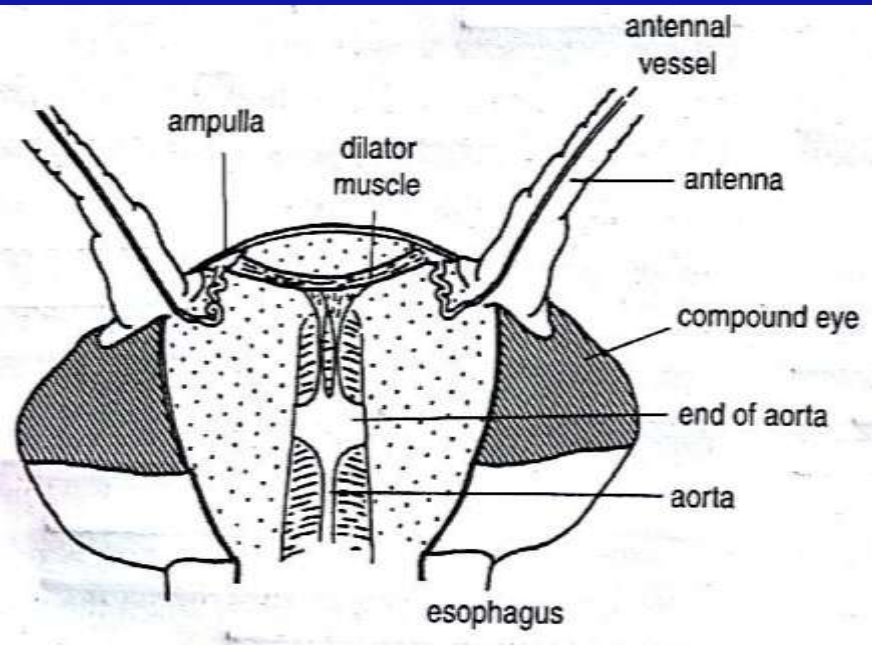
3. Accessory pulsatile organs

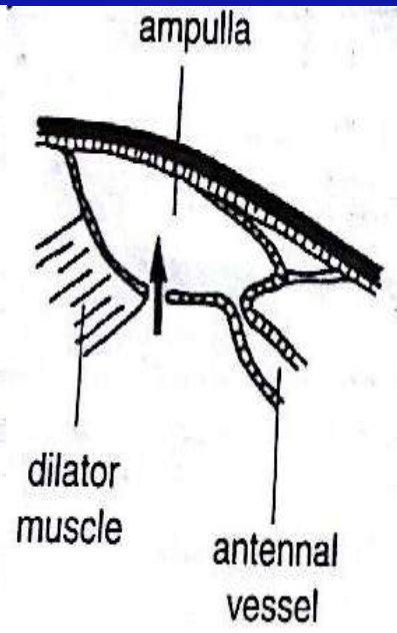
These are muscular membranous structures, varying in shape and are situated at the base of the appendages, such as

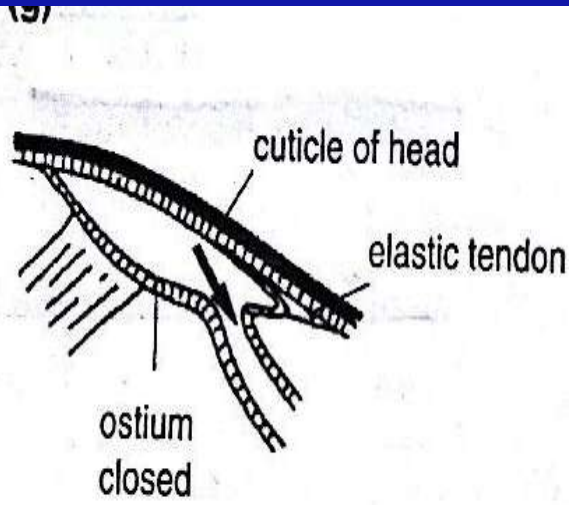
- Antennae
- Legs
- Wings

Antennal Pulsatile Organs

- At the **base of antennae** pulsatile organ is found.
- It consists of **ampulla** from which a fine tube extends almost to the tip of the antennae.
- When the dilator muscle compress the ampulla, the ostium is closed and haemolymph is driven into the antenna from cephalic haemocoel.

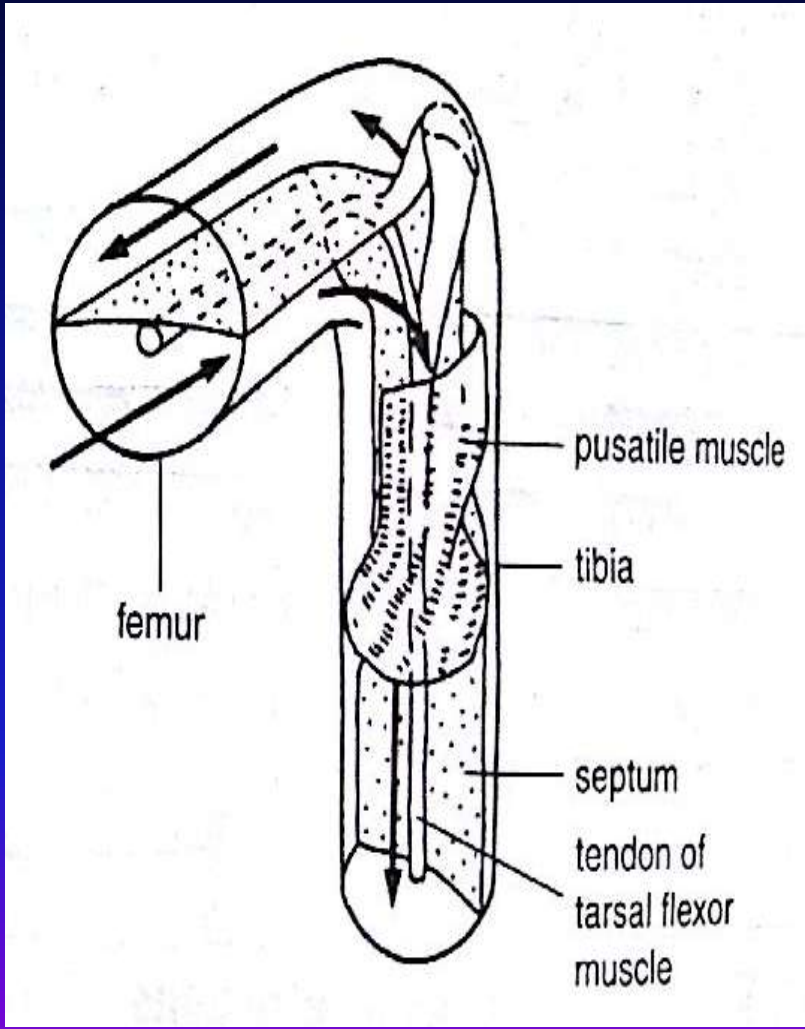






Leg Pulsatile Organs

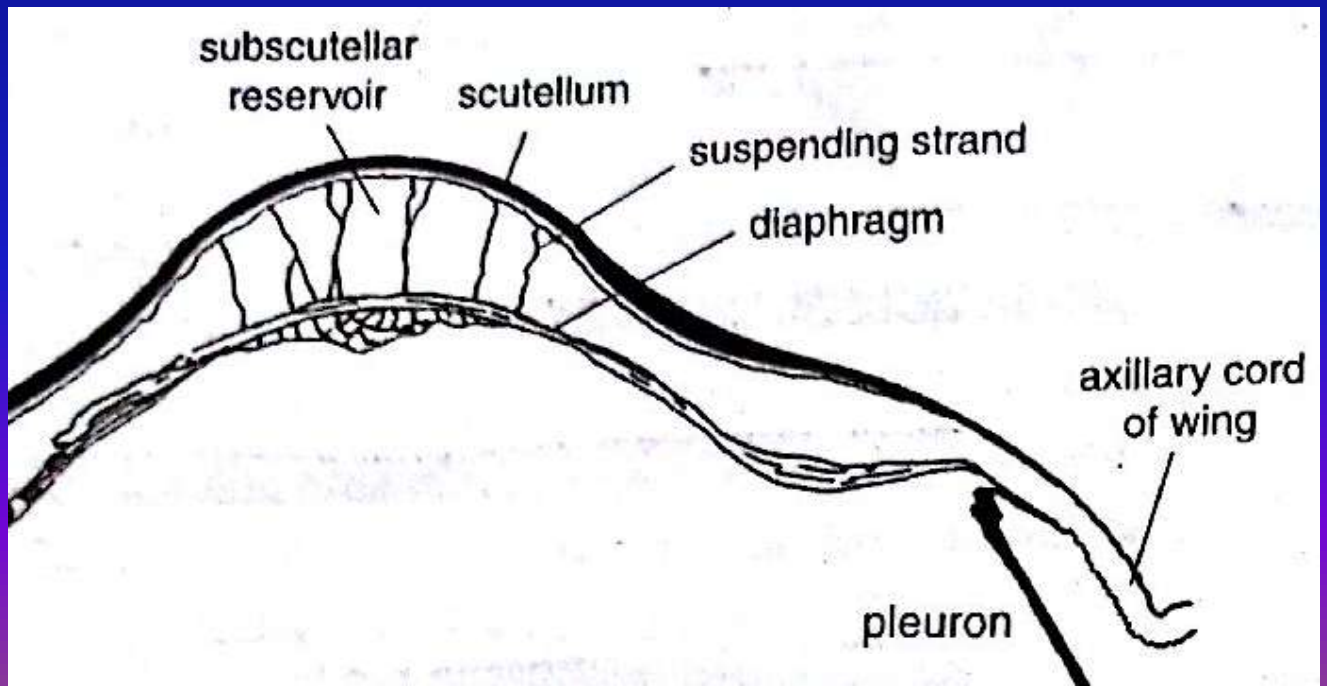
- A longitudinal septum is present in the legs (extension of sternum) which divides the lumen of leg into **two sinuses** and permits **bi directional flow of** haemolymph with in the leg.
- When the muscle contracts (due to myogenic action), it compresses one sinus, forcing haemolymph into the thorax, and at the same time enlarges the other so that haemolymph is drawn into the leg



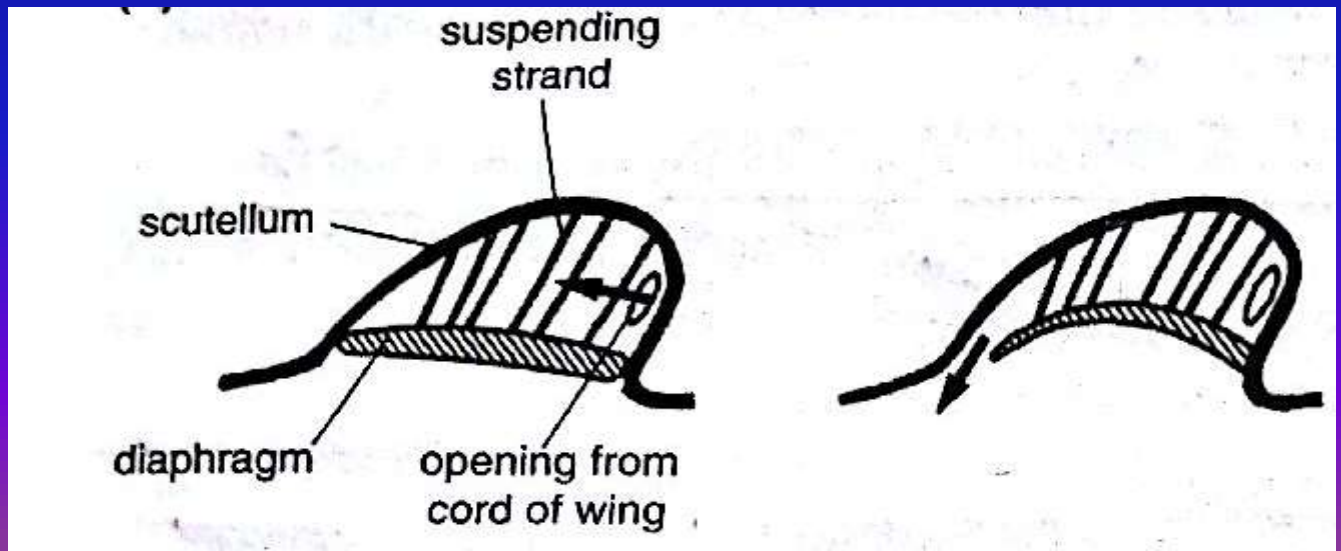
Wing Pulsatile Organs

- A pulsatile organ **drawing haemolymph from the wings** is present in both wing bearing segments of most of the insects, but only in the mesothorax of **Diptera** and **Coleoptera Polyphaga.**

- A reservoir is formed beneath the posterior part of the tergum (scutellum) is called **sub scutellar reservoir**.
- It connects with the posterior veins of the wing via the **axillary cord** of the wing.
- A muscular pump is formed from the ventral wall of the reservoir.

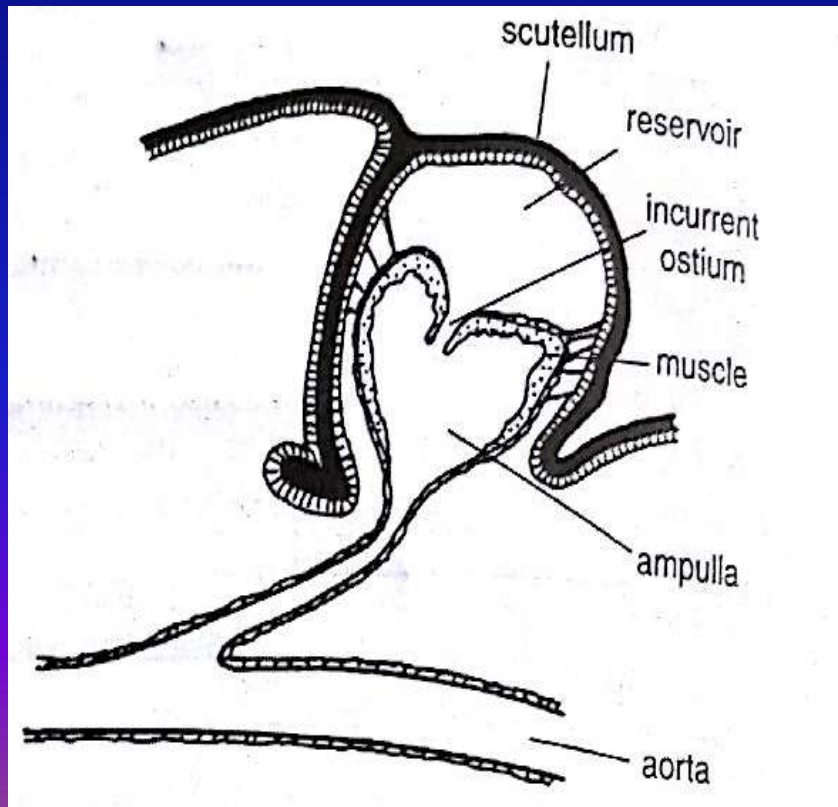


- The pulsatile organ of **Most of holometabolous insects and Hemiptera**, have a muscular diaphragm, which bounds the sub scutellar reservoir on the ventral side.
- It is suspended from the scutellum by a number of filamentous strands.
- Muscles contract- diaphragm flattens & drawing of haemolymph from the wings.
- Muscles relax- diaphragm moves upward & haemolymph is forced into the body cavity.



- The pulsatile organ of **hemimetabolous insects except Hemiptera and in Coleoptera and Hymenoptera Symphyta** is an expansion or diverticulum of the dorsal blood vessel with a pair of incurrent ostia opening from the sub scutellar reservoir.

- The pulsatile organ of **Odonata**, have an **ampulla** in each pterothoracic segment, which is muscular dorsally and suspended from the tergum by elastic ligaments.
- The ampulla connects with the dorsal blood vessel (aorta) by a narrow vessel.
- Muscles contract- ampulla is compressed & haemolymph is driven into aorta and due to the increase in volume of sub scutellar reservoir, the haemolymph is sucked from the wings.
- Muscles relax- ampulla gets its original shape so that haemolymph is sucked into it from reservoir.



Mechanism of circulation

1. Cardiac cycle.

2. General circulation.

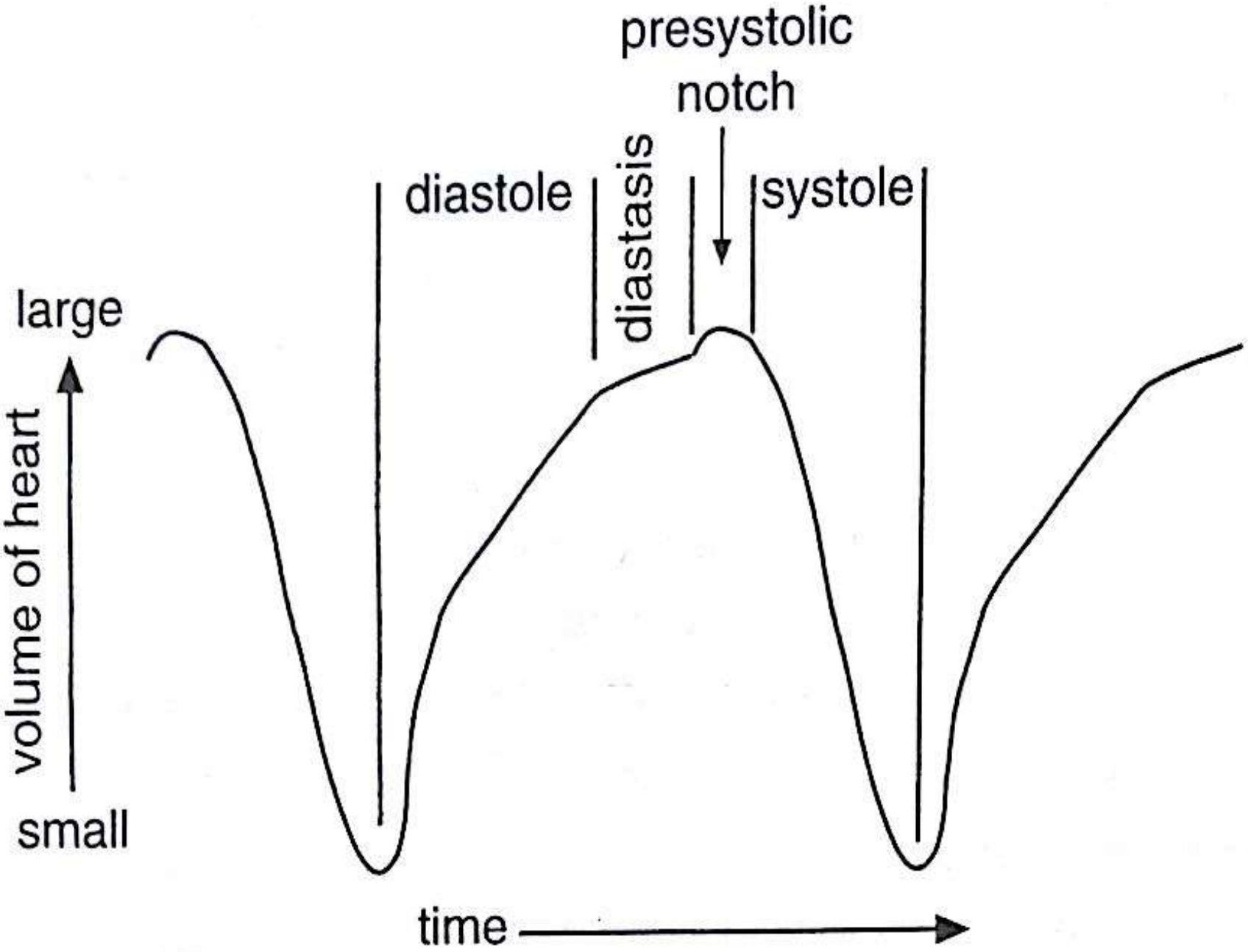
3. Circulation in appendages.

1. Cardiac cycle

- The haemolymph circulation always takes place in **postero-anterior direction** in **dorsal blood vessel**.

- **Diastole**- Expansion phase of heart- relaxation of muscles of heart wall.
- **Systole**- Contraction phase of heart- contraction of muscles of heart wall-.

- **Diastole** - initiated through myocardium and associated connective tissue. In some insects due to contraction of the alary muscles (Eg: *Hydrophilus*).
- It is the longest phase than systole (except in *Lepisma*).
- **Systole** - it is through contraction of muscles of dorsal blood vessel.
- **Diastasis** - it is an intermediate or resting phase, some times occurs in between diastole and systole, where the heart remains expanded.
- **Presystolic notch** appears in b/w diastasis and systole.


presystolic
notch
diastole
diastasis
systole
large
volume of heart
small
time

2. General circulation

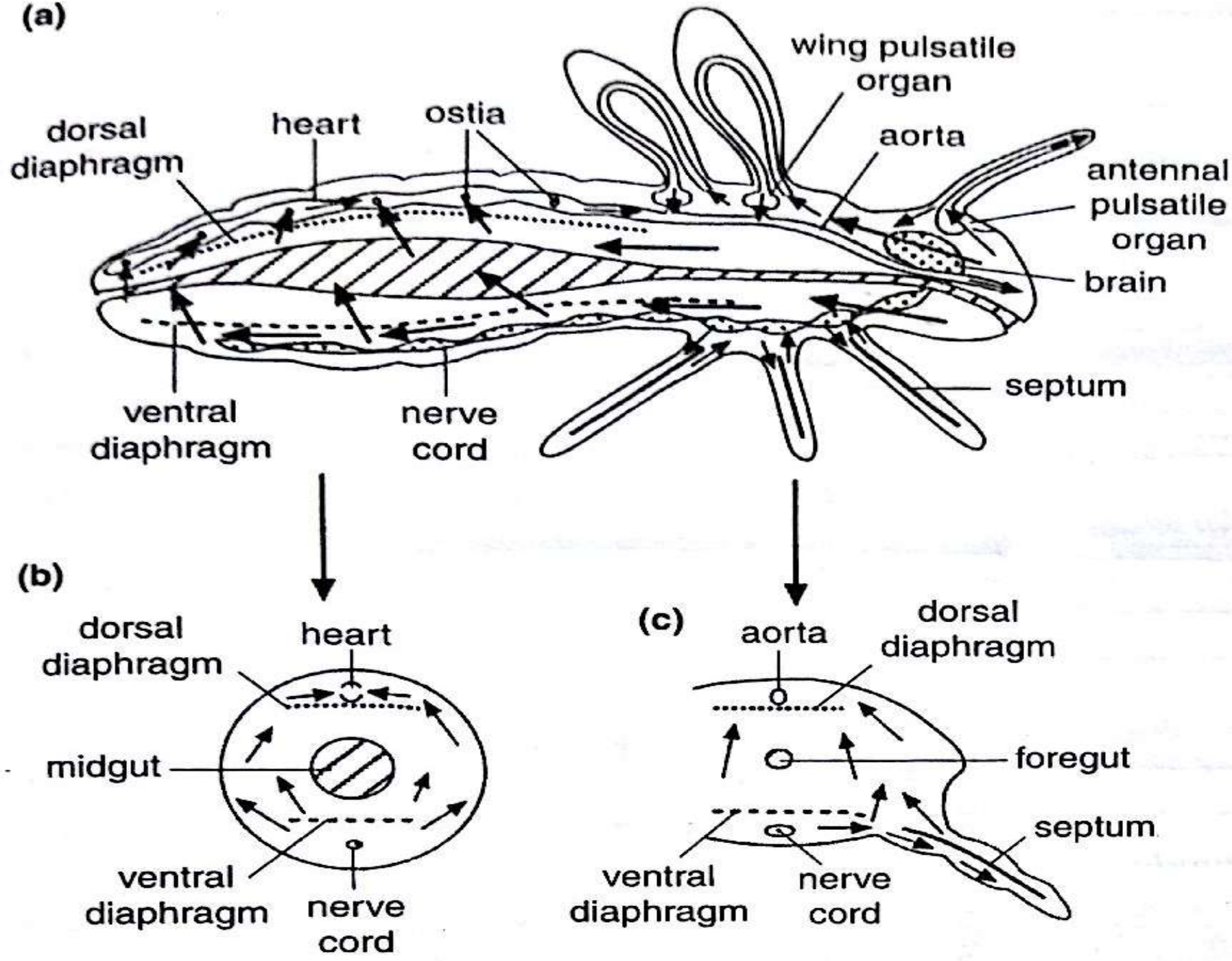
- During diastole, the blood enters into the heart through incurrent ostia.
- During systole, the valves will close and prevents the out flow and back flow of blood and aids in forward flow of the blood in the blood vessel.
- During its forward passage, some amount of blood is discharged out through the excurrent ostia and lateral segmental vessels.

- In some insects entire blood vessel is contractile (*Lepisma*, *Periplanata and* grass hopper) while in others heart is contractile and aorta is non-contractile (*Apis*).

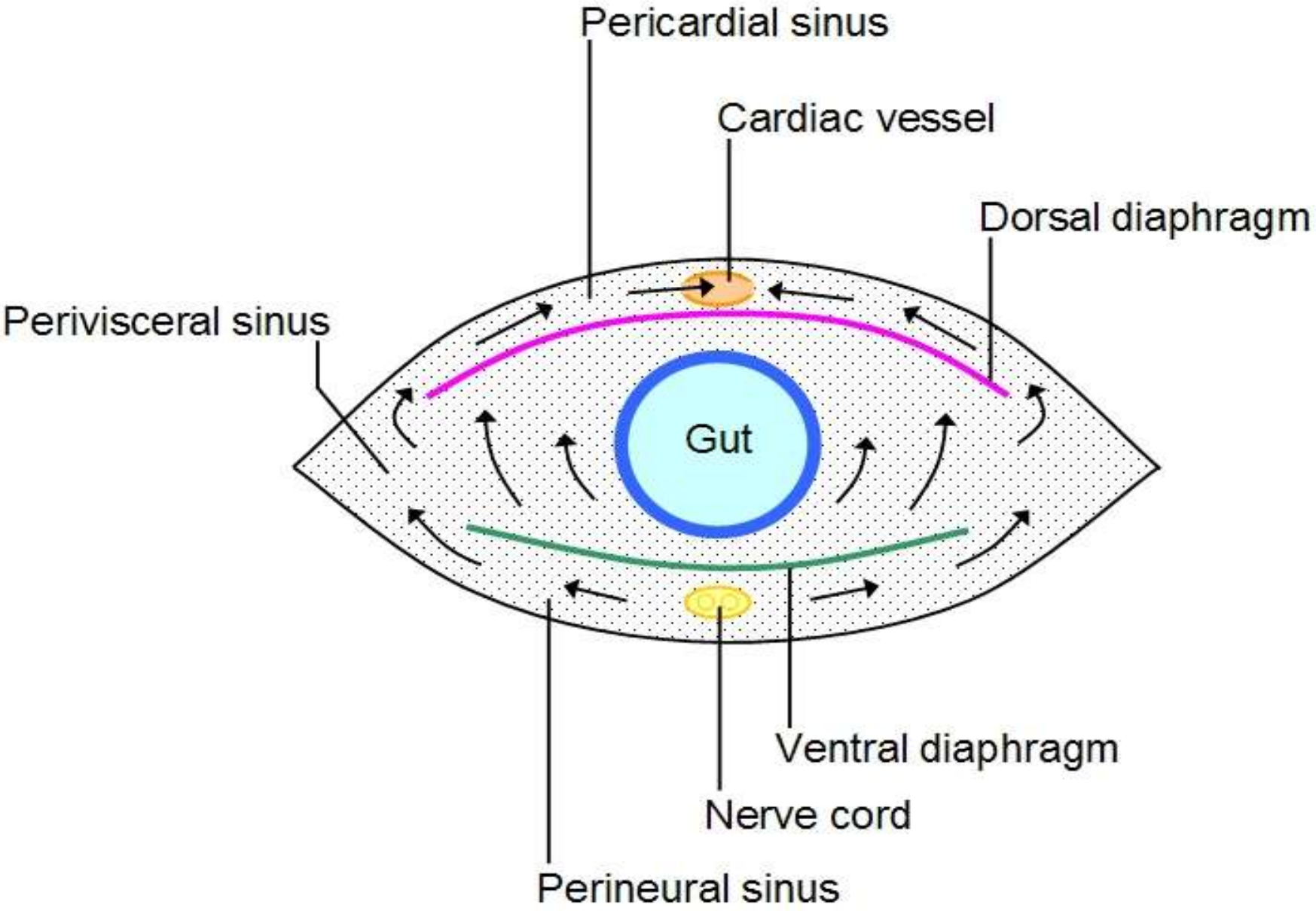
Due to undulating movements of ventral diaphragm

- The accessory pulsatile organs pump the haemolymph to their respective appendages.
- The backward directional flow of haemolymph from cephalic region to thorax and abdomen.
- Percolation of haemolymph into the perineural sinus and assisting the blood supply to the nervous system.

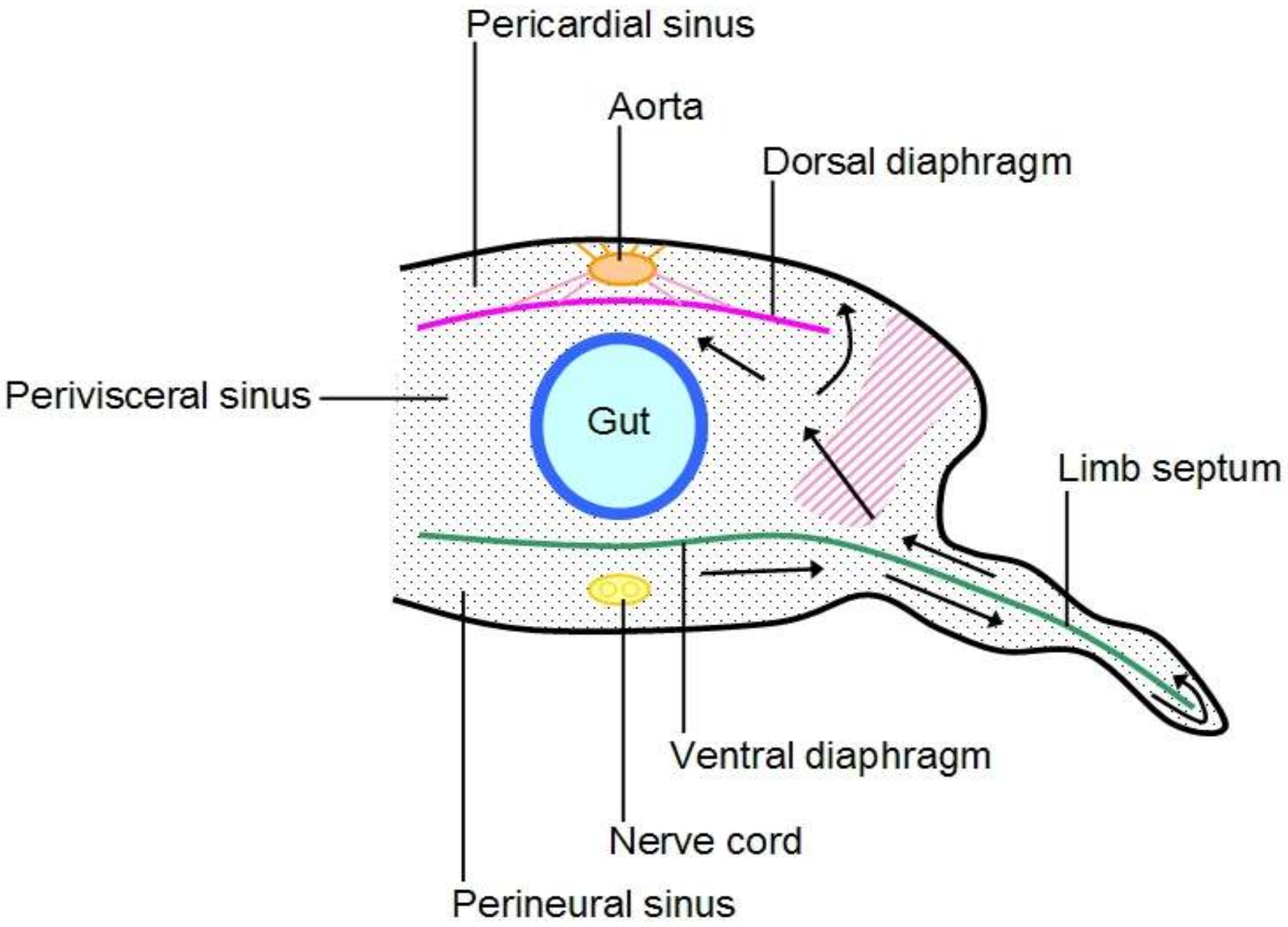
- The dorsal diaphragm becomes flattened due to contraction of the pericardial sinus.
- Due to that, volume reduction of perivisceral sinus occur.
- These changes result into forcing the haemolymph into pericardial sinus which enters the heart again during diastole through the incurrent ostia.


(a)
wing pulsatile organ
dorsal diaphragm
heart
ostia
aorta
antennal pulsatile organ
brain
septum
ventral diaphragm
nerve cord
(b)
dorsal diaphragm
heart
midgut
ventral diaphragm
nerve cord
(c)
aorta
dorsal diaphragm
foregut
septum
ventral diaphragm
nerve cord

Circulation across the insect abdomen



Circulation across the insect thorax



3. Circulation in appendages

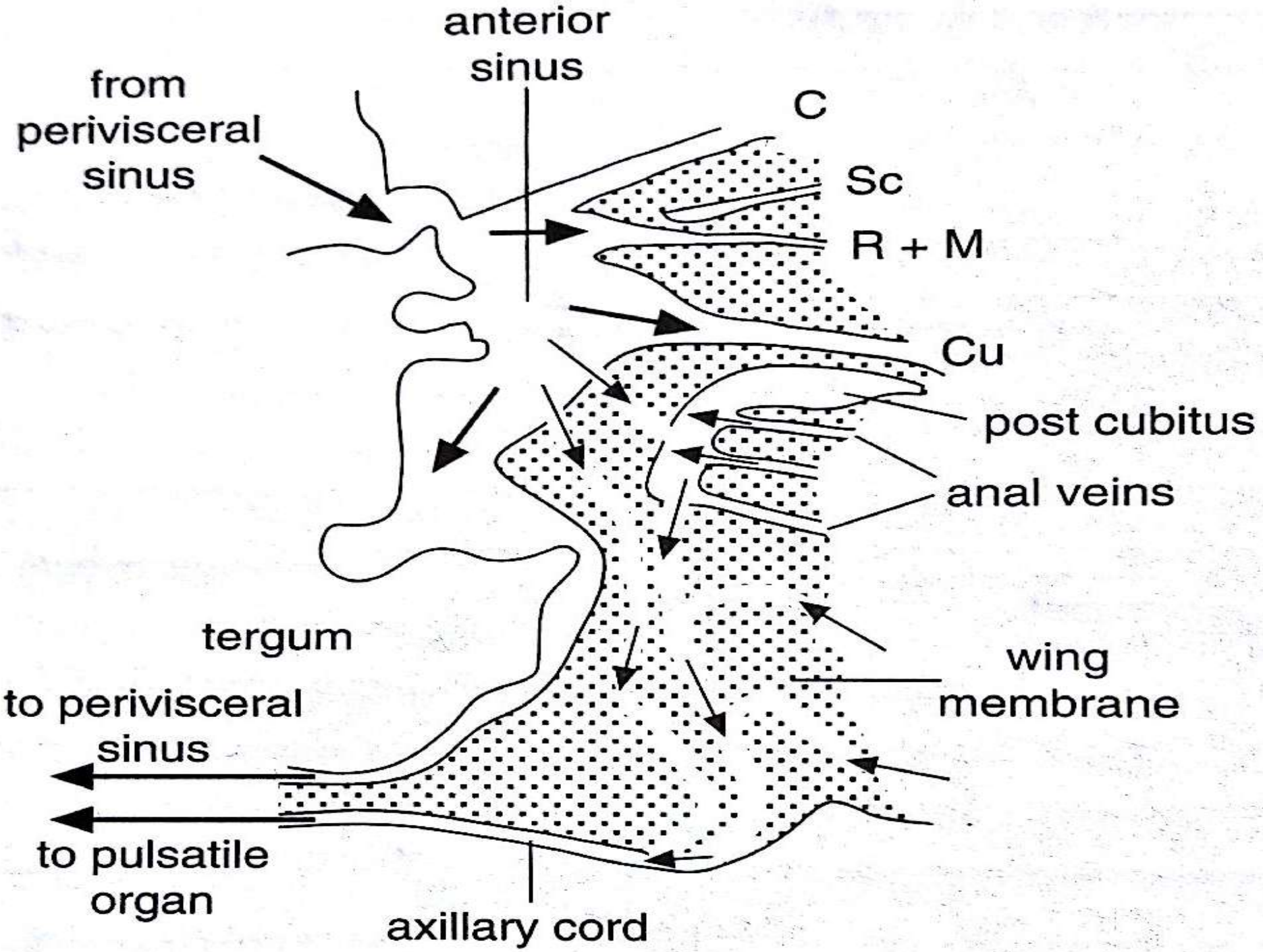
A) **Antennae:** Antennal pulsatile organs pump the haemolymph from cephalic haemocoel into the antennae.

B) **Leg:** The accessory pulsatile organs situated at the base of legs, pump blood into the leg and diaphragm which divides the entire internal cavity of leg into the dorsal and ventral sinuses, and facilitates internal circulation.

C) Wings:

- Thoracic pulsatile organs bring up circulation in the wings.
- The haemolymph circulates along fine channels formed b/w inner walls of veins and the tracheae.
- At the wing base, dorsal and ventral articular membranes form a space, the **anterior sinus**.

- ***The haemolymph flow***
- Perivisceral sinus -> anterior sinus -> anterior half(wing) blood channels-> Cross veins and spaces -> posterior half(wing) blood channels -> Perivisceral sinus.
- The thoracic pulsatile organs aspirate the haemolymph from posterior part of the wing base.


anterior
sinus
from
perivisceral
sinus
C
Sc
R + M
Cu
post cubitus
anal veins
tergum
wing
membrane
to perivisceral
sinus
to pulsatile
organ
axillary cord

Heart beat

- It ranges from 14 beats/ min (*Lucanus* larvae) to 150 beats/ min (*Campodea*).
- The pace maker initiates the heart beating generally exists at the posterior most end of the dorsal blood vessel.
- The rate of beating is high in fresh moulted larva and quite low in before moulting larva.

Reversal of Heart beat

- It is the beating of heart in antero-posterior direction.
- It occasionally found in late larval instars and pupae of Lepidoptera, Coleoptera, Hymenoptera and Diptera.
- It occurs mostly due to mechanical causes like blockage of ostia by fat bodies, obstruction of haemolymph flow in body cavity and due to poor supply of oxygen at the posterior region of the abdomen.

Haemolymph

- It is a watery fluid containing ions, molecules and cells, making up 5-40% of the total body weight of an insect.
- It is clear fluid, sometimes colourless or tinged with green or yellow pigments.
- Rarely red, due to the presence of **'haemoglobin'. Eg: Chironomid larva**, which are aquatic and endo parasites.
- It performs the function of both blood and lymph, but is not involved in gas transportation function. (Except in Chironomid larva)
- It contains **a)Plasma**- fluid portion **b)Haemocytes**- cellular fractions.

a) Plasma

- It is an aqueous solution of
- Inorganic ions (**'Na'** in predators and parasites; **'Mg'**&**'K'** in phytophagous insects,
- Sugars- carbohydrates (mainly **trehalose**),
- Proteins(lipo proteins, glyco proteins and enzymes),
- Amino acids (its higher concentration leads to amino acidemia which affects the osmotic process),
- Lipids (fat particles or lipo proteins),
- Organic acids, pigments and other components (glycerol- anti freezing compound in high altitude insects).

- pH: acidic 6.4 to 6.8, in some insects slightly alkaline 7.0 to 7.5.
- Density: 1.01 to 1.06.
- Water content: 84-92 %
- Osmotic pressure: 6.8 to 15 atm (average 10.5 atm)
- Nitrogenous waste: Uric acid

b) Haemocytes

The insect haemolymph contains a varaiety of mesodermal, amoeboid, nucleated cells called **haemocytes.**

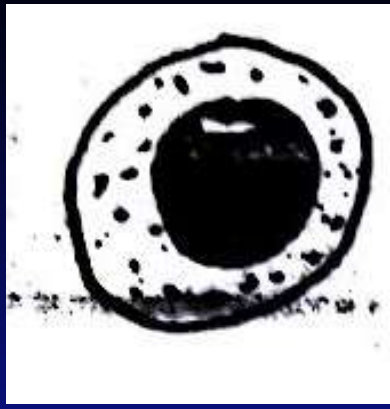
- They are homologous with the **vertebrate leucocytes** and circulate freely in hoemocoel.
- These are produced in the structures known as **hematopoietic organs** which occur behind the prothoracic spiracles of young caterpillars, mitosis occurs and haemocytes(blood cells) will liberate.
- They are paired, segmental structures that open directly into the heart
  (Eg: Crickets, Mole crickets)
- In lepidoptera, they are 4, each at close proximity to each imaginal wing disc.

Types of Haemocytes

Arnold (1974) has classified the haemocytes into the following 9 types

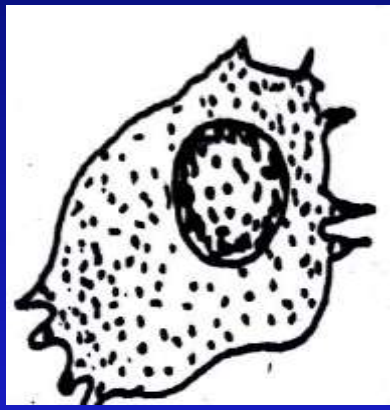
1) Prohaemocytes or Proleucocytes
2) Plasmatocytes or Amaebocytes
3) Granulocytes or Granular haemocyte
4) Oenocytoids or Crystal cells
5) Spherule cells
6) Coagulocytes or Cystocytes
7) Adipocytes or Adipohaemocytes
8) Podocytes or Stellate cells
9) Vermiform cells or Nematocytes

1) Prohaemocytes or Proleucocytes:



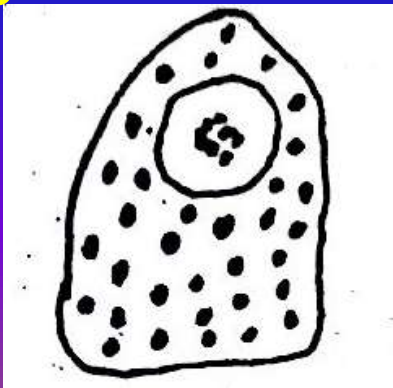
- It is the stem cell from which other haemocytes are derived.
- It is the smallest cell with largest nucleus and very little cytoplasm.

2) Plasmatocytes or Amaebocytes:



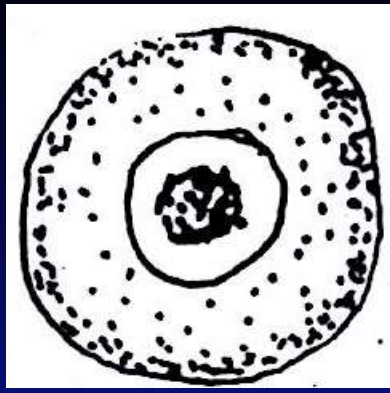
- It is ovoid or fusiform with large nuclei and granular cytoplasm with filiform cytoplasmic processes.
- They aids in phagocytosis & wound healing.

3) Granulocytes or Granular haemocytes:



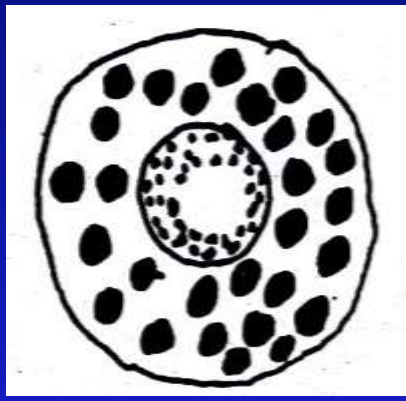
- Compact cells containing oval or spherical shaped small nuclei and large cytoplasm.
- They are most abundant in Lepidoptera and aids in phagocytosis.

4) Oenocytoids or Crystal cells:



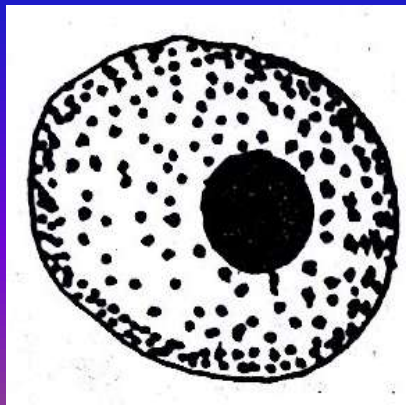
- They resemble oenocytes and are large oval cells with eccentric nuclei & clear crystalline basophilic cytoplasm.
- Encapsulation, phenoloxide activity, immunity and detoxification challenge.

5) Spherule cells:



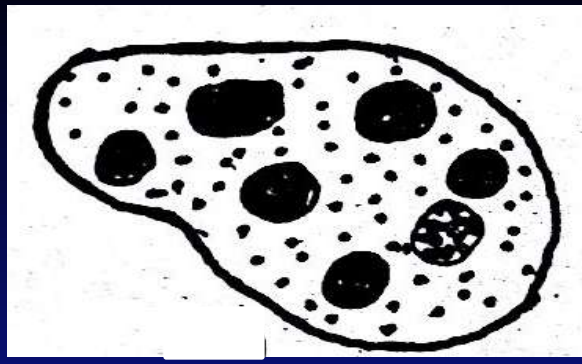
- They are oval or elliptical cells have eosinophilic cytoplasm with large, refractile spherules that contains cuticular components.
- They aids in storage and transportation.

6) Coagulocytes or Cystocytes:



- They are spherical with large nuclei, hyaline cytoplasm with granules.
- They play an important role in blood coagulation and plasma precipitation.

7) Adipocytes or Adipohaemocytes:



- They are large oval cells with eccentric nuclei & vacuolated cytoplasm.
- They contain distinct fat droplets found in Hemiptera, Diptera and Lepidoptera.
- They aids in phagocytosis.

8) Podocytes or Stellate cells:

- They are large flattened cells with number of protoplasmic projections.
- They occur in Lepidoptera, Diptera like *Prodenia, Sarcophaga.*

9) Vermiform cells or Nematocytes:

- They are thread like, spindle shaped with granular basophilic cytoplasm.
- They reported in last instar larva of *Prodenia.*

According to Vostal & Hoffmann 1969; Gouin, 1970, the 8th and 9th cells are variants of plasmatocytes.

Functions of Haemolymph

1) **Lubrication:** keeps internal cells moist and make internal organs to move freely.
2) **Transport & storage:**
   - Transportation of digestive nutrients, hormones and gases (Chironomid larva).
   - Removal of waste materials to the excretory organs.
   - Storage of water and raw materials required for histogenesis.
3) **Protection:** It helps in phagocytosis, encapsulation, detoxification, coagulation and wound healing.

Functions of Haemolymph

4) **Heat transfer:** through its movement in the circulatory system regulate the body heat (Thermoregulation).
5) **Maintenance of osmotic pressure:** Ions, amino acids and organic acids present in the haemolymph helps in maintaining osmotic pressure required for normal physiological functions.
6) **Metabolic medium:** Haemolymph serves as a medium for on going metabolic reactions (trehalose is converted into glucose).

Functions of Haemolymph

7) **Reflex bleeding:** Exudation of haemolymph through slit, pores etc. to repel natural enemies.
Eg: In Aphids.

8) **Hydraulic medium:** Hydrostatic pressure developed due to blood pumping which is useful in the following processes.

- Ecdysis (moulting).
- Wing expansion in adults.
- Eclosion in diptera (adult emergence from the puparium using **ptilinum**).
- Eversion of penis in male insects.
- Eversion of osmeteria in papilionid larvae.
- Eversion of mask in naiad of dragon fly.
- Maintenance of body shape in soft bodied caterpillars.

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