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M.Sc. ZOOLOGY

[FIRST YEAR]

MZON – 11

STRUCTURE AND FUNCTION OF INVERTEBRATES

SCHOOL OF SCIENCES

TAMIL NADU OPEN UNIVERSITY

577, ANNA SALAI, SAIDAPET, CHENNAI – 600 015

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Curriculum Design

Dr. T. Ravimanickam
Associate Professor
School of Science
Tamil Nadu Open University,
Chennai – 15

Dr. S. Vinod Kanna
Assistant Professor
School of Science
Tamil Nadu Open University,
Chennai – 15

Course Writer

Dr. K. Venkatramalingam
Assistant Professor
Department of Zoology
Government Arts college (Arts)
Salem – 7

Content Editor

Dr. T. Ravimanickam
Associate Professor
School of Sciences
Tamil Nadu Open University, Chennai – 15

Course Coordinator

Dr. T. Ravimanickam
Associate Professor
School of Sciences
Tamil Nadu Open University, Chennai – 15

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MZON-11: STRUCTURE AND FUNCTION OF INVERTEBRATES

SCHEME OF LESSONS

BLOCK I: ORGANIZATION OF ORGANISMS

UNIT- 1

Structural Organization

Structure

Objectives

Overview

Answers To Check Your Progress

Objectives

After studying this unit, the students will be able to

- Explain the organization of structure of invertebrates
- Describe the symmetry in invertebrates
- Explain the coelom and metamerism in invertebrates

Overview

In this unit, we will study about the organization and symmetry in invertebrates. Here, we will focus on the levels of body and structural organization, such as unicellular organisms, multicellular organisms, tissue level of organization, organ level of organization and organ system level of organization, symmetry and types of symmetry, such as asymmetrical, bilateral, spherical, radial, tetramerous, pentamerous, hexamerous, octomerous, biradial symmetry and significance of symmetry.

1.0. INTRODUCTION

Zoology explains the knowledge of the different kinds of animals; students were content to spend much of their time studying the anatomy, relationships and classification of the various groups. A first step in this process is the recognition of the major group's phylum, class, order - to which the animals belong. This study is intended to help with the placing of animals into groups and to provide the information on which their classification is based. The book is therefore a summary of an immense amount of knowledge about invertebrate animals.

All animals have a level of body organization like unicellular, multicellular, tissue level, organ level and lastly organ system level. The body form of animal is classified based on outside structure arranged around the imaginary central axis of the animal called symmetry which is fundamental in understanding the organization of an animal. Symmetry in animals is balanced distribution of paired body parts. Animals have various kinds of cavities in their bodies, simple to complex and these cavities are developed into embryos. Accordingly, animals are classified under two categories-deuterostom and protostome.

1.1. LEVELS OF BODY /STRUCTURAL ORGANIZATION

The structural hierarchy of life comprises the cell, which is the lowest level of organization, capable of living as an organism.

1.1.1. UNICELLULAR ORGANISMS

Unicellular organisms are the creatures formed from a cell. Examples include protozoan phylum organisms.

1.1.2. MULTICELLULAR ORGANISMS

Multicellular organisms are organisms that consist of more than one cell, such as all animals, with the exception of protozoa.

1.1.3. TISSUE LEVEL OF ORGANISATION

Cells gather and begin to work together in organisms, this is called a tissue, its first seen in the phylum porifera.

1.1.4. ORGAN LEVEL OF ORGANIZATION

Few tissues come together and begin to work together, it is called an organ. Eg. Testicles and ovary in coelenterates.

1.1.5. ORGAN SYSTEM LEVEL

The digestive system (mouth, esophagus, stomach, intestine, rectum, and anus along with salivary glands, liver, and pancreas) is an example of the most evolved method of carrying out physiological functions in a body.

1.2. SYMMETRY

The arrangement of body parts in an animal in relation to the central axis is called symmetry. The idea of symmetry is derived from **Ernst Haeckel.** An animal is said to be **symmetrical** only when a plane passing through its center axis will divide it into similar halves. When an animal can not be divided into similar halves, it is said to be **asymmetrical**.

1.2.1. TYPES OF SYMMETRY

1.2.1.1. ASYMMETRICAL SYMMETRY

In some animals, there is no body axis and no plane of symmetry. The body parts are irregularly arranged around the central axis. Hence, these animals cannot be divided into two equal halves; this type of symmetry is called asymmetrical. The amoeboid forms (e.g., Amoeba) and many sponges have irregular growth pattern of the body and cannot be divided into two equal halves.

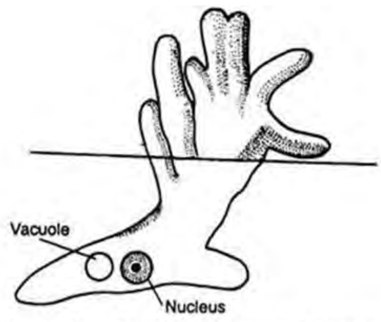


Diagram of *Amoeba* showing the asymmetrical symmetry

Fig.1.1. Asymmetrical symmetry in amoeba

1.2.1.2. BILATERAL SYMMETRY

The animals exhibiting bilateral symmetry are called bilateria. The division or longitutidinal split of the animal's body through a central axis produces two mirror-images (right and left halves) in bilateral. Animals with bilateral symmetry have anterior and posterior, dorsal and ventral, right and left sides. The body parts are arranged on the two sides of the central axis. In bilateral symmetry, the animal is divisible into roughly mirror image halves through one plane (mid sagittal plane) only. Flat worms were the first bilaterally symmetrical animals and other higher groups such as annelids, arthropods, some mollusks and chordates are all bilaterally symmetrical.

Examples - butterfly, crab, or human body.

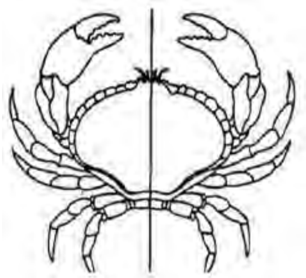


Fig.1.2. Bilateral symmetry in crab

A bilateria's body can be divided into three planes.

(i) Frontal

(ii) Sagittal

(iii)Transverse

Any of the vertical planes perpendicular to the sagittal plane that passes through the body separating the upper and lower side is called the frontal plane. The upper side is also called dorsal, which is usually away from the ground and near the back of the animal. The lower side is also called ventral, which is usually facing towards the ground. A longitudinal plane that passes along the axis of the body of a bilaterally symmetrical animal to separate right and left sides is called the mid-sagittal plane.

1.2.1.3. SPHERICAL SYMMETRY

In spherical symmetry, the shape of the body is spherical. The body can be divided into two identical halves in any plane that runs through the organism's centre. In this type of symmetry, the body of the individual can be divided into similar halves by any plane passing through the centre. In spherical symmetry, polarity does not exist.

Examples-Volvox, some sponges and some corals.

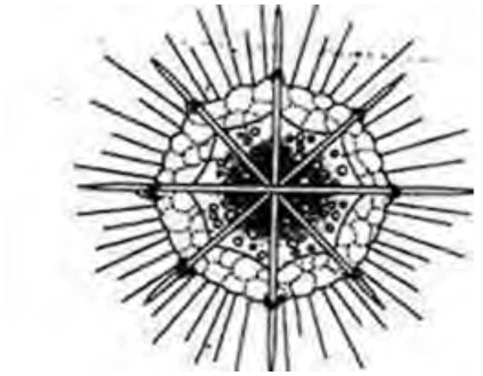
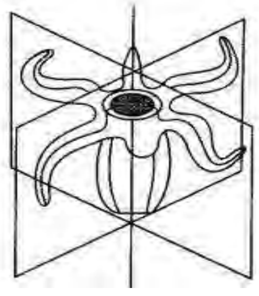


Fig.1.3. Spherical symmetry in radiolarian

1.2.1.4. RADIAL SYMMETRY

In radial symmetry, the body can be divided into two equal halves by any vertical planes passing through the central axis, like the spokes of a wheel. The animals which exhibit primarily radial symmetry are cylinder in form and the similar parts of the body are arranged equally around the axis. The axis extends from the centre of the mouth to the centre of the aboral side. The radial symmetry is seen among the sessile and sedentary animals. The type of symmetry is found in some sponges (Sycon), cnidarians (e.g. Hydra jelly), and echinoderms (e.g. star fish). This type of symmetry is found in Coelenterates and Echinoderms in which body parts are arranged along the main longitudinal axis of the body.



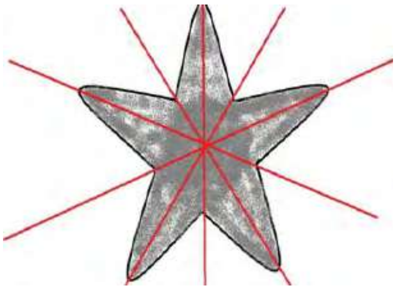


Fig.1.4. Radial symmetry

1.2.1.5. TETRAMEROUS SYMMETRY

Many jelly fishes possess 4 radial canals and the body can be divided into 4 equal parts. Hence, the animals exhibit tetramerous radial symmetry.

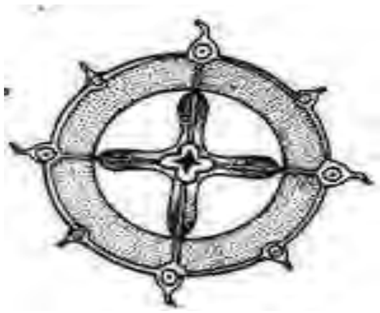


Fig.1.5. Petramerous symmetry

1.2.1.6. PENTAMEROUS SYMMETRY

Most echinoderms possess pentamerous radial symmetry because the body can be divided into 5 roughly equal parts. The body parts are arranged around the axis of the mouth at orientations of 72° apart. The larvae of echinoderms are bilaterally symmetrical but acquire radial symmetry in the adult stage. The radial symmetry of echinoderms is regarded as a secondary acquisition.

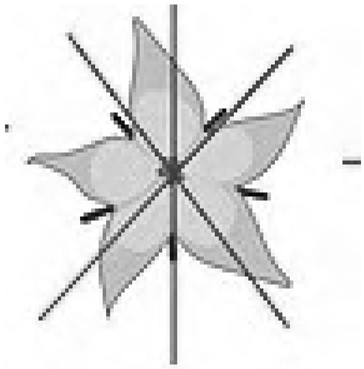


Fig.1.6. Pentamerous symmetry

1.2.1.7. HEXAMEROUS SYMMETRY

The sea anemones and true coral polyps belong to the subclass Hexacorallia (class Anthozoa). The mesenteries and tentacles are arranged in a six-fold pattern. Mesenteries are typically paired and arranged in multiples of six. The body of the hexacorallian polyp exhibits hexameric plan and it has six-fold in internal symmetry.

1.2.1.8. OCTOMEROUS SYMMETRY

The body of octocorallian polyps (subclass Octocorallia) shows octomeric radial symmetry and contains 8 hollow marginal tentacles and 8 mesenteries and the body can be divided into 8 equal parts. The animals with radial symmetry do not have anterior and posterior sides or dorsal and ventral surfaces. They have a mouth bearing the oral side and the side away from the mouth is called the aboral side.

Fig.1.7. Octomer symmetry

1.2.1.9. BIRADIAL SYMMETRY

The body of animals which exhibits biradial symmetry represents a combination of both radial and bilateral symmetry. The organs are arranged radially and the body can be divided into two by a mid-longitudinal plane. Ctenophores exhibit biradial symmetry which are not sedentary but floating animals and show a mixture of bilateral and radial symmetry. Animals such as *Pleurobrachia* have an oval body on which eight comb plates are radially arranged like bands and are used for swimming, whereas mouth, anal pore and statocysts are placed on the anterio-posterior axis. They also have a pair of retractile tentacles. Tentacles demonstrate bilateral symmetry whereas comb plates show radial symmetry.

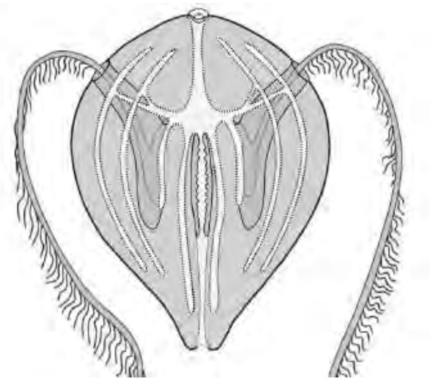


Fig.1.8. Biradial symmetry

1.2.1.10. SIGNIFICANCE OF SYMMETRY

Bilateral symmetry is linked to cephalisation, which is the formation of the anterior end (head of the body) containing nervous tissues, sense organs, and feeding organs. A Bilaterally symmetrical body plan may help animals to find food materials. Other advantages of this symmetry are the streamlining of the body, development of different organs in different body regions and more efficient unidirectional movement. Radial symmetry is useful because the animal can just "sit down" and grab food or detect threats from all directions. Radial symmetry is advantageous to sedentary organisms because sensory receptors are evenly distributed around the body.

Let Us Sum Up

In this unit, we studied about the organization and symmetry in invertebrates. Under this unit, we focused on the levels of body and structural organization, such as unicellular organisms, multicellular organisms, tissue level of organization, organ level of organization and organ system level of organization, symmetry and types of symmetry, such as asymmetrical, bilateral, spherical, radial, tetramerous, pentamerous, hexamerous, octomerous, biradial symmetry and significance of symmetry.

Check Your Progress

1) The idea of symmetry is derived from __________.
2) Symmetry in the animals is balanced distribution of __________.
3) Few tissues come together and begin to work together, this is called __________.
4) There are __________ types of symmetry are present.

Glossaries

Symmetry	:	Arrangement of body parts in relation to the central axis.
Coelom	:	Fluid-filled cavity that accommodates organs.
Metamerism	:	Similar body segments that are serially repeated.

Suggested readings

1. **MOORE, R.C., LOLICKER** and **FISCHER, A.G**. (1952), Invertebrate Paleontology, McGraw Hill Book Co., Inc., New York.
2. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.

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Animal kingdom https://youtu.be/Q8iWZ3bF5m8

Answers to check Your Progress

1) Ernst Haeckel
2) Paired body parts
3) Organs
4) 9

UNIT- 2

Body Coelom

Objectives

After studying this unit, the students will be able to

- Explain the structure of coelom
- Differentiate the types of coeloms
- Describe the significance of coelom in invertebrates

Overview

In this unit, we will study about the coelom and evolution of coelom in invertebrates. Here, we will focus on the body cavity, acoelomates, eucoelomates, protostomes, deuterostomes, schizocoelom, myocoelom, evolution of coelom theories, such as enterocoel theory, gonocoel theory, nephrocoel theory and schizocoel theory, significance of coelom, coelomic fluid definition and significance of coelomic fluid.

2.1. BODY CAVITY

A body cavity is any space or compartment, or potential space in the animal's body. The coelom is fluid-filled and it accommodates organs. A Coelom is a cavity between the body wall and gut wall, lined by mesoderm. Triploblasts may develop an internal body cavity derived from mesoderm, called a coelom.

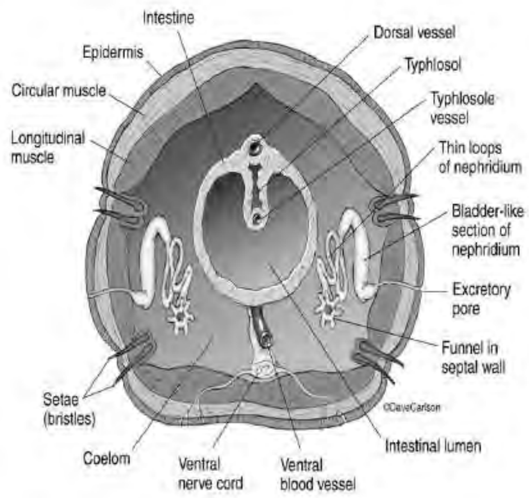

Fig.2.1. Structure of body acvity

2.2. ACOELOMATES

The Acoelomata are relatively simple triploblastic animals which have no perivisceral body cavity or coelom. Triploblasts that do not develop a coelom are called **acoelomates**. The space between the digestive tract and the body wall is filled with a tissue known as parenchyma derived from the mesoderm.

Example - flatworms.

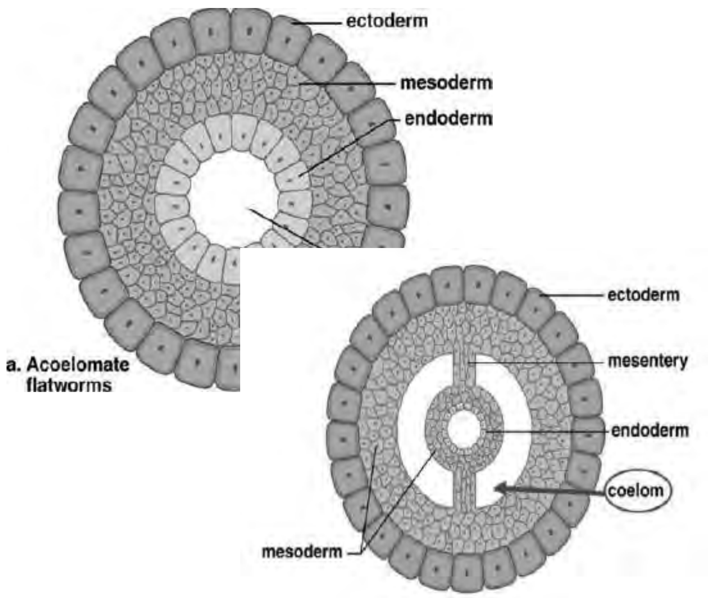

Fig.2.2. Acoelomate flatworm

2.3. EUCOELOMATES

Animals with a true coelom are called eucoelomates or coelomates. A body cavity is present between the digestive tract and the body wall, which is lined by epithelial cells. This cavity is called a coelom. A true coelom arises entirely within the mesoderm germ layer. The cavity communicates with the exterior by the reproductive and excretory ducts.

Examples - Earthworms, Snails, Insects, Starfish, and Vertebrates.

2.4. PROTOSTOMES AND DEUTEROSTOMES

Bilaterally symmetrical, triploblastic eucoelomates can be divided into two groups based on differences in their early embryonic development. They are,

1. Protostomes
2. Deuterostomes

2.4.1. PROTOSTOMES

The word *protostome* comes from Greek words meaning "mouth first". The opening of the digestive cavity or coelom first develops in the mouth.

Examples-Arthropods, Molluscs and Annelids.

2.4.2. DEUTEROSTOMES

Deuterostome originates from words meaning "mouth second". In this, the opening of the digestive cavity or coelom develops, the anus develops first. This is determined by the fate of a structure called the blastopore. Other developmental characteristics differ between protostomes and deuterostomes, including the mode of formation of the coelom and the early cell division of the embryo.

Example - Chordates and Echinoderms.

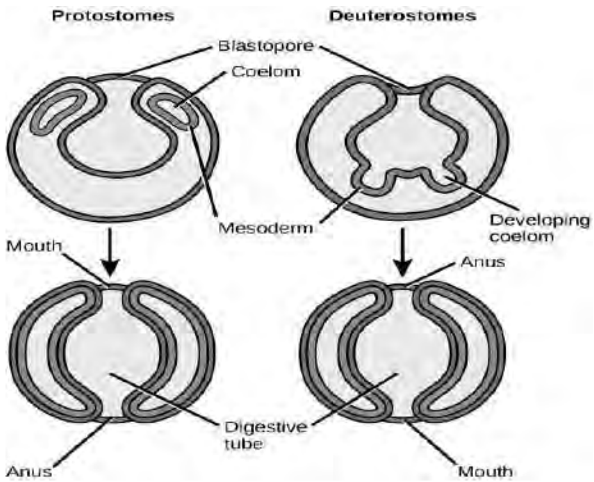

Fig.2.3. Deuterostomes in chordates and echinodermates

2.5. SCHIZOCOELOM

Schizocoelom is present in protostomes. The body cavity originates from the splitting of mesoderm. One part attaches to the ectoderm and the other surrounds the endoderm. The gap between them grows into a coelom. The blastopore forms a mouth. This body cavity is formed from blocks of mesoderm around the gut that enlarge and hollow out.

Examples-Annelida, Mollusca and Arthropoda.

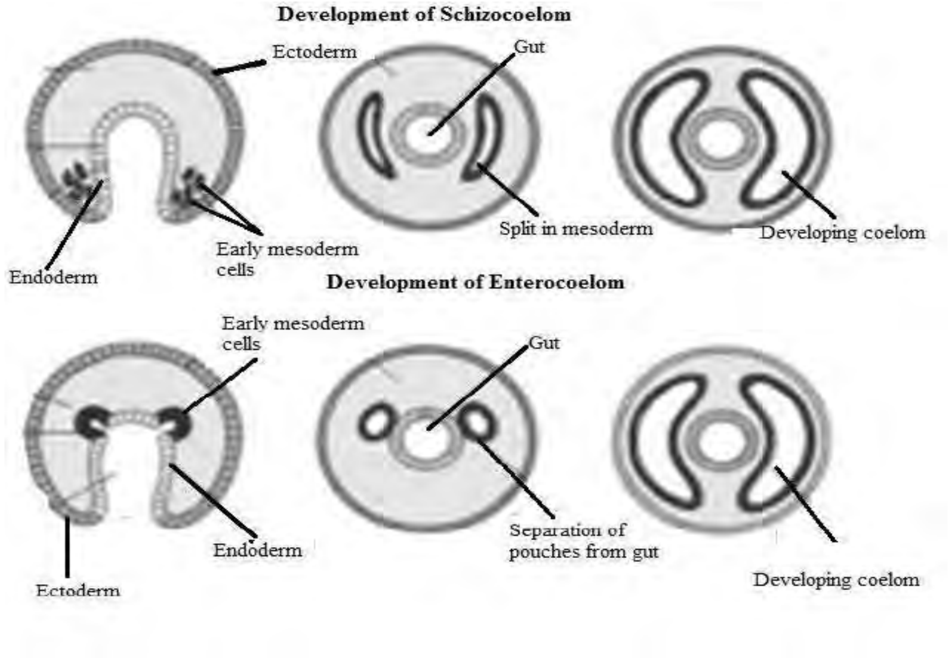

Fig.2.4. Schizocoelom in annelids, molluscs and arthropods

2.6. ENTEROCOELOM

Enterocoelom develops from the embryonic gut or endoderm pocketing. In this type, the body cavity is formed by a primitive gut that breaks off and forms the coelom. It is present in the deuterostomes. The coelom is developed from the fusion of the internal outgrowths of the archenteron, that pinches off and fuses together to form coelom lined by mesoderm.

Examples-Echinodermata and Chordata

2.7. MYOCOELOM

This type of coelom originates in Phoronida in which the mesenchyme rearranges to enclose a place called coelom. It is an unusual method of coelom formation. It is neither enterocoeloms nor schizocoeloms.

2.8. EVOLUTION OF COELOM

The evolutionary origin of the coelom is uncertain. Initially, two theories were proposed:

1. The acoelomate theory holds that coelom descended from an acoelomate ancestor.
2. The enterocoel theory proposes that coelom evolved from cnidarian ancestors' gastric pouches.

This is supported by research on flatworms and small worms recently discovered in marine fauna. Later, Clark (1964) discussed four different theories regarding the origin and evolution of Coelom.

2.8.1. ENTEROCOEL THEORY

This theory was first proposed by Lankester in 1877, supported by Lang (1881), Sedgwick (1884). This theory states that the coelom may have originated by evagination as pouch like structures in the wall of the embryonic archenteron. This type of coelom formation occurs in many existing enterocoelous animals. The gastric pouches of anthozoans (Cnidaria) became separated from the main gastric cavity (gastrovascular cavity) and were transformed into coelomic pouches.

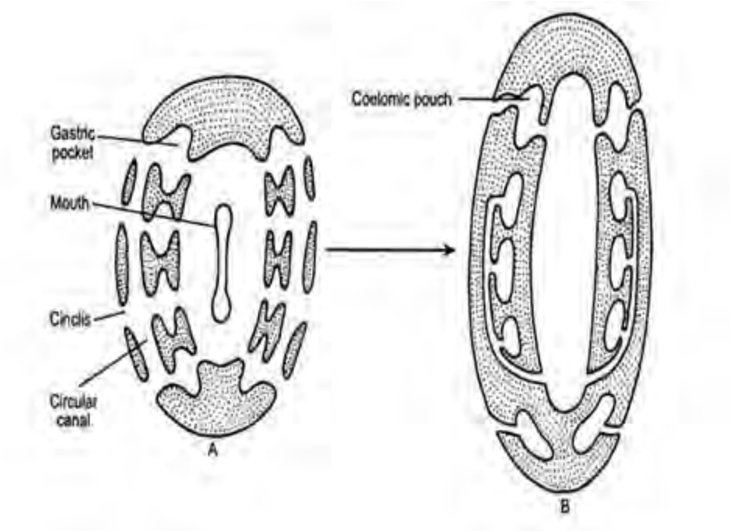

Fig.2.5. Transformation of gastric pockets in anthrozons

2.8.2. GONOCOEL THEORY

The Gonocoel theory was proposed by Meyer (1890) and Goodrich (1946). The origin of coelom arises from the mesodermally derived expanded gonadal cavities and the cavities persisted after the release of gametes. For example, the gonads of tricladid flatworms are arranged in a linear order and the segmental coelom of annelida may have developed from this tricladid.

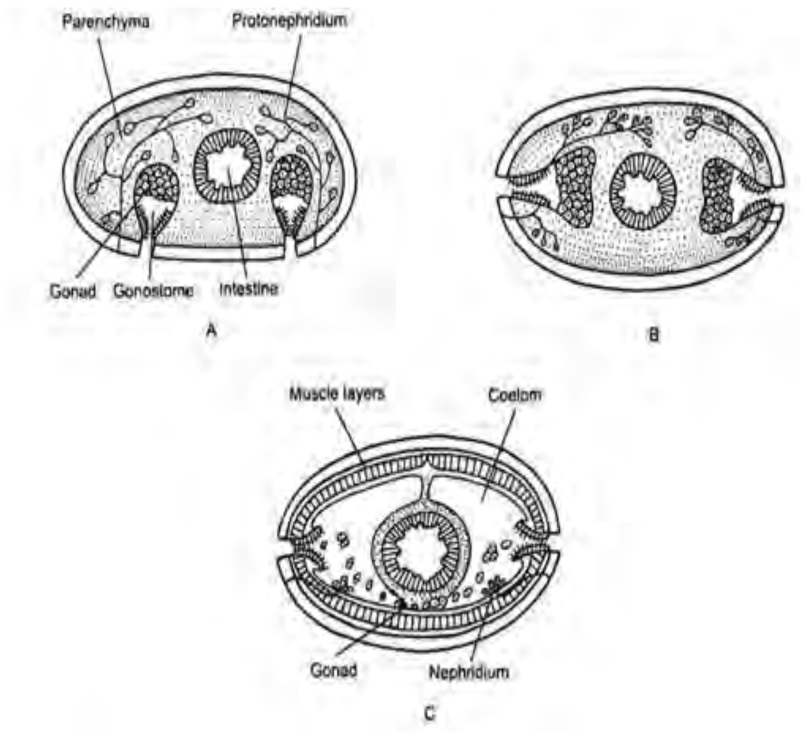

Fig.2.6. Diagrams showing the gonocoel theory of coelom formation

2.8.3. NEPHROCOEL THEORY

This theory was proposed by Lankester (1874) and Snodgrass (1938). This theory states that the coelom originated from the expanded nephridia of flatworms. The chief objection to this theory is that protonephridia has not been recorded in all coelomates, even the echinoderms do not have excretory organs.

2.8.4. SCHIZOCOEL THEORY

The Schizocoel theory was proposed by Clark (1964). The theory states that the coelom could have evolved by the splitting of mesodermal plates.

2.9. THE IMPORTANCE OF COELOM

The coelom is extremely important in the lives of animals. These are:

(i) The coelomic fluid content facilitates smooth transportation of particles or materials in solution.

(ii) Coelom functions as a shock absorber and protects against mechanical shock. Coelom affords flexibility to the body organs to move and protects them from any damage during bends of the internal organs.

(iii) Gonads which develop from coelomic epithelium are housed in the cavity of the coelom. So also, are the nephridial tubules, which connect the coelom to the exterior and in some cases allow the passage of eggs and sperm.

(iv) The coelom is a hydrostatic skeleton that aids in the locomotion of soft-bodied animals and gives the body a definite shape. It is filled with incompressible coelomic fluid.

(v) The coelomocyte cells that either float freely in the coelom or are attached to the wall support the immune system. They support the immune system by initiating humoral immune response and phagocytosis.

(vi) The coelomic fluid also helps in gaseous transport and transport of nutrients and waste products.

(vii) Coelom gives the extra space required by organs to develop and function. Because of coelom, things like heart pumping, carrying a child in the womb, and so on are possible.

2.10. COELOMIC FLUID DEFINITION

The fluid inside the coelom is known as coelomic fluid. This is circulated by mesothelial cilia or by contraction of muscles in the body wall which are themselves of mesin.

2.11. SIGNIFICANCE OF COELOMIC FLUID

The coelomic fluid serves several functions:

(i) It acts as a hydroskeleton

(ii) It allows free movement and growth of internal organs.

(iii) It serves for transport of gases, nutrients and waste products around the body.

(iv) It allows storage of sperm and eggs during maturation; and it acts as a reservoir for waste.

Let Us Sum Up

In this unit, we studied about the coelom and evolution of coelom in invertebrates. Under this unit, we focused on the body cavity, acoelomates, eucoelomates, protostomes, deuterostomes, schizocoelom, myocoelom, evolution of coelom theories, such as enterocoel theory, gonocoel theory, nephrocoel theory and schizocoel theory, significance of coelom, coelomic fluid definition and significance of coelomic fluid.

Check Your Progress

1) __________is the cavity between the body wall and gut wall.
2) Triploblast that do not develop a coelom are called __________.
3) In the early embryonic stages, the triploblastic eucoelomates are divided into two groups, they are __________ and __________.
4) The fluid inside the coelom is called __________.

Glossaries

Coelom	:	It is the principal body cavity in most animals, located between the intestinal canal and the body wall.
Gonocoel	:	It is the cavity that contain gonads.
Myocoel	:	It is a coelomic cavity which forms in the part of mesoderm.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Coelom https://youtu.be/vezNURbyQtc

Answers to check Your Progress

1) Coelom
2) Acoelomates
3) Protosomes and deuterostomes
4) Coelomic fluid

UNIT-3

Metamerism

Answers To Check Your Progress

Objectives

After studying this unit, the students will be able to

- Explain metamerism in invertebrates
- Describe the evolution of metamerism in invertebrates with theories
- Explain the significance of metamerism in in invertebrates

Overview

In this unit, we will study about the metamerism and evolution of metamerism in invertebrates. Here, we will focus on the occurrence of metamerism, characteristic features of metamerism, types of metamerism, such as true metamerism, homonomous metamerism, heteronomous metamerism, external metamerism, internal metamerism, complete metamerism, incomplete metamerism and pseudometamerism, theories of origin and evolution of metamerism such as, pseudometamerism theory, fission theory, cyclomerism theory, locomotory theory, embryological theory, and significance of metamerism.

3.1. METAMERISM

Metamerism is a Greek term. Meta means after, mere denotes part. Metamerism is an architectural body plan in which similar body segments and organ systems are serially repeated one after another. The similar body segments are called metameres or somites. Metamerism is the phenomenon of having a linear series of body segments fundamentally similar in structure, though not all such structures are entirely alike in any single life form because some of them perform special functions. The animals which exhibit such features are called metamerically segmented. Structurally, each metamere or somite is constructed on the basis of some fundamental plan and usually possesses a part of almost all the body systems.

The body of Annelids is divided into a number of segments longitudinally. All the segments look alike. They are called metameres and this is called metamerism. In these segments, all systems are repeatedly arranged. The metameric segmentation in annelids is both external and internal. The body is divided into a number of segments which contain all body organs, but the alimentary canal is a long and straight tube extending through all the segments. The caphalic and anal regions may not be metameric because sense organs are present in the caphalic region, whereas new segments are produced in front of the anal segment in the anal region. In arthropods the segmentation is external. Internal segmentation is found in chordates.

3.2. OCCURRENCE OF METAMERISM

Metamerism was first reported in annelids in the animal kingdom. Each segment contains appendages, muscles, nerves, blood vessels, excretory organs and a pair of coelomic sacs which are repeated in all segments. It is also seen in kinorhynchs, arthropods and most chordates. Recent studies state that the cestodes are metamerically segmented but the metamerism of these animals is of a different type.

3.3. METAMERISM'S DISTINGUISHING FEATURES

1. Metamerism is always confined to the intermediate trunk segments except the anterior head and a posterior pygidium or telson.
2. Each metamere represents a mirror image of the other.
3. Segmental structures are interdependent on each other.
4. They are combined to form a single functional unit.
5. All the segments of the body work in coordination.

3.4. TYPES OF METAMERISM

3.4.1 GENUINE METAMERISM

In true metamerism, the segmentation of the body develops by the segmentation of the mesoderm. New segments are developed at the posterior end in front of the pygidium and the older segment occurs at the anterior end just behind the head.

True metamerism is found in annelids, arthropods and in most chordates. The body of annelids consists of a number of segments and the number remains constant in a particular species except in certain cases of asexual reproduction. The segmental structures are inter-dependent and integrated so that the individuality of the body is preserved. The segments jointly work with all other segments.

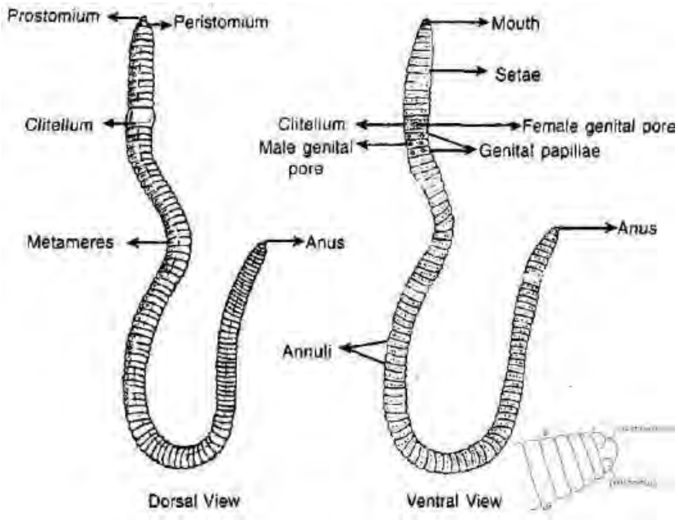


Fig.3.1. Metamerism in annelids

3.4.2. HOMONOMOUS METAMERISM

In homonomous metamerism, the segments or somites of the animal are similar and identical. This is a primitive type of segmentation. It is not found in any existing animal because a few anterior segments are specialised to form the head, which is called cephalization. Each metamere contains segmental blood vessels, nerves, nephridia and coelomoducts. This type of segmentation is found in polychaetes. The formation of a 'head' is suggested in polychaetes by anteriorly placed structures and their association with parapodial cirri.

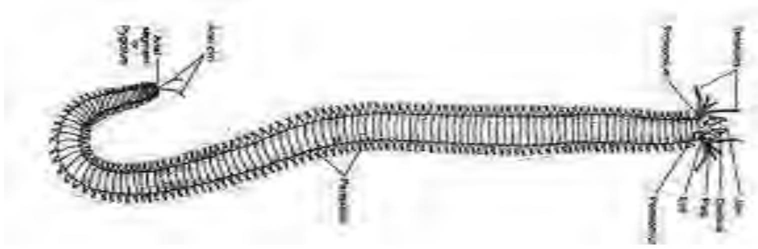


Fig.3.2. Homonomous metamerism in polychaete

3.4.3. HETERONOMOUS METAMERISM

The body segments of arthropods and chordates are dissimilar. Different body regions have different sizes of segments according to certain organ systems. This type of metamerism is called heteronomous metamerism.

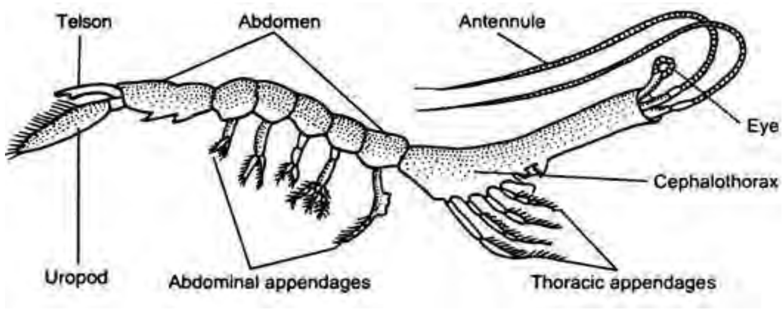


Fig.3.3. Heteronomous segmentation in crustacean

3.4.4. EXTERNAL METAMERISM

In arthropods, the metamerism is external. Internally, the segments are not marked by partitions.

3.4.5. INTERNAL METAMERISM

In vertebrates there is internal metamerism, seen in the embryos and confined to the muscular, skeletal (vertebrae and ribs) and nervous system.

3.4.6. COMPLETE METAMERISM

When the segmentation is visible in all organs, the metamerism is referred to as complete metamerism. It is found in annelids. The larval and embryonic stages of Arthropods and other vertebrates exhibit complete metamerism with uniform metameres, but these metameres become unclear as the adlts specialization progresses.

3.4.7. INCOMPLETE METAMERISM

When the segmentation is not seen in all the organs, the metamerism is called incomplete metamerism. It is seen in arthropods and chordates. Metamerism in Arthropods and other higher animals is incomplete because of division of labour.

3.4.8. PSEUDO-METAMERISM OR STROBILIZATION

Pseudometamerism or strobilization is found in tapeworms (Platyhelminthes) where segmentation of the body is developed by the segmentation of the ectoderm. The body consists of a number of segments or proglottids which vary in different individuals of the same species. New segments are added to the body throughout life. The proglottids or segments differ in the degree of development. The segments or proglottids are functionally independent. There is no cooperation between the segments. The new segments are formed at the anterior end, just behind the scolex.

3.5. THEORIES OF ORIGIN AND EVOLUTION OF METAMERISM

3.5.1. PSEUDOMETAMERISM THEORY

This theory was proposed by Hymen and Goodrich in 1951. According to this theory, metamerism evolved secondarily as a result of the repetition of body parts such as blood vessels, coelom, nerves, and so on. Later, a segmented condition is aroused by the formation of cross-partitions between them, so that each segment receives a part of each system. Whose ancestor was acoelomate and unsegmented, as seen in cestodes like tapeworms. It contained the various systems or organs which had serially spread out along the entire length of the body (pseudo-segmentation).

3.5.2. FISSION THEORY

This theory was proposed by Perrier in 1882. According to this theory, the metameric segmentation formed from some non-segmented ancestors divided repeatedly by transverse fission or asexual budding to produce a chain of sub-individuals or zooids. Even modern-day Annelids and Platyhelminthes animals go through this process. Later, these sub-individuals integrated morphologically and physiologically into one complex individual. Thus, according to this theory, a segmented animal is a chain of completely coordinated sub-individuals.

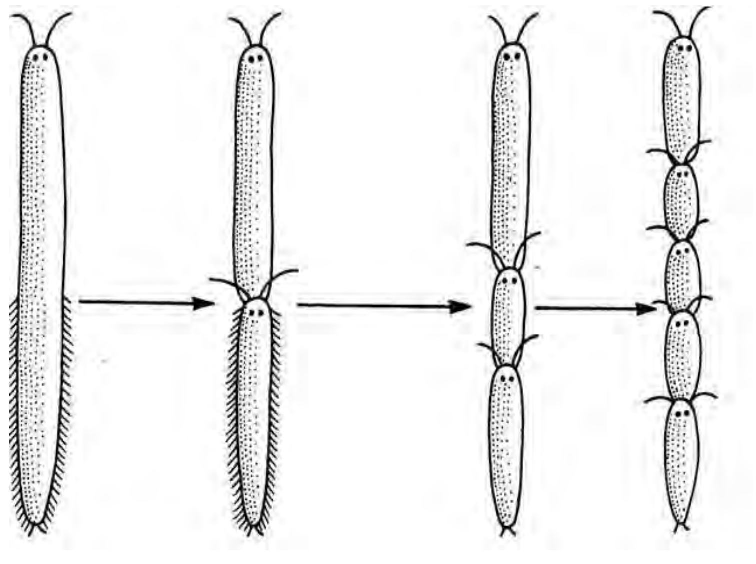


Fig.3.4. Fission in species platyhelminthes

3.5.3. CYCLOMERISM THEORY

This theory was proposed by Sedgwick in 1884 and supported by Remane in 1950 and 1963. Metamerism in chordates evolved for better organ arrangement in coelom, according to this theory. This theory assumes that coelom originated in some ancestral radiate actinozoan coelenterates, through the separation of four gastric pouches from the central digestive cavity. Initial division of two pouches resulted in three pairs of coelomic cavities, namely protocoel, mesoscoel and metacoele in ancestral coelomates. Later, the loss of protocoel and mesoscoel led to unsegmented coelomates like Molluscs. Then the sub division of metacoele produced primary segments, leading to the development of segmented Annelids. This created septa and compartments in the coelom, allowing organs to be better arranged.

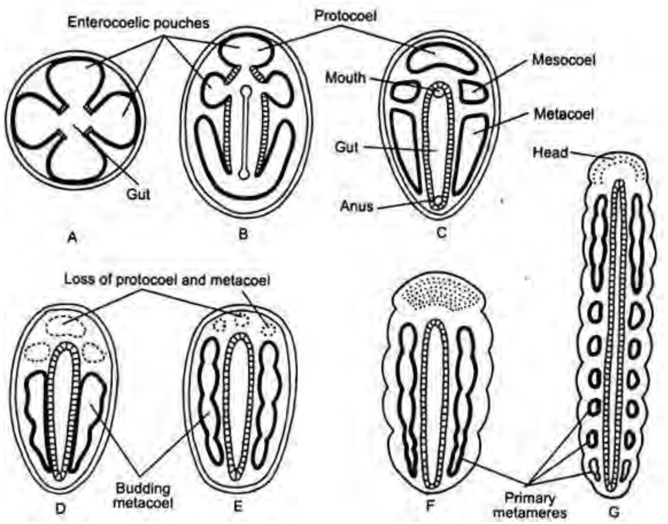


Fig.3.5. Cyclomerism in coelenterates

3.5.4. LOCOMOTORY THEORY

R.B. Clark (1964) proposed the locomotion theory to explain the origin of metamerism. This theory postulates that metamerism evolved as an adaptation to different kinds of locomotion. Metamerism in Annelids most likely evolved as an adaptation to peristaltic locomotion and burrowing. Locomotion involves shortening and lengthening of the body by circular and longitudinal muscles which act against each other. As coelom is filled with coelomic fluid which acts as a hydrostatic skeleton to facilitate locomotion, but peristaltic movement is not possible until it is compartmented by the development of septa. The development of compartmented coelom confines fluid pressure to a specific region of the body and does not affect the entire body.

The septa and metameric segmentation together allow the part of the body to contract and other parts in the longitudinal axis relax. This enables a strong peristaltic wave to propagate down the body. For burrowing, the animals need a hard skeleton but they lack such structure and the coelomic fluid, and inter-segmental septa act as hydraulic skeleton. In chordates, metamerism evolved independently of locomotion. Metamerism allowed the tail muscles to be arranged segmentally for the undulatory movement of the body.

3.5.6. EMBRYOLOGICAL THEORY

It suggests that mechanical stresses in the mesoderm during elongation of the embryo or larva resulted in mesoderm fragmentation, manifested in the adult as a meristic repetition of all mesodermal derivatives.

3.6. METAMERISM'S IMPORTANCE

1. Fluid filled coelomic compartments provide hydrostatic skeletons for burrowing. Differential turgor pressures caused by the flow of coelomic fluid from one part of the body to the other can cause precise movements.
2. Metamerism offers division of labour. Different segments can be specialized for different functions, leading to the development of a high grade of organization.
3. Metameres help not only in burrowing but also in all types of locomotion.
4. Metamerism helps in finding and feeding food particles.
5. The repetitions of parts or organs in the metameres are useful; if the organs in one segment fail, the organs in other segments may be functional.
6. The loss of segments containing reproductive cells does not result in the animal's death in a metameric organism.
7. Metamerism helps in swimming, burrow formation movement, bending of annelida.

Let Us Sum Up

In this unit, we studied about the metamerism and evolution of metamerism in invertebrates. Under this unit, we focused on the occurrence of metamerism, characteristic features of metamerism, types of metamerism, such as true metamerism, homonomous metamerism, heteronomous metamerism, external metamerism, internal metamerism, complete metamerism, incomplete metamerism and pseudometamerism, theories of origin and evolution of metamerism such as, pseudometamerism theory, fission theory, cyclomerism theory, locomotory theory, embryological theory, and significance of metamerism.

Check Your Progress

1) The similar body segments are called ___________.
2) Metamerism was first reported in ___________ in the animal kingdom.
3) ___________ types of metamerism are present in the animals.
4) Fluid filled coelomic compartments provide ___________ for burrowing.

Glossaries

Metamere	:	These are somites.
Strobilization	:	It is a form of asexual reproduction in certain cnidarians and helminths.

Suggested readings

1. **MOORE, R.C., LOLICKER** and **FISCHER, A.G**. (1952), Invertebrate Paleontology, McGraw Hill Book Co., Inc., New York.
2. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.

Weblink

Metamerism https://youtu.be/pW9bXTWLzME

Answers to check Your Progress

1) Metamerism
2) Annelids
3) 8
4) Hydrostatic skeleton

BLOCK II: LOCOMOTION AND NUTRITION

Unit 4 **Locomotion**

Unit 5 **Hydrostatic Skeleton**

Unit 6 **Nutrition in Lower MetazoanUnit 7 Filter-Feeding**

UNIT- 4

Locomotion

Structure

Objectives

Overview

4.3.9. Rolling movement theory

4.3.10. Walking moment theory

4.3.11. Reticular theory

4.3.12. Reversible gel-sol transformation theory

4.4. Flagellum

4.4.1. Flagella Structure

4.4.2. Ultra Structure of flagellum

4.5. Types of Flagella

4.5.1. Anematic

4.5.2. Stichonematic

4.5.3. Pantonematic

4.5.4. Acronematic

4.5.5. Pentacronematic

4.5.6. Monotrichous

4.5.7. Peritrichous

4.5.8. Lophotrichous

4.5.9. Amphitrichous

4.6. Movement types of flagella

4.6.1. Tractellum

4.6.2. Pulsellum

4.6.3. Undulation movement

4.6.4. Sidewise lash movement

4.6.4.1. Effective stroke

4.6.4.2. Recovery stroke

4.6.5. Simple conical gyration movement

4.7. Theories of flagellar locomotion

4.7.1. Screw propellar theory

4.7.2. Sidewise Lashing Movement/Theory of Ulehla and Krijsman

4.7.3. Metzner's theory

Objectives

After studying this unit, the students will be able to

- Explain the locomotion in invertebrates
- Describe and illustrate the locomotion in invertebrates
- Explain the flagellar and ciliary movement in protozoa

Overview

In this unit, we will study about the locomotion in invertebrates. Here, we will focus on the locomotion exhibited by Protozoans, theories supporting the amoeboid movement, flagellum, types of flagella, movement types of flagella, theories of flagellar locomotion, functions of flagella, cilia, types of cilia, ciliary movement and molecular basis of ciliary movement.

4.0. INTRODUCTION

4.1. LOCOMOTION

Movement is a trademark in the life of animal life. Sessile animals have to move their surrounding water or air in order to catch food, usually by using their tentacles or by using beating cilia to generate water currents and capture small food particles. Most animal phyla include species that swim, but whether living on land or in the sediments of the sea floor and lakes, animals crawl, walk, run, hop or stay put. Locomotion requires energy, and most animals spend a considerable amount of their time expending energy to overcome the forces of friction and gravity that tend to keep them stationary.

The energy cost of transport or any kind of movement is different depending on the surrounding environment. In the aquatic environment, most animals are buoyant and overcoming gravity is less of a problem. Because water is a much denser medium than air, the primary problem is resistance/friction, hence the most energy-efficient means of locomotion for aquatic organisms is their adaptation to a sleek, hydrodynamic shape. Invertebrates such as squid, scallops and some cnidarians are jet-propelled using water that they squirt in and out of certain body parts.

At the cellular level, all animal movement is based on two systems of cell motility; microtubules and microfilaments. Microtubules are responsible for the beating of cilia and the undulations of flagella and microfilaments are the contractile elements of muscle cells. But muscle contraction in itself can not translate to movement in the animal unless the muscle has some kind of support to work against and that is some type of a skeleton.

Skeletons support and protect the animal's body and are essential to movement. There are three types of skeletons: the endoskeleton, the exoskeleton and the hydrostatic skeleton. Most cnidarians, flatworms, nematodes and annelids have a hydrostatic skeleton that consists of fluid held under pressure in a closed body compartment. These animals can control their body form and movement by using muscles to change the shape of the fluid filled compartments. Hydrostatic skeletons are ideal for life in aquatic environments and they may protect internal organs from shocks and provide support for crawling and burrowing, but they can not support any form of terrestrial locomotion in which an animal’s body is held off the ground.

The exoskeleton is a hard encasement deposited on the surface of an animal. Most mollusks are enclosed in calcium carbonate shells secreted by a sheet like extension of the body wall, the mantle. Animals increase the diameter of the shell by adding to its outer layer. Arthropods have a joint exoskeleton, the cuticle. As the animal grows in size, the exoskeleton of an arthropod must be periodically molted and replaced by a larger one.

An endoskeleton consists of hard supporting elements buried within the soft tissues of an animal. Sponges, for example, are reinforced by either hard spicules or consisting of inorganic material or soft fibers made of protein. Echinoderms have an endoskeleton of hard plates beneath the skin and sea urchins have a skeleton of tightly bound ossicles. Ossicles of sea stars are more loosely bound, which allows the animal to change the shape of its arms. Chordates have endoskeletons consisting of cartilage, bone or both.

Invertebrates, the animal phyla without backbones, are mostly aquatic, with the exception of earthworms and snails, which can be found on moist soil and vegetation.

4.2. LOCOMOTION EXHIBITED BY PROTOZOANS

Three main types of locomotion are exhibited by protozoans. They are,

I. Amoeboid movement
II. Flagellar movement
III. Ciliary movement.

4.2.1. AMOEBOID MOVEMENT

The movement of the animal is made by the formation of pseudopodium. This is the most primitive kind of movement. In the direction of movement of amoeba, a new pseudopodium is formed and the pseudopodium on the opposite side gradually disappears.

LOCOMOTOR ORGANELLES

Most protozoa possess definite locomotor organelles which are closely associated with the body surface.

4.2.1.1. PSEUDOPODIA

Pseudopodia are also known as false feet. The pseudopodium may be defined as a temporary projection of a part of the cytoplasm mainly formed from the ectoplasm. They act as locomotory and feeding organs. These are characteristic organelles of Sarcodina, certain Sporozoa and many Mastigophora.

4.2.2. TYPES OF PSEUDOPODIA

Pseudopodia is classified into two types based on numbers.

4.2.2.1. MONOPODIA

Only a single pseudopodia is formed on the surface of the body.

Eg: *Entamoeba histolytica*

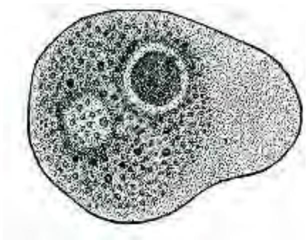


Fig.4.1. Monopodia in *Entamoeba histolytica*

4.2.2.2. POLYPODIA

Several pseudopodia formed on the surface of the body.

Eg: *Amoeba proteus*

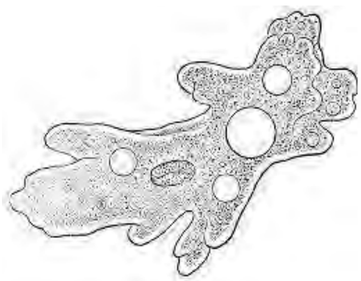


Fig.4.2. Polypodia in *Amoeba proteus*

According to form, structure and activity, four different kinds of pseudopodia are recognized,

They are:

1. Lobopodium
2. Filopodium
3. Reticulopodium or Rhizopodium
4. Axopodium or Actinopodium

4.2.2.3. LOBOPODIUM [GK. LOBES = LOBE; PODIUM = FOOT]

The pseudopodium is broad with rounded or blunt tips. It is a short, finger or tongue-like projection which is accompanied by a flow of endoplasm and ectoplasm. The ectoplasmmic area is distinctly clear, called the hyaline cap. It is the characteristic of many amoebas such as Amoeba, Entamoeba and Arcella.

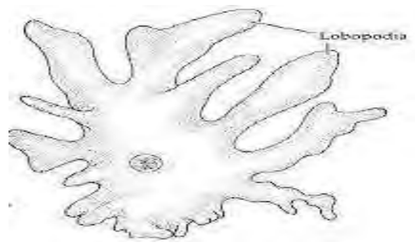


Fig.4.3. Lobopodia

4.2.2.4. FILOPODIUM [L.FILO = A THREAD; PODIUM = FOOT]

The filopodium is a slender, thread-like or filamentous projection. It is formed by the ectoplasm alone and without a hyaline cap. The filaments are narrow and may be branched but do not anastomose. Filopodium is the characteristic in Gromia, Euglypha, etc.

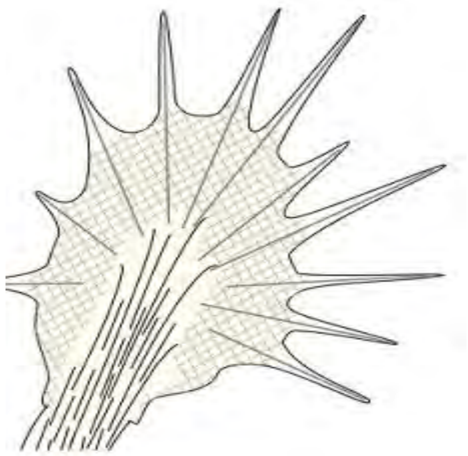


Fig. 4.4. Filopodia

4.2.2.5. RETICULOPODIUM OR RHIZOPODIUM [L. RETICULOS = A NET, PODIUM = FOOT]

They are also known as rhizopodia or myxopodia. They are filamentous, profusely interconnected and branched. They form a network. The primary function of these pseudopodia is ingestion of food and the secondary function is locomotion. They exhibit two way flow of the cytoplasm. They are commonly found in foraminifers.

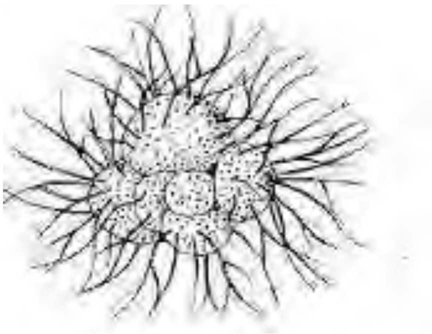


Fig.4.5. Reticulopodium

4.2.2.6. AXOPODIUM OR ACTINOPODIUM [GK. AXO = AN AXLE; PODIUM = FOOT; AKTIS = RAY]

These are fine needle like, straight pseudopodia radiating from the surface of the body. It is a semi-permanent structure and is made up of an axial rod enveloped by cytoplasm. The axial rod is made up of a number of fibrils and arises either from the central part of the body or from the nucleus. The main function of these axopodia is food collection. Axopodia are mainly found in Heliozoans and radiolarians.

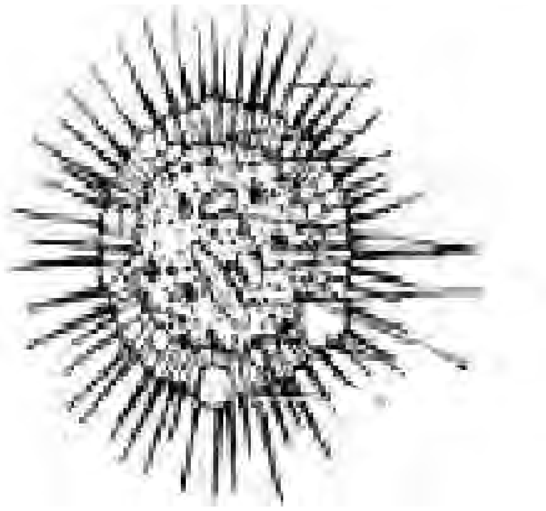


Fig.4.6. Axopodia

4.2.3. MECHANISM OF AMOEBOID MOVEMENT

Pseudopodia form in two ways during the amoeboid movement.

(a) Profluent

(b) Eruptive.

4.2.3.1. PROFLUENT TYPE

The ectoderm bulges out as a blunt projection in the profluent type, and endoplasm flows into this projection. By Profluent method, a single pseudopodium or many pseudopodia may be formed at a time.

4.2.3.1. ERUPTIVE TYPE

Ectoplasm and endoplasm burst out in an eruptive manner in eruptive type by dissolving the cell surface type of pseudopodium is restricted to small forms of amoeba where the gelated ectoplasm layer is very thin.

4.3. THEORIES SUPPORTING THE AMOEBOID MOVEMENT

The Amoeboid movement is considered to be the most primitive kind of animal movement. The following theories have been presented regarding the amoeboid movement. The physiology of pseudopodia formation is explained with the help of the following theories,

i. Surface tension theory
ii. Sol-gel theory or Change of viscosity theory
iii. Molecular folding and unfolding theory
iv. Front contraction theory or Fountain zone theory
v. Rear contraction and Hydraulic theory
vi. Actin and Mysin interaction theory

4.3.1. SURFACE TENSION THEORY

This theory was proposed by Berthold in 1886. In surface tension theory, it is assumed that the pseudopodium is formed from any place on the surface of the body by the change of the surface tension. Because protoplasm is a fluid, there must be surface tension to make the mass spherical. The surface tension may be decreased at any point due to external or internal changes. At the point of low surface tension, the fluid flows outwardly, forming an outgrowth, called pseudopodium.

4.3.2. SOL-GEL THEORY OR CHANGE OF VISCOSITY THEORY

This theory was proposed by Hyman (1917). According to this theory, the body of the Amoeba is made up of 4-regions,

(a) The outer most thin and elastic cell membrane or plasma membrane,

(b) Plasmagel, an outer stiffer jelly-like region of the ectoplasm,

(c) The plasmasol, an inner more fluid region of the endoplasm and

(d) A hyalin fluid which is a clear ectoplasmic area between the plasma membrane and plasmagel.

This theory states that the change of sol to gel and gel to sol states in the peripheral cytoplasm forms pseudopodium. A local reversion of plasmagel to plasmasol takes place at the anterior end by internal chemical reaction.

The gel at the anterior end becomes thinner and weak. The rest of the plasmagel exerts pressure on the weakened area. The contracting plasmagel of the posterior end is continuously changed into plasmasol and it flows forwards and breaks the weak gel.

Previously, the plasmagel tube is continuously regenerated by plasmasol gelation, and a new pseudopodium forms. The animal then progresses forward with the help of the pseudopodium.

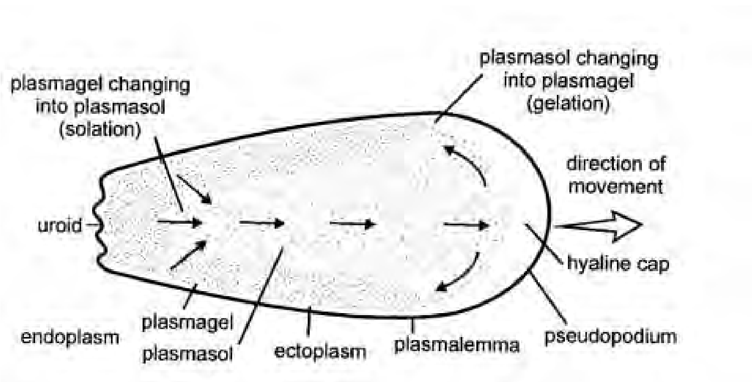


Fig.4.7. Sol-gel transformation in amoeba

4.3.3. MOLECULAR FOLDING AND UNFOLDING THEORY

Goldacre and Lorch (1950) and Goldacre (1952) suggested that the protein molecules in Amoeba are present in folded and unfolded forms and explained the molecular basis of gelation (gel) and solation (sol) state of the protoplasm of Amoeba. They suggested that the forces which are generated by the folding and unfolding of the protein molecules, could help in locomotion. The sol state of the protoplasm is due to the folding of protein molecules and the gel state is due to the unfolding of protein molecules.

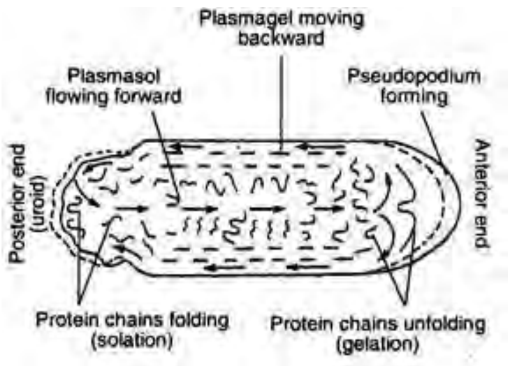


Fig.4.8. Pseudopodium formation on tha basis of folding and unfloding during amoeboid movement

4.3.4. FRONT CONTRACTION THEORY OR FOUNTAIN ZONE THEORY

This theory was proposed by Allen in 1962. According to this theory, the endoplasm contains long, protein chains. These chains contract at the anterior end and at this end the plasmasol changes into plasmagel by folding the protein chains. This plasmagel flows forward, touches the hyalin cap, and then flows backward, resembling a fountain. This anterior region now develops a tension which is transmitted at the posterior end of the endoplasm. Amoeba is propelled forward by the fountain-like movement of the gel. The attachment of Amoeba to the substratum is necessary for locomotion.

4.3.5. REAR CONTRACTION AND HYDRAULIC THEORY

This was proposed by Rinaldi and Jahn in 1963. According to them, the contraction in gel at the posterior end gives rise to hydraulic pressure in sol. This pressure is not equally distributed. It is highest at the posterior end, lowest at the anterior end and moderate in the middle. Gel at the posterior end always changes to sol due to contraction of the plasmagel and gel at the anterior end becomes thinner. Sol from the posterior end flows forward, breaks the gel of the anterior end and forms a new pseudopodium and brings about the forward movement of Amoeba.

4.3.6. ACTIN AND MYOSIN INTERACTION THEORY

Huxley (1973) proposed that the amoeboid movement occurs due to the interactions of actin and myosin microfilaments. He also suggested that one kind of filament glides on the other and these filaments are largely confined in the gel region of the ectoplasm. This gliding helps to pull the animal forward. The gliding as well as movement is enhanced by the addition of ATP and Ca^{++} or Mg^{++} ions. According to Stochem (1982), actin proteins build the plasmagel and myosin proteins build the plasmasol. A hydrostatic pressure is created by the contraction of the actin filaments at the rear end which pushes the plasmasol of the myosin forward that forms the pseudopodium and brings about the locomotion of Amoeba.

4.3.7. OSMOTIC THEORY OF AMOEBOID FLOW

The sol-gel theory can be explained with the help of the osmotic theory of amoeboid flow. The cytoplasm of Amoeba contains both actin and myosin protein molecules and their interaction helps in the formation of pseudopodia. During conversion from endoplasm to ectoplasm, a mesh of actin filaments is developed by the polymerization of actin molecules which form the rigid gelatinous condition of ectoplasm. When the chemical signals bind to the membrane receptors, the ectoplasm transforms into endoplasm at the rear end by depolymerization. Then the myosin subunits bind to the actin molecules which transform the actin mesh into a contractile jacket that forces the fluid interior endoplasm forward.

The breakdown of the actin network by depolymerization increases the osmotic pressure which draws water from the endoplasm to the periphery of the protoplasm of Amoeba that creates the extension of the cell forming a pseudopodium.

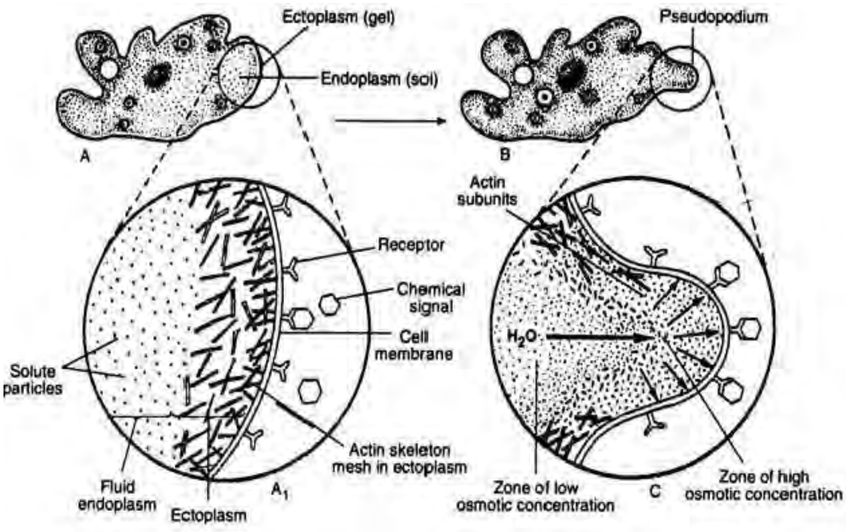


Fig.4.9. Pseudopod formation on the basis of osmotic theory of amoeboid

4.3.8. STREAMING PROTOPLASM THEORY

Rossenhof (1755) proposed this theory. The movement in the Amoeba was always accompanied by streaming, so it came to be generally accepted that the really fundamental feature of the amoeboid movement was the streaming of the protoplasm.

4.3.9. ROLLING MOVEMENT THEORY

Jennings (1904) observed that in *Amoeba verrucosa*, a carbon particle on Amoeba's upper surface first passes forward and then turns downwards along the anterior tip, remains on the lower surface for a time as the body rolls forward and then passes upward at the posterior end to repeat the cycle. But Jennings found it impossible to explain why *Amoeba proteus* moves with pseudopodia.

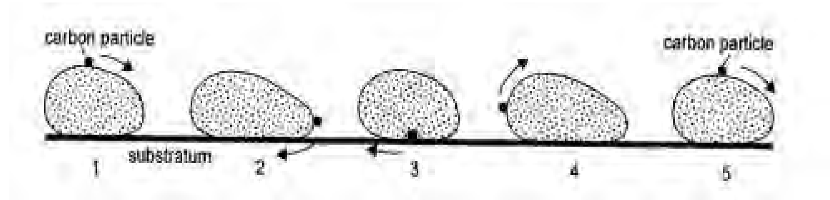


Fig.4.10. Rolling movemnet of *Amoeba verrucosa*

4.3.10. WALKING MOVEMENT THEORY

This theory was roposed by Dellinger (1906). A contractile substance present in the cytoplasm is responsible for the extension of pseudopodia which become attached to the substratum and then contract to pull the body forward. Amoeba appears to walk on its leg like pseudopodia.

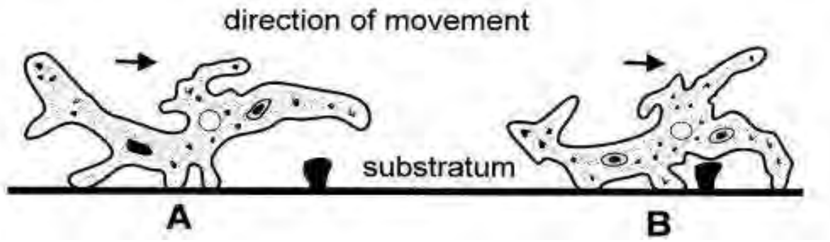


Fig.4.11. Walking movement of amoeba

4.3.11. RETICULAR THEORY

Heitzman observed a living three dimensional network of contractile fibres which was supposed to be embedded in a non-living and non-contractile fluid. Thus, amoeboid movement is ascribed to contraction of the reticulum, the substance of the fibres being transferred during contraction to the nodes of the reticulum, where it accumulates in the form of granules.

4.3.12. REVERSIBLE GEL-SOL TRANSFORMATION THEORY

This theory was postulated by Yagi (1961) and Marsland (1954). This theory is the most widely accepted explanation of the amoeboid movement. This theory suggests that solation occurs at the anterior end in which endoplasm flows under pressure generated by contraction of the cortical plasma gel at the posterior end. This results in the propulsion of amoeba.

4.4. FLAGELLUM

Flagella are microscopic hair-like structures involved in the locomotion of a cell. The word "flagellum" means "whip". The flagella have a whip-like appearance that helps to propel a cell through the liquid. Some special flagella are used in few organisms as sensory organs that can sense changes in pH and temperature. Archaeal flagella are nonhomologous. Bacterial flagella are a coiled, thread-like structure, sharp bent, consisting of a rotary motor at its base and are composed of the protein flagellin.

Eukaryotic flagella are complicated cellular projections that pummel backwards and forward and are found in protist cells, gametes of plants, and animals. It is made up of a protein called tubulin. The length of the flagellar state is about 150 µm. They consist of an inner elastic central axis called axoneme and an outer protective contractile cytoplasmic sheath. The sheath is made up of fibrillar substances which are a semifluid matrix and the fibrils of the sheath frayed out laterally along the length of the flagella and these lateral hair-like projections of the flagellum are called mastigonemes or flimmer. The term mastigoneme was given by Deflandre (1934). The outer sheath is circular or more or less flattened in cross section.

4.4.1. FLAGELLA STRUCTURE

The flagella structure is divided into three parts:

- Basal body
- Hook
- Filament

Basal Body

It is attached to the cell membrane and cytoplasmic membrane, and consists of rings surrounded by a pair of proteins called MotB. The rings include:

L-ring: An outer ring found in gram +ve bacteria that is anchored in the lipopolysaccharide layer.

P-ring: Anchored in the peptidoglycan layer.

C-ring: Anchored in the cytoplasm

M-S ring: Anchored in the cytoplasmic membrane

Hook: It is a broader area present at the base of the filament. This hooks connects the filament to the motor protein in the base.

Filament: A thin hair-like structure arises from the hook.

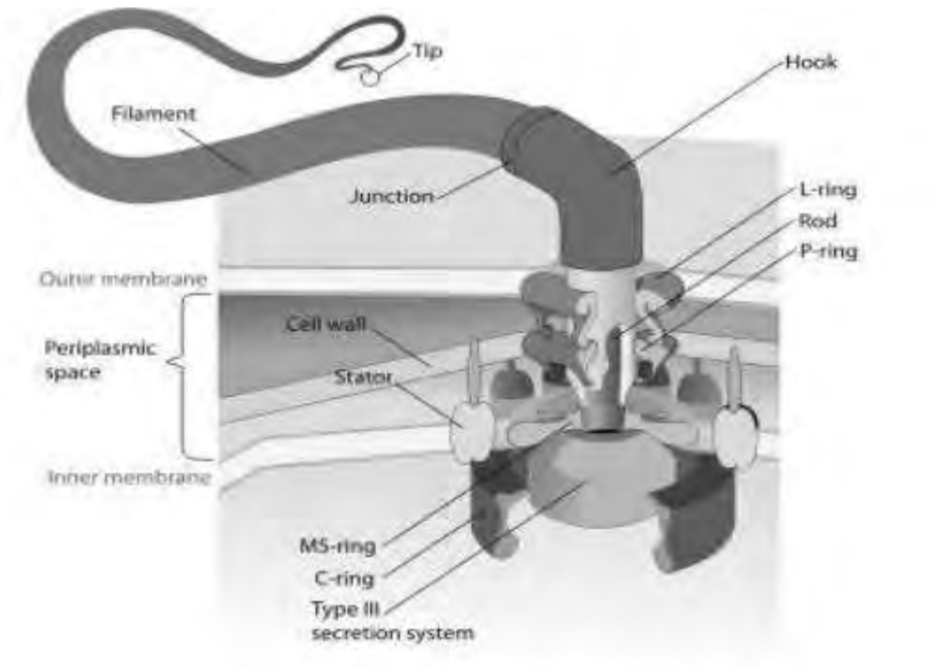


Fig.4.12. Structure of flagellum

4.4.2. ULTRA STRUCTURE OF FLAGELLUM

A typical flagellum consists of an elongated, stiff axial fiber called an axial filament or axoneme enclosed by an outer sheath. The axoneme develops from a basal granule known as the blepharoplast or kinetosome. Blepharoplast lies below the cell surface in the ectoplasm. The region around blepharoplast is called the microtubular organizing center that controls the assembly of microtubules.

The axial filament consists of 2 central longitudinal fibers enclosed by a membranous inner sheath. The 2 central longitudinal fibers are surrounded by 9 longitudinal peripheral doublets which form a cylinder between the inner and the outer sheath. Each peripheral paired fiber is connected to the internal membranous sheath by radial spokes.

Each peripheral doublet also has pairs of arms directed towards the neighboring doublet. These arms are made of a protein called dynein. The arms create the sliding force.

The peripheral doublets are surrounded by an outer membranous sheath called a protoplasmic sheath, which is an extension of the plasma membrane. Some flagella also bear lateral appendages called flimmers or mastigonemes along the length of the axoneme above the level of the pellicle.

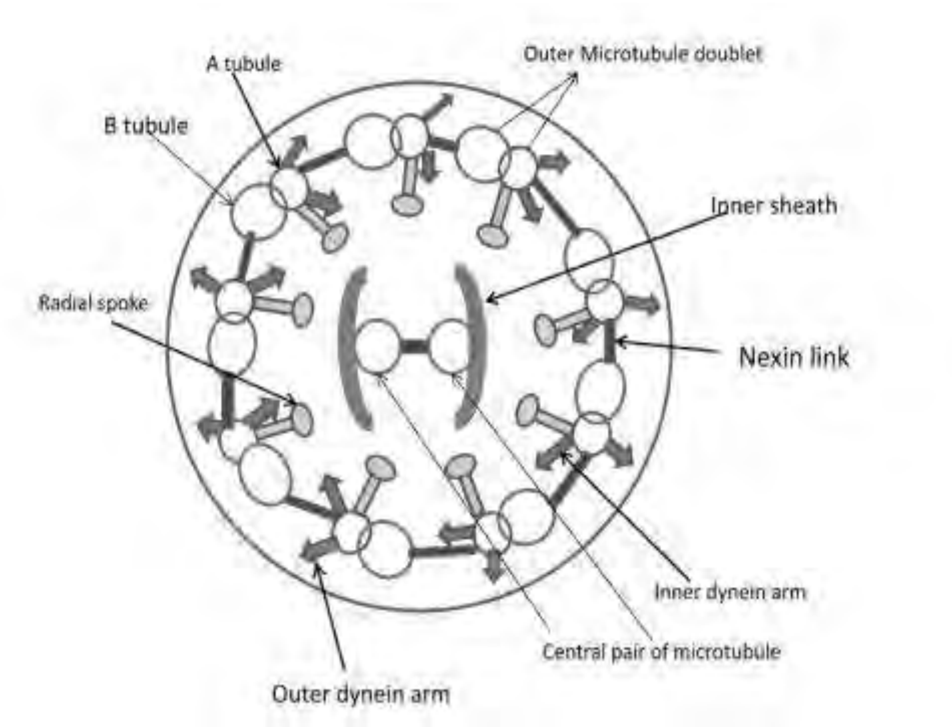


Fig.4.13. Structure of axoneme of cilia and flagella

4.5. TYPES OF FLAGELLA

Flagella are classified according to the disposition of the mastigonemes, based on the arrangement of lateral appendages and the nature of the axial filament.

4.5.1. ANEMATIC

The flagella is simple without any lateral appendages and mastigonemes.

Eg: *Chilomonas, Cryptomonas, Noctiluca.*

4.5.2. STICHONEMATIC

Flagella have a single row of mastigonemes on one side of the flagellum. Eg; *Euglena.*

4.5.3. PANTONEMATIC

Flagella has two or more rows of mastigonemes on the axoneme.

Eg; *Peranema, Monas socialis.*

4.5.4. ACRONEMATIC

Lateral appendages are absent. Flagellum does not bear any arrangement of mastigonemes but a terminal filament is seen. Eg; *Polytoma, Chlamydomonas*.

4.5.5. PENTACRONEMATIC

Flagellum is provided with two or more rows of lateral appendages and the axoneme ends in a terminal naked axial filament.

Eg: *Urceolus*

4.5.6. MONOTRICHOUS

A single flagellum are present at one end. These are known as polar flagellum and can rotate clockwise and anti-clockwise. The clockwise movement moves the organism forward while the anti-clockwise movement pulls it backwards.

4.5.7. PERITRICOUS

Several flagella are attached to the organism. These are not polar flagella because they are found all over the organism. These flagella rotate anti-clockwise and form a bundle that moves the organism in one direction.

4.5.8. LOPHOTRICHOUS

Several flagella are present at one end of the organism. These are known as polar flagellum and can rotate clockwise and anti-clockwise. The clockwise movement moves the organism forward while the anti-clockwise movement pulls it backwards.

4.5.9. AMPHITRICHOUS

Single flagellum is present on both ends of the organism. These are known as polar flagellum and can rotate clockwise and anti-clockwise. The clockwise movement moves the organism forward while the anti-clockwise movement pulls it backwards.

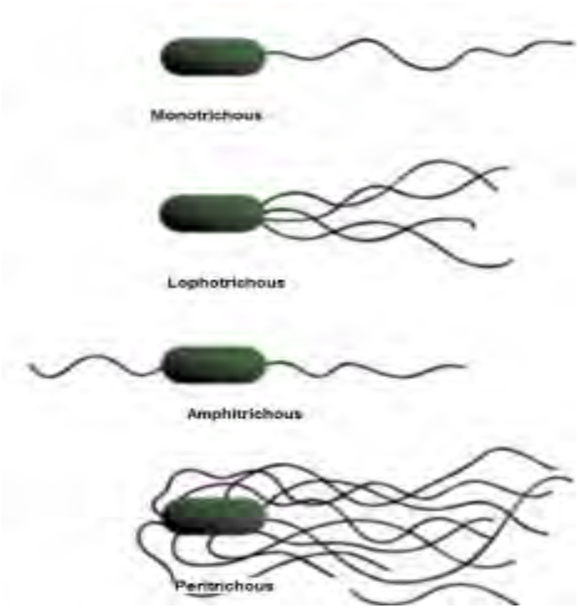


Fig.4.14. Types of flagella

4.6. MOVEMENT TYPES OF FLAGELLA

4.6.1. TRACTELLUM

The flagella generally originate from the anterior part of the body and the flagellum which is directed forward is called the leading flagellum and its movement helps to pull the organism forward. Another flagellum originating from the anterior end is directed backward is called trailing flagellum. This flagellum helps to move the organisms backward. Eg; *Bodo.*

4.6.2. PULSELLUM

When the flagellum is situated at the posterior end of the body and is used to push the body forwards by its vibration. Eg; *Trypanosoma*.

4.6.3. UNDULATION MOVEMENT

Undulation from the base to the tip causes pushing force and pushes the organism backwards. Similarly, undulation from the tip to the base causes pulling force and causes the organism to pull forward. Also, when the flagellum ends to one side and shows wave like movement from base to tip, the organism moves laterally in the opposite direction. Finally, when the undulation is spiral, it causes rotation of the organism in the opposite direction and this is called gyration.

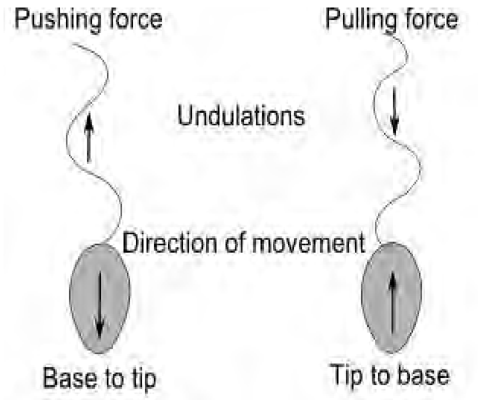


Fig.4.15. Undular movement of flagellum

4.6.4. SIDEWISE LASH MOVEMENT

The flagellar movement of many organisms is a paddle-like beat or sidewise lash consisting of strokes, namely effective stroke and recovery stroke.

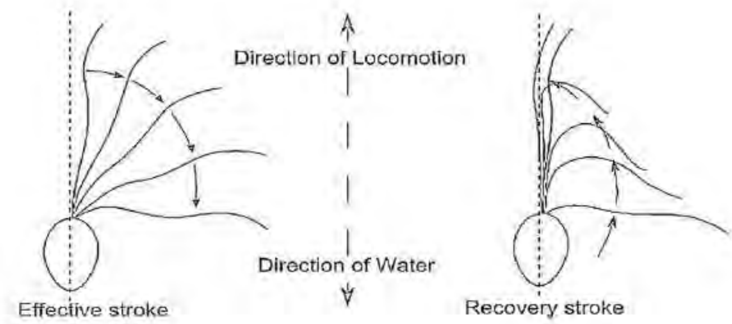


Fig.4.16. Sidewise lash movement of flagellum

4.6.4.1. EFFECTIVE STROKE

During an effective stroke, the flagellum becomes rigid and starts bending against the water. This beating in water at right angles to the longitudinal axis of the body causes the organism to move forward.

4.6.4.2. RECOVERY STROKE

During recovery stroke, the flagellum becomes comparatively soft and will be less resistant to the water. This helps the flagellum move backwards and then to the original position.

4.6.5. SIMPLE CONICAL GYRATION MOVEMENT

In this kind of movement, the flagellum turns like a screw. This propelling action pulls the organism forward through the water with a spiral rotation around the axis of movement and gyration on its own.

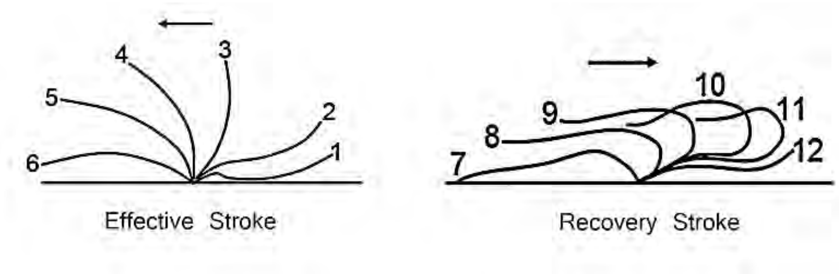


Fig.4.17. Stroke movement of flagella

4.7. THEORIES OF FLAGELLAR LOCOMOTION

Various theories are proposed for explaining the movement of flagella:

4.7.1. SCREW PROPELLAR THEORY

According to Butschlii, the movement of flagella commonly involves the generation of waves that are transmitted along it either in a single plane or in a screw pattern. The waves pass to the tip of the main flagellum which beats at a rate of about 12 beats per second. It postulates a spiral turning of the flagellum like a screw resulting in a propeller action which pulls the animal forward. In Euglena, this rotation causes the tip of the organism to rotate while at the same time pushing it to one side. Because of this, Euglena rotates as it swims. The movement of its body thus is comparable with that of a propeller, as it sets up forces on the water that bring about forward displacement.

4.7.2. SIDEWISE LASHING MOVEMENT/THEORY OF ULEHLA AND KRIJSMAN

Recent discoveries by Ulehla and Krijsman (1925) suggest that the flagellum beats in a side wise lash, consisting of an effective downstroke or bending and a relaxed recovery stroke or straightening. In the effective stroke, the flagellum is held out rigidly with slight concavity in the direction of stroke, while in the recovery stroke the flagellum is relaxed, strongly curved and is brought forward again. This draws the body of the animal forward. According to this theory, the ordinary movement of a flagellum is a sidewise lash consisting of an effective downward stroke followed by a relaxed recovery stroke by which the flagellum is brought forward again.

4.7.3. METZNER'S THEORY

Metzner has advocated that the flagellum beats in a circle tracing a cone and generates sufficient current to pull the animal forward.

4.7.4. SLIDING TUBULE MODEL THEORY

This is the most widely accepted model. The sliding of the microtubules involves the movement of the flagellum. According to this theory, the peripheral microtubules form a linkage with each other and maintain a constant length. The adjacent doublets slide past each other, causing the entire flagellum to bend. The dynein arms of the doublets provide the sliding force and sliding involves the establishment of the cross-linkages.

4.8. FUNCTIONS OF FLAGELLA

Flagella perform the following functions:

1. They help an organism with movement.
2. They act as sensory organs to detect temperature and pH changes.
3. Few eukaryotes use flagellum to increase reproduction rates.
4. Recent research has proved that flagella is also used as a secretory organelle. Eg., *Chlamydomonas*

4.9. CILIA

Cilia are fine, short, hair-like, centriole-based protoplasmic processes, characteristic of many protozoan and metazoan cells. Ciliary movement is exhibited by the beating of the cilia. It is the most advanced, complicated and co-ordinated mode of locomotion. Cilia is found on the outer body surface of certain Mollusca, Annelida, and Nemertine larvae and has similar structures and functions to flagella, but the cilium is shorter and moves differently. They are present in large numbers. Cilia exhibits beating motion.

Cilia develop from basal granules, blepharoplasts, or kinetosomes, which are structurally similar to the centrioles that produce spindle fibers during cell division in animals. In some species, the basal body functions as a centriole in mitosis. The fine structure shows that the peripheral fibres are present in a triplet pattern which is twisted and are interconnected by other fibrils.

The subfibrils are also connected with a central cylinder at the proximal part of the basal granule by 9 spokes, one to each triplet, forming a cart wheel structure, but at the distal part it is absent and is closed by basal plate. The shaft region arises from a basal body or kinetosome. The kinetosomes form a longitudinal row that is connected by means of fine, striated fibrils called kinetodesma.

Each kinteosome gives rise to one kinetodesmos (fibril), which joins the longitudinal bundle and extends anteriorly. The length of the cilium is smaller, it measures 5 to 10μ. Cilium consists of a matrix surrounded by a membrane that is continuous with the plasma membrane of the cell surface. Within the matrix is an axoneme composed of 11 micro tubular fibrils, each is formed of rows of molecular sub units of a globular protein called tubulin. Two of the 11 fibrils are single ones (diameter about 24 nm), and lie centrally. There is a sheath enclosing the central fibrils, while the other nine are doublets, each composed of an A and B subfibre and form a circle around the central pair.

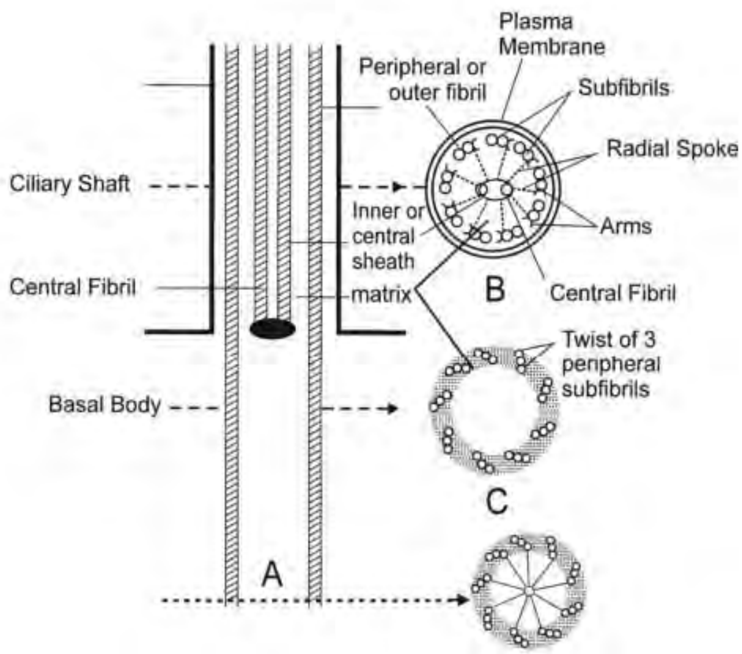


Fig.4.18. Structure of cilium

A-cilium in L.S. B-Free part of cilium in T.S. C-Basal body (Distal) in T.S. D-Basal body (Proximal) in T.S

4.10. TYPES OF CILIA

4.10.1. HOLOTRICHS

Cilia are present all over the body. Eg: *Paramecium*

4.10.2. PERITRICHS

Cilia are present only in the peristomial region. Eg: *Paramecium*

4.11. CILIARY MOVEMENTS

Four types of ciliary movements have been recognized, which are as follows:

4.11.1. THE PENDULUS CILIARY MOVEMENT

The pendulus type of ciliary movement occurs in a single plane.It occurs in the ciliated protozoans which have rigid cilia.

4.11.2. THE UNCIFORM CILIARY MOVEMENT

The unciform (hook-like) ciliary movement occurs commonly in the metazoan cells.

4.11.3. THE INFUNDIBULIFORM CILIARY MOVEMENT

The infundibuliform ciliary movement occurs due to the rotary movement of the cilium and flagellum.

4.11.4. THE UNDULANT MOVEMENT

The undulant movement is the characteristic of the flagellum. In undulant movement, the waves of the contraction proceed from the site of implantation and pass to the border.

4.12. MOLECULAR BASIS OF CILIARY MOVEMENT

The ultra structure of flagella or cilia has been revealed by the sliding tubule model theory. According to the theory, the microtubules do not change length but adjacent doublets slide past each other, causing the entire organelle to bend. Sliding involves the establishment of cross bridges and utilization of Adenosine Tri Phosphate (ATP), as in muscle contraction, ATPase called dynein is present in the arms that project from one side of the A subfibrils of the flagellum and cilium. These arms point towards the B subfibrils of the next doublet, an arrangement which suggests that they connect with this, much as the ATPase of myosin muscle filament can connect them with the thin actin filaments. Thus the sliding takes place in the flagella or cilium.

Let Us Sum Up

In this unit, we studied about the locomotion in invertebrates. Under this unit, we focused on the locomotion exhibited by Protozoans, theories supporting the amoeboid movement, flagellum, types of flagella, movement types of flagella, theories of flagellar locomotion, functions of flagella, cilia, types of cilia, ciliary movement and molecular basis of ciliary movement.

Check Your Progress

1) There are __________ types of skeletons are present.
2) There are __________ main types of locomotion exhibited by protozoans.
3) __________ are microscopic hair like structure involved in the locomotion of a cell.
4) There are two types of cilia are present, they are __________ and __________.

Glossaries

Acronematic	:	Hairless flagellum
Flagellum	:	Slender thread like appendage
Setae	:	Stalk that supports capsule.

Suggested readings

1. **MOORE, R.C., LOLICKER** and **FISCHER, A.G**. (1952), Invertebrate Paleontology, McGraw Hill Book Co., Inc., New York.
2. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.

Weblink

Flagellar movement in protozoan https://youtu.be/PBrxh3N8CuA

Ciliary movement in protozoan https://youtu.be/atIGCTnqRhA

Answers to check Your Progress

1) 3
2) 3
3) Flagella
4) Holotrichs and peritrichs

UNIT- 5

Hydrostatic Skeleton

Structure

Objectives

Overview

Objectives

After studying this unit, the students will be able to

- Explain the hydrostatic movement in invertebrates
- Describe the action of hydrostatic movement in Coelenterata, Annelida and Echinodermata

Overview

In this unit, we will study about the hydrostatic movements in invertebrates. Here, we will focus on the hydrostatic skeleton, mechanism of action of coelenterate hydrostatic skeleton, hydrostatic locomotion in Annelida, locomotory structures such as , parapodia, setae and suckers, hydrostatic skeleton in Hirudinea, mechanism of locomotion such as, slow walking and crawling, rapid crawling, swimming and burrowing, hydrostatic skeleton in echinoderms and its associated structures such as, madreporite, ring canal, tiedann's body, polian vesicles, lateral canal and tube feet, role of tube feet in locomotion and mechanics of locomotion in Echinodermata.

5.0. HYDROSTATIC SKELETON

A hydrostatic skeleton is a skeleton formed by a fluid-filled compartment within the body, called the coelom. The organs of the coelom are supported by the aqueous fluid, which also resists external compression. This compartment is under hydrostatic pressure because of the fluid and supports the other organs of the organism. This type of skeletal system is found in soft-bodied animals such as sea anemones, earthworms, Cnidaria, and other invertebrates.

Movement in a hydrostatic skeleton is provided by muscles that surround the coelom. When the muscles in a hydrostatic skeleton contract, the shape of the coelom changes. The pressure of the fluid in the coelom produces movement. For example, earthworms move by waves of muscular contractions of the skeletal muscle of the body wall hydrostatic skeleton, called peristalsis, which alternately shorten and lengthen the body. Lengthening the body extends the anterior end of the organism. Most organisms have a mechanism to fix themselves in the substrate. Shortening the muscles then draws the posterior portion of the body forward. Although a hydrostatic skeleton is well-suited to invertebrate organisms such as earthworms and some aquatic organisms, it is not an efficient skeleton for terrestrial animals.

The coelom is fluid-filled, which creates hydrostatic (water) pressure and acts as a hydrostatic skeleton. The hydrostatic skeleton is made possible by closed fluid-filled internal spaces of the body. It is of great importance in a wide variety of animal groups because it permits the antagonistic action of muscles used in locomotion and other movements. In hydrostatic skeletons, force is transmitted not through rigid skeletal elements but instead by internal pressure. Higher phyla such as coelentrate and echinodermata animals use hydrostatic mechanism for their movement.

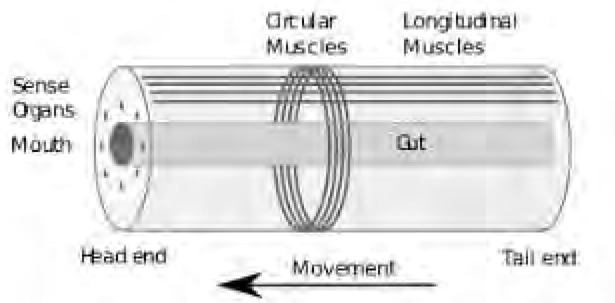


Fig.5.1. Hydroststic skeletal structure

5.1. COELENTERATE HYDROSTATIC SKELETON

The phylum Coelenterata (Cnidaria) has about 9000 species. Coelenterates are diploblastic, but tissues are not grouped into organs. A single body cavity remains filled with surrounding water having a mouth surrounded by tentacles, but no posterior anus. The body fluid functions as a hydrostatic skeleton. In Cnidaria, the water-filled gastrovascular cavity acts as a hydrostatic skeleton. A hydrostatic skeleton is composed of water or body fluids in a cavity of the body. The contractile elements of the body wall acts against this hydrostatic skeleton. Some epitheliomuscular cells of the body wall are contractile. They help with movement.

Hydra is a very common organism belonging to Coelenterata. It has three main regions associated with movements. (i) Tentacles and oral discs, which are mostly used for feeding. (ii) Pedal disc, through which the animal remains attached to the substratum and slow creeping movement is done by pedal disc. (iii) s the column, this region is responsible for the main changes in the body and movements. The central cavity known as coelenteron is closed at the posterior end. The coelenteron contains fluid, due to which the animal is able to build up a level of pressure leading to translation of muscular contraction and consequently the movements of the body. In Hydra, the coelenteric fluid along with surrounding epidermal and gastrodermal muscle fibres constitute a hydrostatic skeleton.

5.1.1. MECHANISM OF ACTION

The polyp closes its mouth and contracts longitudinal epithellomuscular cells on one side of the body. The polyp bends toward that side. Now these cells contract while the mouth is open. Thus, water escapes from the gastrovascular cavity. Therefore, the polyp collapses. Contraction of circular epitheliomuscular cells causes constriction of a part of the body. The mouth is closed and water in the gastrovascular cavity is compressed. Therefore, the polyp elongates.

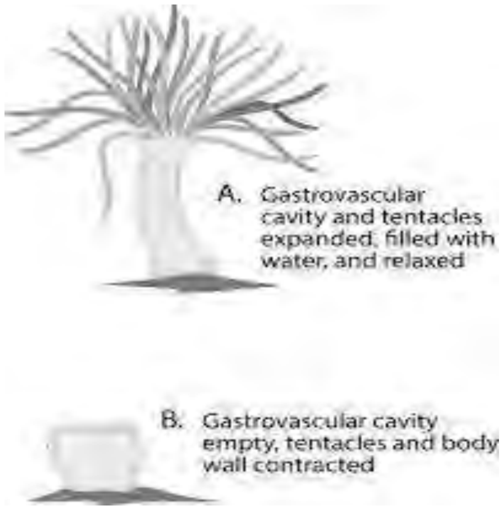


Fig.5.2. Structure of gastrovascular cavity

5.2. HYDROSTATIC LOCOMOTION IN ANNELIDA

Hydrostatic Skeletons, also called Hydroskeletons, provide the primary skeletal support and rigidity for the body. Not all skeletons are rigid. Many invertebrate groups use their body fluids as an internal hydrostatic skeleton. For example, the muscles in the body wall of the earthworm have no firm base for attachment but develop muscular force by contracting against the coelomic fluid, which is enclosed within a limited space and is incompressible, much like the hyudraulic brake system of an automobile. Alternate contractions of the circular and longitudinal muscles of the body wall enable the worm to thin and thicken, setting up backward moving waves of motion that propel the animal forward. Earthworms and other annelids are helped by the septa which separate the body into independent compartments.

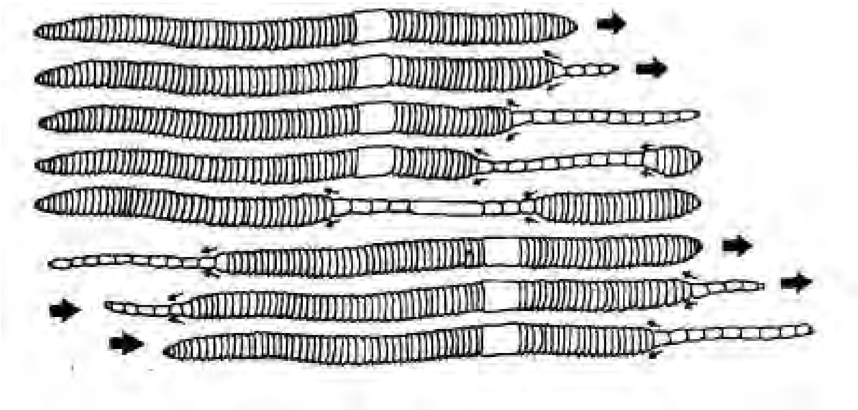


Fig.5.3. Locomotor components in Annelida include (a) body musculature, (b) hydrostatic skeleton, and (c) locomotor structures. Locomotion is thus the result of co-ordinated effort of all these.

5.2.1. BODY MUSCULATURE

The layout of the muscle layers surrounding the coelom is essentially the same in all the major classes of Annelida. The body wall has a layer of circular muscles below the epidermis. This is followed by a layer of longitudinal muscles. In polychaetes, the circular muscles are thin and the longitudinal muscles are usually arranged in four blocks, two dorsolateral and two ventrolateral. In oligochaetes, the longitudinal muscles form a continuous layer inner to the circular muscle layer and their long fibres may extend over 2-3 segments; well developed oblique muscles help in localized contraction and expansions of the body's segments.

In both these groups, the coelom is divided internally by means of transverse septa. The latter helps in resisting the stress caused due to change in the hydrostatic pressure of the coelomic fluid. Of course, septa are less developed and broken down in polychaetes, with coelomic communication between segments. The body musculature is best developed in Hirudinea where, in addition to a double layer of oblique muscles there are vertical columns of muscles that perform functions between the circular and longitudinal muscles. Namely, the dorsoventral muscles. Contraction of dorsoventral muscles results in flattening the body of the animal and causes efficient undulations of the body resulting in swimming. But in leeches, coelom is very poorly developed. When a cylinder surrounded by circular muscles contracts towards one end, the diameter at that end decreases, resulting in the movement of coelomic fluid.

The movement of coelomic fluid may cause,

(i) Increase in length of the contracting end of the body (the other end to remain unaltered);

(ii) Increase the diameter of the other end (total length remaining the same),

(iii) increase in the length of the other end (the diameter remaining unchanged) and

(iv) Elongation of both ends of the body.

But the existence of longitudinal muscles and their contraction in conjunction with regional hydrostatic or coelomic fluid pressure help in the restoration of the cylinder to its original state.

5.2.2. HYDROSTATIC SKELETON

The functioning of the hydrostatic skeleton in an animal depends upon the musculature being arranged around an enclosed volume of fluid. Then, contraction of some of the muscles can cause pressure on the fluid, which can be transmitted to the rest of the body, in all directions. The hydrostatic skeleton in annelids is composed of the coelom, the fluid in the coelomic space (or spaces), and the surrounding musculature. The volume of coelomic fluid is constant. Generally, contraction of any muscle in the body wall of an annelid would cause an increase in the hydrostatic pressure, which in turn would cause stretching of flaccid muscles. In annelids with circular and longitudinal 'muscles, contraction of one set of muscles is accompanied by stretching of the other.

Polychaetes have feebly developed body musculature. The spacious coelom is compartmentalised by transverse septa. However, there are perforations in the transverse septa which allow continuity of the coelomic fluid between compartments.

So, in polychaetes the hydrostatic skeleton is not well developed. In oligochates, the body musculature is well developed and the transverse septa do not have the perforations during locomotion. The coelom is mostly isolated in the adjacent segments. As the longitudinal muscles of a segment contract, the circular muscles relax and, owing to the incompressibility of the coelomic fluid, the segment becomes shorter but thicker. Simultaneous protrusion of the setae helps the worm anchor to the substratum. When the reverse happens, i.e., when the circular muscles contract, the longitudinal muscles relax, the segments become long and thin, the setae are withdrawn and the body progresses forward. However, the contraction and relaxation activities are localised, being limited to a few segments of the body, the wave of contraction and relaxation passing from one end to the other. This results in the animal's progression.

In comparison with the polychaete and oligochaete annelids, in Hirudinea the body musculature is better developed; the coelom is greatly reduced; the coelomic cavity is not septated as the transverse septa are lacking and the coelomic fluid is to a large extent replaced by the botryoidal tissue. The suckers present at either end of the animal can attach to the substratum. The Posterior sucker is attached to the substratum. The wave of circular cotraction results in elongation of the body, which is extended forward. The anterior sucker is now attached and the posterior sucker is released. The longitudinal control action results in shortening of the body and the posteiior sucker is brought forward. This is repeated and thus the crawling movement, so typical of a leech, is brought about.

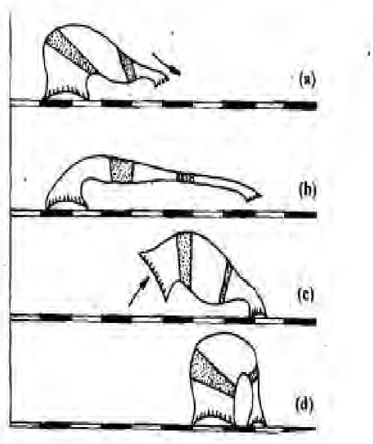


Fig.5.4. Successive stages in leaping or crawling locomotion in a leech

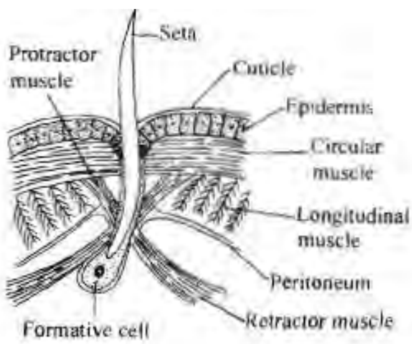


Fig.5.5. Setae with its muscle attachments showing relation to adjacent structures

5.3. LOCOMOTORY STRUCTURES

Annelids possess three types of locomotory structures, namely parapodia, setae and suckers.

5.3.1. PARAPODIA

The coelomic cavity extends into parapodia, which are segmentally arranged, lateral, hollow extensions of the body. Each parapodium basically consists of two lobes, a dorsal notopodium and a ventral neuropodium and each lobe bears a bundle of bristles or setae supported by an aciculum. Associated with each parapodium are dorsal and ventral sets of oblique muscles, and also the intrinsic protractor and retractor muscles. During movement, two parapodia of a segment remain in opposite phases of motion and thus cause a sort of paddling activity through water. The bristles and acicula are protruded and withdrawn through the activity of the intrinsic muscles. Parapodia are the main locomotory organs of polychaetes. In accordance with the different functions that they perform, parapodia exhibit variations of form among different polychaetes. Creeping and swimming forms have well developed parapodia; the burrowing forms and the tube dwellers have feebly developed parapodia, especially in the posterior part of their body.

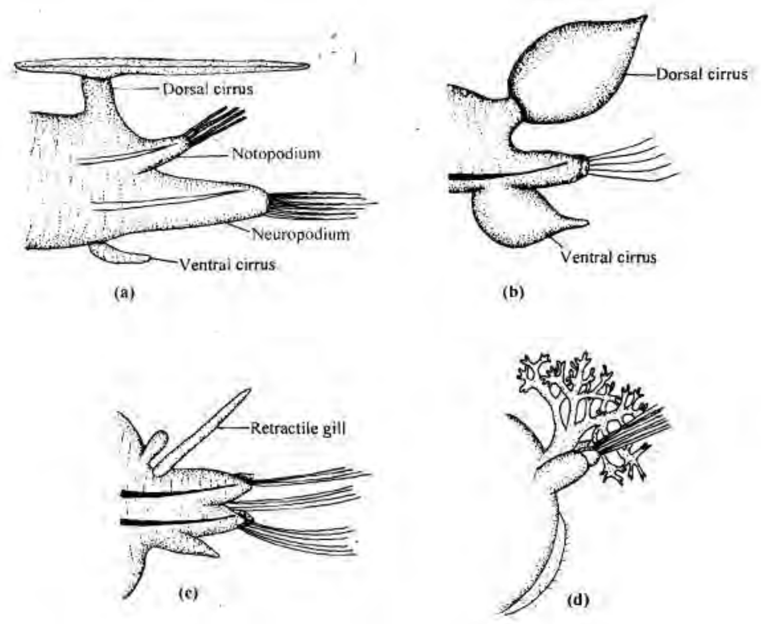


Fig.5.6. Modifications of parapodia among polychaetes; A. Lepidonotus, B. phyllodoce, C. Glycera, D. Arenicola

The parapodia become variously modified in different polychaetes. The modifications are related to different functions. They are well-developed and modified into creeping and swimming types. In these forms, the parapodia are restricted to some anterior-most segments as head crown and are poorly developed or absent in the rest of the body segments. In sand or mud burrowers and tube-dwellers the parapodia are poorly developed or absent, especially those of the posterior part of the body.

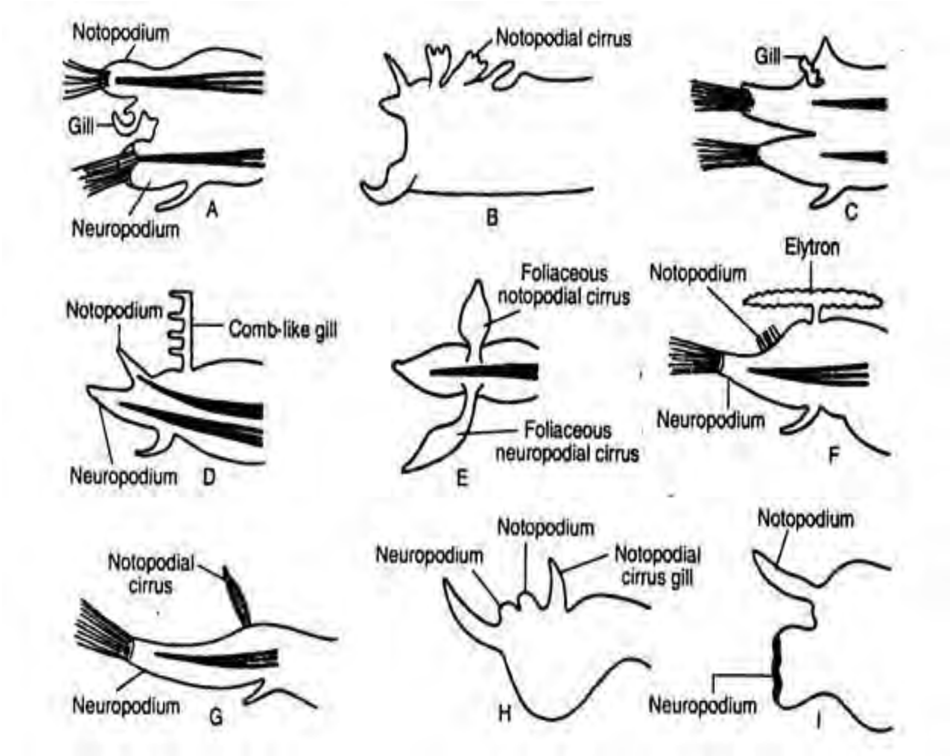


Fig.5.7. A. Parapodium of Nepthys. On its underside, the notopodium has a curved gill. B. Parapodium of Amphionme. The notopodium is distinct. C. Parapodium of Glycera. D. Parapodium of Eucine. It is uniramous with reduced notopodium. The notopodical cirrus acts as the comb-like gill. E. Parapodium of Phyllodoce. The cirri have follaceous leaves.F. Parapodium of Polyone.

5.3.2. SETAE

Setae are the main locomotor structures in oligochaetes, but as already seen, they are also present in polychaetes. In oligochactes they are mostly present in the ventral region of the body; setae are secreted by setal sacs. They are moved by protractor and retractor muscles. Like parapodia, setae may also show variations in form reflecting their functional significance. Burrowing forms have short, simple, and blunt setae, whereas swimming forms have long, forked, or plumose setae.

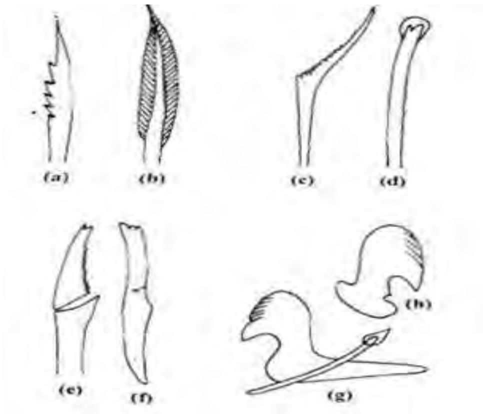


Fig.5.8. Different types of setae

5.3.3. SUCKERS

Suckers are characteristic of Hirudinea which lack setae and parapodia. One sucker is present at the anterior end and the other at the posterior end of the body; they are formed by the fusion of several body segments. The powerful longitudinal muscles converge on the suckers; the suckers have their circular muscles concentrically arranged. Secretion from the associated epidermal glands also helps in adhesion of the suckers to the substratum.

5.4. HYDROSTATIC SKELETON IN HIRUDINEA

The coelom spaces in Hirudinea are greatly reduced due to the development of body musculature and obliteration of coelom by the thick muscular coat and botryoidal tissue. Reduction of coelom results in the increase of hydrostatic pressure and renders rigidity to the body. As a consequence, the hydrostatic skeleton is highest developed in hirudinea amongst the annelids.

5.4.1. MECHANICS OF LOCOMOTION

Among annelids, polychaete's, though more primitive than the other two groups, show a more complex mode of locomotion. Essentially, the locomotion in polychaetes is dependent on the antagonistic action of muscles on either side. When the longitudinal muscles of one side of a segment are contracted, those of the opposite side are in a fully stretched or relaxed state. In this way, a series of waves can be formed along the whole body of the animal. Polychaetes exhibit several types of locomotion

5.4.1.1 SLOW WALKING OR CRAWLING

When an animal moves on the shstratum, it exhibits this type of locomotion. It involves a metachronal rhythm of action in the parapodia.

Every fifth or sixth parapodium on one side of the body is at the same stage in the cycle of forward recovery stroke and backward effective stroke. During the effective stroke (Power stroke), the parapodium on one side is turned down towards the ventral side of the substratum; the parapodia as well as the setae protrude. The parapodia on the other side of the segment is now raised toward the dorsal side and carried forward in a recovery stroke with the setae withdrawn. Next, the parapodia reverse their role: those which complete backward effective stroke perform the forward recovery stroke and vice versa.

5.4.1.2. RAPID CRAWLING

This movement depends mainly on the contralateral waves of contraction of the longitudinal muscles of the body wall, causing lateral undulations of the body. The parapodial activity described above supplements the body's undulations. This results in rapid crawling. The crawlers include polychaetes of many families like nereis, syllids, phyllodocids etc.

5.4.1.3. SWIMMING

The movements involved are basically similar to rapid crawling mentioned above, but during swimming the waves are fewer but larger and more frequent. These animals are pelagic, having no contact with the substratum.

5.4.1.4. BURROWING

Some polychaetes are burrowing. Examples are glycerids and capitellids. Their parapodia are smaller. Burrowing is accomplished through proboscis protrusion (buccal cavity and phayrnx). Later, the proboscis is withdrawn into the body and, and the animal crawls into that space. Burrowing in polychaete is different from that in oligochaetes. These show crawling and digging or burrowing movement.

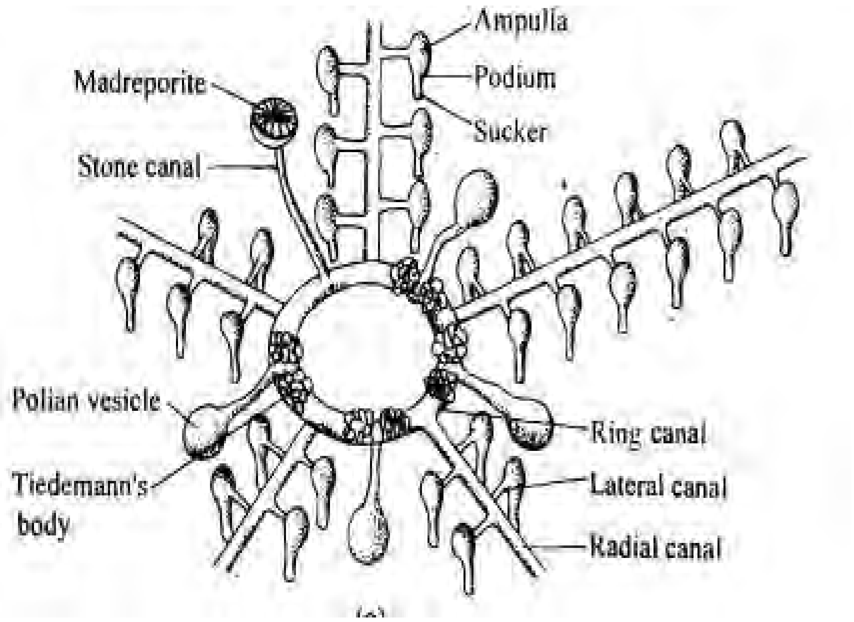
The action of longitudinal and circular muscles upon the coelomic fluid creates a peristaltic wave; while the setae, which are fewer in number, are shorter, help in getting a local grip on the substratum. The digging or burrowing action is accomplished by the forward extension of the anterior segments into the spaces of the soil particles. The expansion of the space is now caused by an increase in hydrostatic pressure. The animal now pulls the posterior part of the body forward.

5.5. HYDROSTATIC SKELETON IN ECHINODERMS

Star fishes (Asterias) are the members of the phylum Echinodermata which possess a characteristic hydrostatic skeleton. The operation of a coelomic hydrostatic skeleton has most extensively been studied in echinoderms. The coelomic body cavity is well developed in asteroids (star fishes), but because the body wall is rigid, peristaltic movement is not possible. In Asterias, the water vascular system bears tube feet and has a central coelomic cavity that transports sea water within the animal. Tube feet are short tubular external projections of the body wall located in the ambulacral groove.

Locomotion in echinoderms is accomplished by a unique canalicular system which is known as the water-vascular system. This system is characteristic of echinoderms, in most of which it is quite well developed. It is made up of a series of canals that branch off the coelom. The canals contain fluid. Sea water has free access to the system via a perforated sieve plate called the madreporite on the aboral side of the animal. The fluid is much like seawater but has a high content of potassium ions. Some proteins, and several types of amoebocytes float in it.

A peculiar hydrostatic pressure mechanism is found in star fishes, which is known as the water-vascular system, used for locomotion and prey capturing. The structural organisation of the water-vascular system is basically the same in all echinoderms. This system is composed of the following structures.



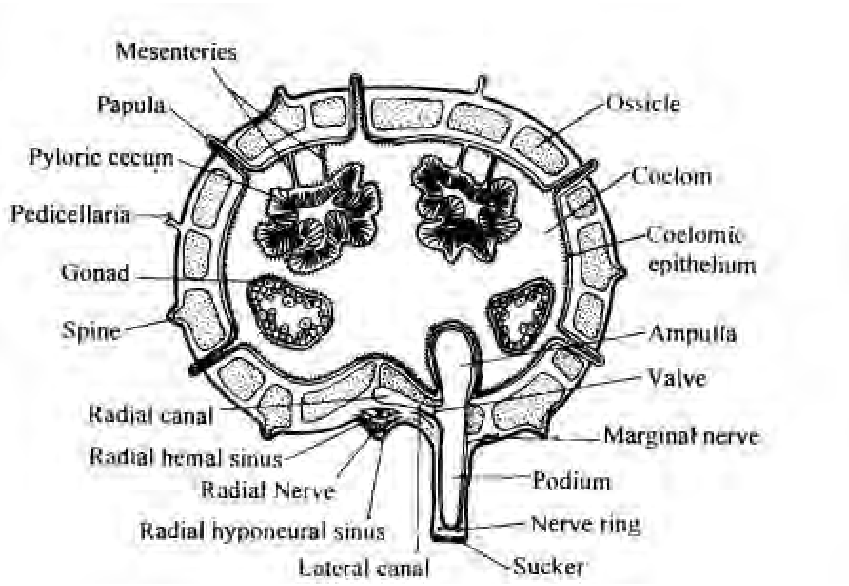


Fig.5.9. Hydrostatic skeleton of echinoderm

5.5.1. MADREPORITE

It is a round, thick and sieve-like calcareous plate, which is situated on the aboral surface of the central disc of star fishes. It consists of numerous fine radiating furrows having more or less 250 small bones and each pore leads into a small pore canal. The entire pore canals connect to form a larger collecting canal, which eventually leads to a sac-like ampulla beneath the madreponite. The ampulla is continued into a stone canal.

Stone canal is also known as Madreporic canal, which is a S. shaped tube-like structure which opens into a ring canal on the oral side. The cells lining the stone canal are provided by cilia or flagella which create water current to draw water into it.

5.5.2. RING CANAL

A ring canal is present around the oesophagus. It is pentagonal in structure and lies in a radial position.

5.5.3. TIEDMANN'S BODY

These are small, rounded and glandular sac like structures, opening into a ring canal. They are nine in number. Each Tiedmann's body consists of the outer peritoneum enclosing a stroma of connective tissue and some muscle fibres along with numerous tubules.

5.5.4. POLIAN VESICLES

Polian vesicles are thin walled contractile structures. They are located at each interradius and open on the outer surface of the ring canal. It is supposed that they store water and help in regulating the water pressure.

5.5.5. RADIAL CANAL

A radial canal arises from the ring canal along each radius, which extends up to the tip of the arm. Each radial canal runs through the ambulaeral groove and ends as a lumen in the mi terminal tentacle.

5.5.6. LATERAL CANALS

The radial canal gives out two series of lateral canals along the entire length of each arm. Each lateral canal opens into a tube foot.

5.5.7. TUBE FEET

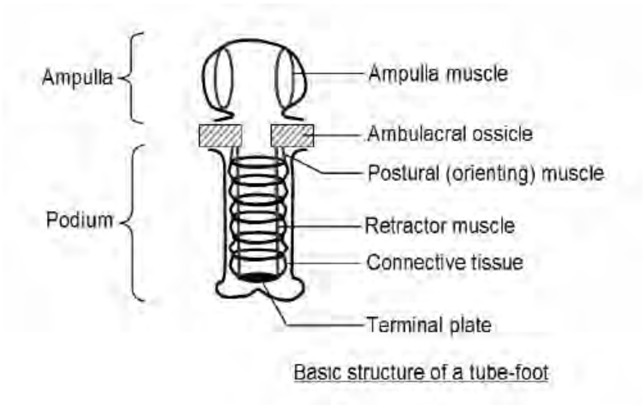


Fig.5.10. Basic structure of tube feet

Each lateral canal opens into a tube foot. There are two double rows of tube feet with respect to each series of alternately present short and long lateral canals. Each tube foot consists of three regions; a rounded sac like ampulla, a middle tubular podium and a cup like sucker at the terminal lower end of the podium. The tubular podium extends through the ambulacral groove. The walls of the tube foot contain longitudinal muscles and the wall of the ampulla contains circular muscles. The most peculiar function of these systems is locomotion by providing a hydrostatic pressure mechanism.

5.6. ROLE OF TUBE FEET IN LOCOMOTION

In *Asterias forbesi*, the circulating fluid enters each tube foot on the side of the ambulacral margin, and leaves it on the side of the ambulacral axis, while the current enters the ampulla on its aboral side and leaves it orally. Each tube foot-ampulla unit may be cut off from the rest of the water vascular system by a valve, so arranged as to maintain the pressure developed within the unit. The functioning of the unit depends upon differences between the musculature of the ampulla and the tube foot.

In the ampulla, the muscles consist mainly of rings of smooth muscles which are set vertically and lie parallel to the long axis of the arm. Contraction of these muscles brings about protraction of the tube foot and drives the fluid out of the ampulla into the foot. The increase in pressure is wholly translated into elongation of the foot that subsequently comes into contact with the substratum. The musculature of the tube foot, in contrast to that of the ampulla, consists of longitudinal muscles, which are bounded on the inner side of the coelom.

5.7. MECHANICS OF LOCOMOTION IN ECHINODERMATA

The water vascular system and other components of the coelom echinoderms are lined by an endothelium and are filled with coelomic fluid. This is of primary importance in locomotion in echinoderms. The fluid-filled tube-foot with vascular walls of its ampulla provides the basic component of a hydraulic system. The terminal sucker of the tube feet is also muscle-operated.

The walls of the tube-foot are provided with longitudinal muscles, while the ampulla also has its muscles. With the valves closed, the contraction of the ampullar muscles maintains the hydraulic pressure and causes the extension and elongation of the tube-foot in the desired direction. When the tube foot touches the substratum, the sucker produces a vacuum resulting in adhesion. Once this happens, the longitudinal muscles of the tube foots are contract. This shortens the tube foot, driving the fluid back into the ampulla.

Echinoderms such as many asteroids, echinoids and holothurians can creep using this mechanism; some can even climb steep rocks. Furthermore, holothurians can burrow into sand or mud by utilizing the hydrostatic mechanism in conjunction with body muscles. The asteroid Astropecten, which has no suckers on its tube feet, can burrow into sand or mud using tube feet. Some of its skeletal elements are used in manipulating the tube feet.

Let Us Sum Up

In this unit, we studied about the hydrostatic movements in invertebrates. Under this unit, we focused on the hydrostatic skeleton, mechanism of action of coelenterate hydrostatic skeleton, hydrostatic locomotion in Annelida, locomotory structures such as , parapodia, setae and suckers, hydrostatic skeleton in Hirudinea, mechanism of locomotion such as, slow walking and crawling, rapid crawling, swimming and burrowing, hydrostatic skeleton in echinoderms and its associated structures such as, madreporite, ring canal, tiedann's body, polian vesicles, lateral canal and tube feet, role of tube feet in locomotion and mechanics of locomotion in Echinodermata.

Check Your Progress

1) The __________ is made possible by closed fluid filled internal spaces of the body.
2) Annelids possess __________ types of locomotory structures.
3) Structure characteristics of hirudinea is __________ and __________.
4) In oligochates, the main locomotory structure is __________.

Glossaries

Hydrostatic skeleton	:	It is a flexible skeleton supported by fluid pressure.
Musculature	:	It is the system or arrangement of muscle in a body or organ.
Parapodia	:	It is a lateral extension of the foot used as an undulating fin for swimming.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Hydrostatic movement https://youtu.be/z_HtYDO9msw

https://youtu.be/UD008bsQZFY

Answers to check Your Progress

1) Hydrostatic skeleton
2) 3
3) Setae and parapodia
4) Setae

UNIT- 6

Nutrition in Lower Metazoan

Suggested Readings

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Answers To Check Your Progress

Objectives

After studying this unit, the students will be able to

- Explain nutrition in invertebrates
- Describe the various patterns of feeding and digestion in lower metazoans

Overview

In this unit, we will study about the nutrition in invertebrates. Here, we will focus on the types of nutrition in invertebrates such as, holophytic nutrition, holozoic nutrition, parasitic nutrition, saprozoic nutrition, mixotrophic nutrition, parasitic mode of feeding in Protozoans such as, import, invagination, phagocytosis and pinocytosis and digestive mechanism in amoeboid feeding.

6.0. NUTRITION IN LOWER METAZOANS

The process of taking food and using it for growth, metabolism, and repairing of cells is called nutrition. Nutritional stages are ingestion, digestion, absorption, transport, assimilation, and excretion. There are seven main classes of nutrients that the body needs. These are carbohydrates, proteins, fats, vitamins, minerals, fibre and water. All living organisms on the earth need energy to remain alive and maintain the equilibrium state of their bodies. The energy is obtained from internal or external materials and chemical compounds by biological or biochemical reactions. Nutrition is the supply of such chemicals from outside sources or their own synthesis using simple substances and the sun's or chemical energy.

6.1. TYPES OF NUTRITION IN INVERTEBRATES

6.1.1. HOLOPHYTIC NUTRITION

This is an autotrophic (self feeding) type of nutrition in which animals synthesize the food by photosynthesis. Energy is obtained from the sun to synthesize the food. This method is also called autotrophic phototrophy.

Fig.6.1. Holophytic nutrition in paramecium

6.1.2. HOLOZOIC NUTRITION

Holozoic nutrition involves the ingestion and internal processing of solid and liquid food in an organism. This involves the steps of ingestion, digestion, absorption, assimilation and excretion. Most invertebrates obtain their food by eating fully or parts of other organisms. Such a mode of nutrition is called holozoic. This is also referred to as the heterotrophic mode of nutrition. Examples of animals that exhibit holozoic nutrition include all vertebrates. Even unicellular organisms, such as amoeba, have holozoic nutrition.

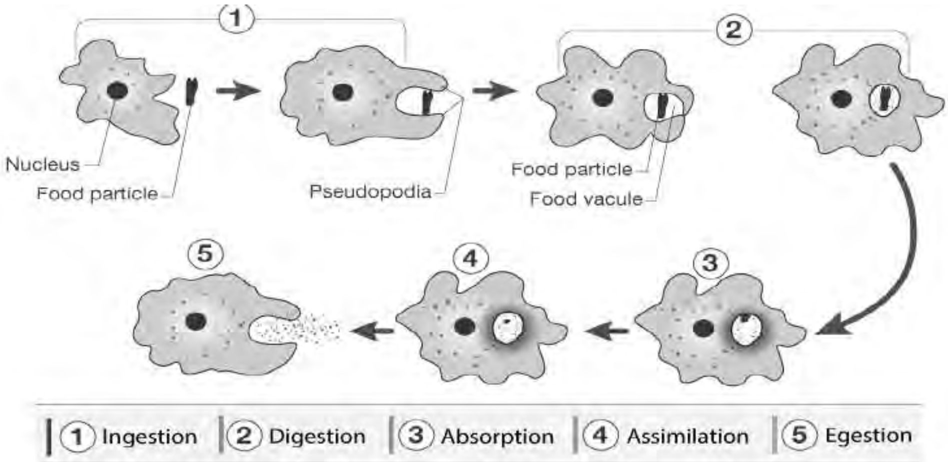

Fig.6.2. Holozoic nutrition in amoeba

6.1.3. PARASITIC NUTRITION

Organisms that live in or on other organisms and acquire food at the expense of their host are called parasites. Most parasites are harmful to the hosts' health; sometimes, they even kill the host. A louse on a human head and tapeworms are two examples of parasites.

There are two types of parasites:

6.1.3.1. ECTOPARASITES

That lives externally in the body of their host organisms to drive food.

6.1.3.2. ENDOPARASITES

The organisms live inside the body of their host organisms. Invertebrates show different ways of obtaining food from their hosts. Some absorb predigested food from their body surface, while others obtain pre-digested/partially digested food from their mouth and process it in their own digestive system. Some use the serum of their host blood.

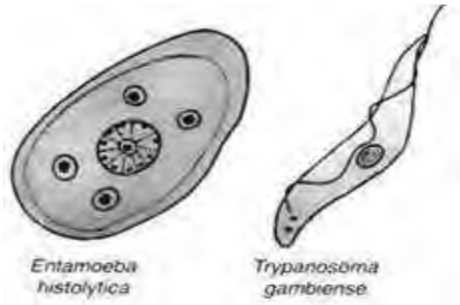

Fig.6.3. Endoparasites

6.1.4. SAPROZOIC NUTRITION

Saprophytic animals feed on dead and decayed organisms for energy. They are an important part of the ecosystem as they help to keep our environment clean and recycle nutrients back into the ecosystem. This heterotrophic mode of nutrition involves absorption of food by osmosis, through the body's surface. This is also called osmotrophy. Food consists largely of solution of dead organic matter processed by decomposing bacteria. Some examples of saprophytes are fungi and certain types of bacteria. These are also to blame for the deterioration of bread and other similar food products.

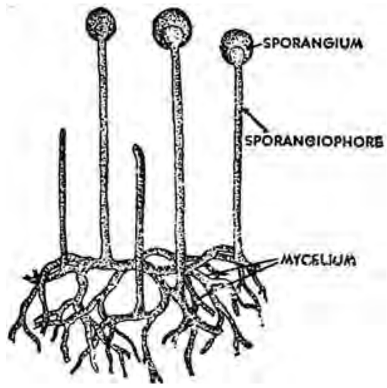

Fig.6.4. Saprozoic nutrition in fungus

6.1.5. MYXOTROPHIC NUTRITION

In this mode of nutrition, the animal adopts a combination of more than one mode of nutrition.

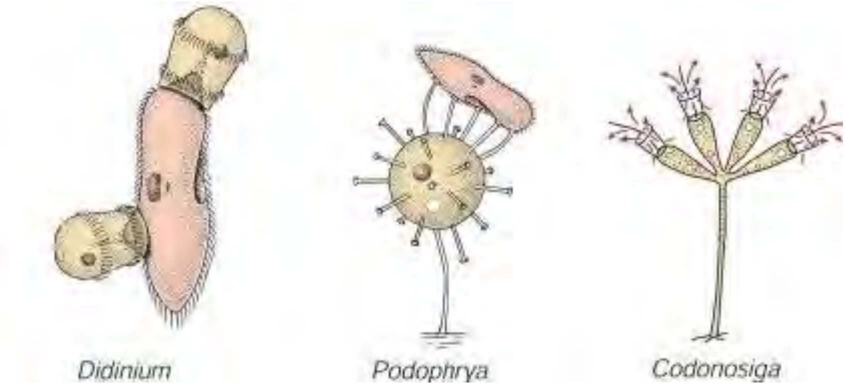

Fig.6.5. Myxotropic nutrition in didinium, podophyra and codonosiga

6.2. PARASITIC MODE OF FEEDING IN PROTOZOA

6.2.1. PHAGOTROPHY

Most of the intestine dwelling protozoans ingest their food particles by phagotrophy. E.g. parasitic ciliates Nyctotherus and Sarcodine, Entamoeba.

6.2.2. OSMOTROPHY

These parasites absorb digested nutrients from their body surface, e.g. Trypanosoma.

There may be two types.

a) Coelozoic:

All food on the body's surface should be absorbed.

b) Histozoic:

It feeds upon the tissues of the host.

6.3. AMOEBOID FEEDING IN PROTOZOANS

It adopts the phagotrophic type of feeding mechanism. Amoeba is acellular (often called unicellular), therefore its feeding method is called phagocytosis. In this feeding mechanism, solid food particles are engulfed by amoeba. This process is so typical that it is often called amoeboid feeding. The solid food of amoeba consists of bacteria, diatoms, flagellates, ciliates, rotifers and desmids. Amoeba consumes solid food by capturing and engulfing it with phagocytosis. When the body surface (plasmalemma) comes into contact with food, pseudopodia form. Amoeba and amoeboids use four well identified methods for ingestion of food, depending on the type and nature of food.

6.3.1. IMPORT

The food comes in contact of plasmalemma and passively sinks into ectoplasm and then in endoplasm.

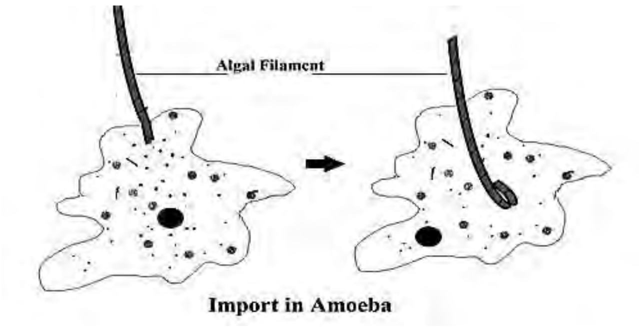

Fig.6.6. Import in amoeba

6.3.2. INVAGINATION

The ectoplasm forms a kind of tube (ectoplasmic tube) and takes the food into it. The tube is later converted into a food vacuole.

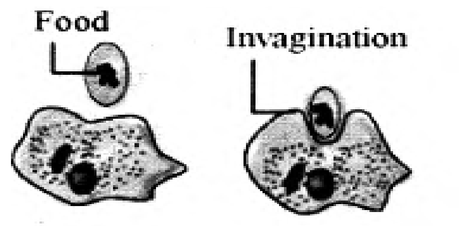

Fig.6.7. Invagination in amoeba

6.3.3. PHAGOCYTOSIS/CIRCUMVALENCE

Amoeba engulfs the food with the help of pseudopodia. When food is close to the plasmalemma, the pseudopodia forms a cup-like structure around the prey, which is known as a “food cup”. The opening of the food cup constricts and is finally closed and envelopes the food as food vacuole or gastric vacuole. Food and water are present in the food vacuole.

6.3.4. PINOCYTOSIS

In this method, liquid food is taken into the body. It is similar to phagocytosis. A food vacuole is also formed by liquid food and water. Proteins, inorganic ions and oil droplets are taken inside by pinocytosis. The food is surrounded by pinocytosis channels through which liquid food flows into pinocytosis vesicles or pinosomes.

6.4. MECHANISM OF DIGESTION IN AMEOBOID FEEDING

6.4.1. DIGESTION

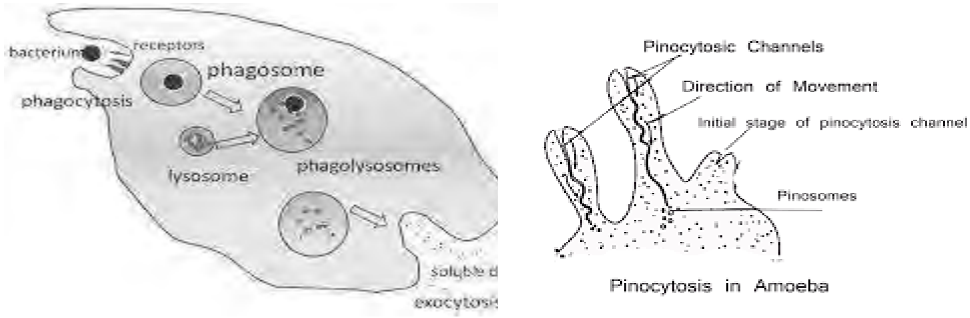

Fig.6.8. Pinocytosis in amoeba

The food vacuole is a temporary, non contractile vacuole that contains food and water, surrounded by a membrane. After reaching the endoplasm, it fuses with lysosomes that contain a variety of enzymes. These lytic enzymes (protease, amylase and lipase) are mixed with food during cyclosis of cytoplasm. The food is digested during cyclosis of endoplasm.

6.4.2. ABSORPTION

After the digestion process, the digested food diffuses into the surrounding endoplasm. The process of digestion is completed in roughly 30 hours. The digested food is assimilated and used in metabolic activities.

Fig.6.9. Adsorption in amoeba

6.4.3. EGESTION

After diffusion of digested food, the food vacuole is reduced in size. At the end of digestion, it contains undigested part of food. Reversed phagocytosis empties this.

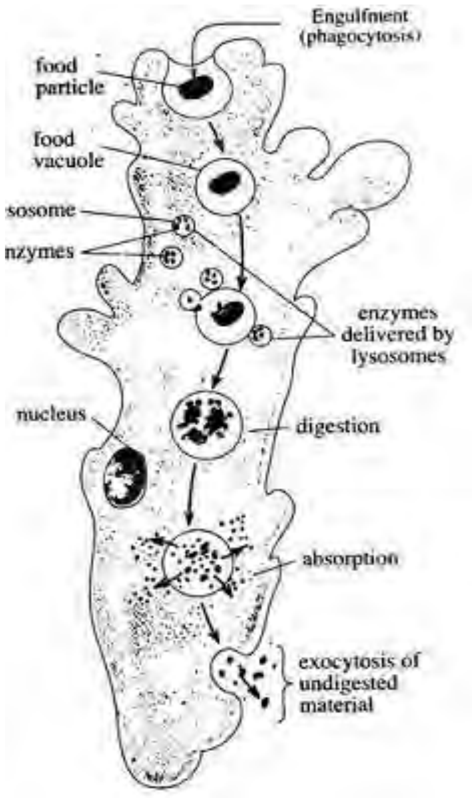

Fig.6.10. Scheme of nutrition within a food vacuole

Let Us Sum Up

In this unit, we studied about the nutrition in invertebrates. Under this unit, we focused on the types of nutrition in invertebrates such as, holophytic nutrition, holozoic nutrition, parasitic nutrition, saprozoic nutrition, mixotrophic nutrition, parasitic mode of feeding in Protozoans such as, import, invagination, phagocytosis and pinocytosis and digestive mechanism in amoeboid feeding.

Check Your Progress

1) The process of taking food and using it for metabolism and cell repairing is called __________.
2) There are __________ types of nutrition in invertebrates.
3) The feeding method of amoeba is called __________.
4) __________ and __________ are the two types of digestion mechanism takes place in amoeba.

Glossaries

Holozoic : It is the process of internalizing and processing liquid or food particles.

Saprozoic : It is the process of feeding on dead organic matter for nutrition.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Nutrition in invertebrates https://youtu.be/aSo5dnUQcRA

Patterns of feeding digestion in lower metazoans
https://youtu.be/JPSKZYi1OiU

Answers to check Your Progress

1) Nutrition
2) 5
3) Phagocytosis
4) Absorption and egestion

UNIT- 7

Filter-Feeding

Objectives

After studying this unit, the students will be able to

- Explain the filter feeding mechanism in invertebrates
- Describe and illustrate the action of filter feeding mechanism in Polychaetes, molluscs and Echinodermata

Overview

In this unit, we will study about the filter feeding in invertebrates. Here, we will focus on the filter feeding mechanism in Polychaetes, molluscs and Echinodermata.

7.0. FILTER FEEDING

Filter feeding is a form of food procurement in which food particles or small organisms are randomly strained from water. Filter feeding is found primarily among small to medium sized invertebrates but occurs in a few large vertebrates (*e.g.,* flamingos, baleen whales). An animal that obtains its food by filtering organic matter or minute organisms from a current of water that passes through some part of its system. Filter feeders are a sub-group of suspension feeding animals that feed by straining suspended matter and food particles from water, typically by passing the water over a specialized filtering structure.

In order to obtain food, sponges pass water through their bodies in a process known as filter-feeding. Water is drawn into the sponge through tiny holes called incurrent pores. As it passes through the channels and chambers inside the sponge, bacteria and tiny particles are taken up from the water as food. Filter feeders can be important to the health of a water body. Filter feeders like mussels and oysters filter small particles and even toxins out of the water and improve water clarity. For example, oysters are important in filtering the water of the Chesapeake Bay.

7.1. FILTER FEEDERS IN POLYCHAETES

Filter feeding is another mode of nutrition that has evolved in several families of sedentary and tube dwelling polychaetes. Most of the sedentary and tubicolous polychaetes are filter feeders. They do not have a proboscis. Their head is provided with long bipinnate filaments called radides with a ciliated groove running along the oral surface. Radides are used in food collection.

Chaetopterus, which lives in a U-shaped parchment tube, has a unique method of food selection. The notopodia of particular segments of the body form fans. The beating of these fans produces a water current which enters the tube from the anterior end and flows out of the posterior end. The food particles in this water current are filtered out into the mucous bag formed by ciliated glandular epithelium. This mucus bag ends in a ciliated food cup where the food is rolled up into a ball and passed forward to the mouth along the ciliary groove. At intervals, the secretory process stops and the cilia in the ventral groove move in reverse. As a result, the ball or pellet containing food is transported from food cup to mouth and swallowed. In *Neries diversicolor*, under some conditions, the mucous secretion forms into a net within a burrow, water pumped through these net particles collected in this secretion and finally, the material is swallowed from time to time. This is perhaps the simplest form of filter feeding in Polychaets.

In the lugworms, for example, *Arenicola excavates*, the filter feeding is again specialized. They live in L-shaped burrows. It periodically ingests sand with the help of its simple proboscis. This causes the sand to cave in, forming a funnel-shaped depression at the surface. These sand filters suspend food particles from the water percolating down the funnel. This organically rich sand is then ingested by the worm.

One kind of filter feeding is seen in fan worms or feather duster worms, where the prostomium palps have developed to form a funnel shaped or spiral crown consisting of pinnate processes called radioles, for example in Sabella. During feeding, the particles are first trapped in the mucus of the radiole surface and then passed on to the mouth with the help of cilia. When the worm pulls back its anterior end into the free end of the tube, the radioles are rolled and closed up together.

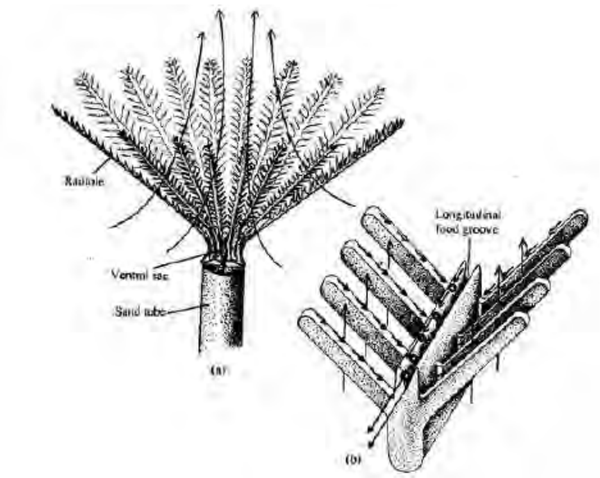


Fig.7.1. Filter feeding in fanworrn Sabella (a) Water current passing through radioles. (b) Water current and ciliary tract over a part of radiole.

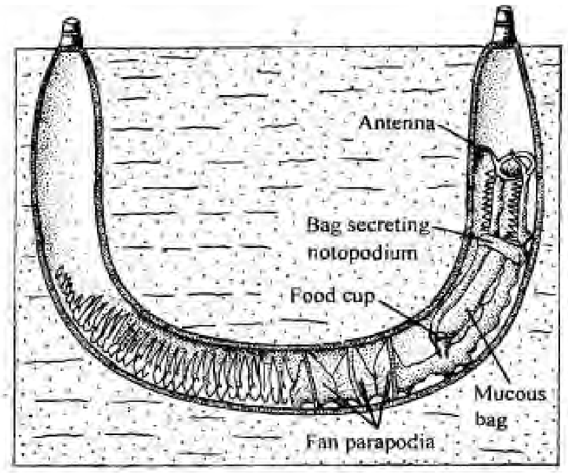


Fig.7.2. Chaetopterus in its tube

Sabella is a suspension feeder of the littoral zone, extracting its food from water currents created by cilia present upon the branchial crown. The branchial crown consists of a large number of cephalic tentacles or filaments which are stiff and pinnate. These are arranged into two rows of thirty. The branchial crown forms a wide funnel with the mouth of the animal lying at its base.

The cilia are used to secure the food and to direct it towards the mouth. The pinnules at the distal end of the filament are separated from the ones on the next adjacent filament but towards the lower part of the branchial funnel they are brought closer together and finally interlock. Towards the base of each filament, two rows of pinnules pass into two continuous folds-basal folds or gill folds. These various structures constitute part of the sorting mechanism that ensures that only suitable particles are directed into the digestive system. The large particles are removed from the animal through the action of rejection currents.

7.2. FILTER FEEDING IN MOLLUSCA

Filter feeders are molluscs that feed by straining suspended matter and food particles from water, typically by passing the water over their gills. Mussels are filter feeders, which means they are like a small living pump. Filters work as gills, extracting oxygen and food from the water.

The Bivalvia molluscs are filter feeders, extracting the nutritious matter from the sea where they live. They draw water from their gills through the beating of the cilia. Suspended food is trapped in the mucus of the gill. The foods they eat are phytoplankton, zooplankton, algae and other nutrients and particles in water. The trapped food is then transported to the mouth, where it is eaten, digested and expelled as feces. They filter about 5L of water per hour. Bivalves that are buried under the ground extend a siphon to the surface for feeding.

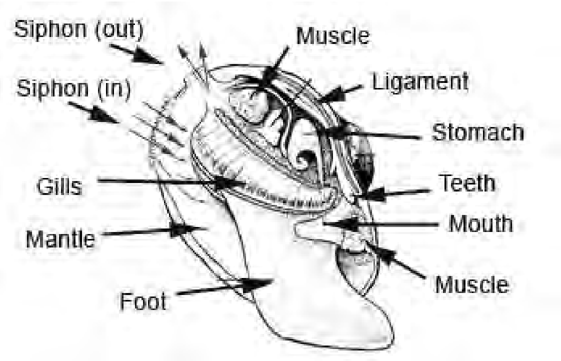


Fig.7.3. Internal feature of mollusca

In Molluscs, the alimentary system is adapted for filter feeding by the ciliated gill. The water current is initiated and maintained by the beating of the lateral cilia of the gill filament. Water enters through an inhalant siphon and leaves through an exhalent siphon. The beating of lateral cilia draws water into the mantle cavity through an inhalent siphon. The water current enters the gill through the ostia and goes outside through an exhalent siphon. The incoming water current is loaded with food such as micro-organisms and food particles. The beating of lateral cilia of gill filaments towards the outer surface of the lamellae throws the fine food particles over the lamellar surface. The lamellar surface secretes a mucus sheet to trap these food particles. The beating of frontal cilia moves the food loaded mucus sheet towards the food groove. Ciliary beating moves the food into the mouth.

7.3. FILTER FEEDING IN ECHINODERMATA

Crinoids (Sea lilies and feather stars) are pentamerous, stalked echinoderms with a cuplike body bearing five usually branched and commonly featherlike arms. Most of a crinoid's body consists of an endoskeleton composed of numerous calcareous pieces, called plates or ossicles. The visceral mass of the crinoid animal is encased in the aboral cup that is typically composed of 2-3 circlets of plates. The mouth and anus are on the upper or oral surface of the animal. Five radial plates (the uppermost circlet of aboral cup plates) are aligned with the radial water vascular canals and give rise to five arms on the oral side of the body. Each arm is an articulated series of ossicles extending outward from the body. Arms contain extensions of coelomic, nervous, water vascular, and reproductive systems and bear an ambulacral groove bordered by fingerlike tube feet, or podia.

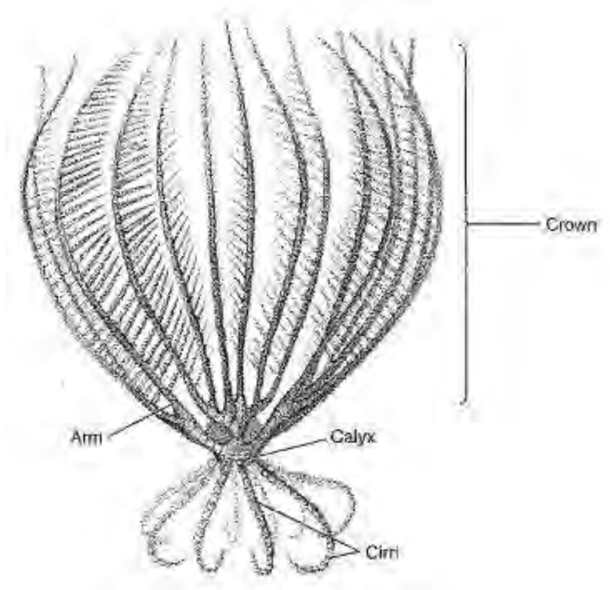


Fig.7.4. External feature of crinoid

Echinoderms are filter feeders, substrate eaters or carnivores. The gut is V-shaped in the Crinoidea with the mouth and anus being on the same surface. In the other groups, such as Echinoidea and Holothuroidea, it is a straight-through gut with the mouth and anus on approximately opposite sides of the body. The modes of feeding vary greatly between the constituent taxa.

Crinoids and some brittle stars tend to be passive filter-feeders, absorbing suspended particles from passing water; sea urchins are grazers, sea cucumbers deposit feeders. Crinoids employ a large net-like structure to sieve water as it is swept by currents, and to absorb any particles of matter sinking from the ocean overhead.

Let Us Sum Up

In this unit, we studied about the filter feeding in invertebrates. Under this unit, we focused on the filter feeding mechanism in Polychaetes, molluscs and Echinodermata.

Check Your Progress

1) __________ is a form of food procurement in which small organisms are randomly strained from water.
2) In molluscs, the alimentary canal is adapted foe filter feeding by the __________.
3) Peristaltic movement is found in __________.
4) __________ are pentamerous, stalked echinoderm.

Glossaries

Radiole	:	It is the heavily feather-like tentacles found in invertebrates.
Littoral zone	:	It is the part of a sea, lake or river that is close to the shore.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

Weblink

Filter feeding in polycheats https://youtu.be/lAg5q-H-43I

Filter feeding in molluscs https://youtu.be/YWtj7DnBX-4

Filter feeding in Echinodermata https://youtu.be/f2gKgj9Dqy4

Answers to check Your Progress

1) Filter feeding
2) Ciliated gills
3) Gastro intestinal tract
4) Crinoids

BLOCK III: RESPIRATION AND EXCRETION

UNIT- 8

Respiration and Respiratory Organs

Suggested Readings

Weblink

Answers To Check Your Progress

Objectives

After studying this unit, the students will be able to

- Explain the respiration in invertebrates
- Describe the basic respiratory process in invertebrates
- List out and explain the organs of respiration

Overview

In this unit, we will study about the respiration and respiratory organs in invertebrates. Here, we will focus on the structure and functions of gills, aquatic respiration by gills, gills in Mollusca, adaptive or secondary gills and integument, types of ctenidia based on the topography, types of ctenidia based on the arrangement of leaflets, ctenidia in different groups of mollusc, gill respiration in Arthropoda, modification of gills in Arthropoda, structure of typical gill, hydrofuge hairs and respiratory siphon, lophophores, aerial respiration in Arthropoda and types of tracheal system.

8.0. RESPIRATION

Respiration involves gaseous exchange with the environment with intake of oxygen and release of carbon dioxide, followed by utilizing oxygen in the oxidative process and ultimately producing ATP. Small and microscopic animals (e.g. protozoans, sponges) obtain their required amount of oxygen and release carbon dioxide by simple diffusion. From such simple structure and physiology, the complexities evolved. As the animals become larger and the surface area available for gas exchange is reduced, more and more specialized devices have evolved (e.g. gills and lungs).

Annelids breathe through their skin or their gills. In Arthropoda, while gills are retained by aquatic forms, terrestrial members of the group have evolved book-lungs (scorpions) and tracheae (centipedes, milipedes and insects). Xiphosura and Crustacea are almost exclusively aquatic. They evolved in water and remained there. There are also same water-dwelling arthropods, which have actually invaded land and acquired terrestrial adaptations. They returned to the aquatic medium and made it their second home. This includes many adult insects (water-bugs, water-beetles, and so on) that breathe through their tracheae while living in water. Thus, aquatic respiration in Arthropoda may be by gills (usually called branchial respiration) or by tracheae (tracheal respiration).

8.1. ORGANS OF RESPIRATION

The organs of an animal's body which are needed for the exchange of gases (O_2 & CO_2) between the surrounding medium and the body are known as respiratory organs. Depending upon the habitat, types of respiration are classified into two; (1) aquatic and (2) Terrestrial. Invertebrates have two types of respiratory organs: gills and lophophores for aquatic respiration and trachea and lungs for terrestrial (aerial) respiration. All these respiratory structures consist of a common plan: a moist semi permeable and highly vascularized membrane always exposed to external oxygen rich surrounding medium.

8.1.1. GILLS

Gills or bronchial are respiratory organs of aquatic animals. First gill like structure can be found in tubicolus/burrowing annelids and members of minor phyla. They had tentacles or branchial crowns at the oral end. They perform respiratory exchange of gases also. Well organized and well-developed gills are found in two phyla; Arthropoda and Mollusca.

On the basis of their form and shape, there are two types:

8.1.1.1. PECTINATE GILL

Pectinate gills have a longitudinal axis from which filaments (lamellae) protrude on one side (uni or mono pectinate) or on both sides (bipectinate). Some aquatic gastropods possess one ctenidium known as monopectinate and others have a pair of ctenidia known as bipectinate.

Fig.8.1. Pectina gill

8.1.1.2. PLATE GILLS

These are one of the branchial lamellae of mollusca. These are flat or plate-like gills that can take on a variety of shapes. Each gill-plate is a tiny sac, and within these are the fine branches of the air-tubes present.

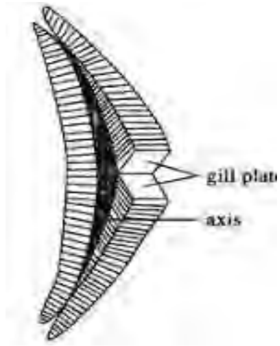


Fig.8.2. Plate gills

8.1.2. AQUATIC RESPIRATION BY GILLS

Two modes of aquatic respiration in insects are recognised. In one, the insects obtain oxygen dissolved in water. This may be affected either by the general body surface or by means of different types of gills. Tracheal gills of the aquatic larvae of mayfly, stonefly and caddisfly are the lateral outgrowths of the body wall and contain tracheal branches. Rectal gills are present in the rectum of Odonata larvae. The stonefly larvae possess tracheal gills on various regions of the body and anal gills on each side of the anus. The blood-gills of some dipteran larvae are blood-filled out-growths of the body wall.

Gills are used for respiration in Xiphosura, Crustacea, and many larval insects. A gill is a vascular outgrowth of the body wall. It remains bathed in water and gaseous exchange occurs on its surface. In Limulus (Xiphosura), five pairs of book-gills are present on the ventral surface. These are flat, lamellate abdominal appendages. Each gill supports about 150 gill lamellae arranged in a manner which gives it the appearance of the leaves of a book. Hence, it is called book gills.

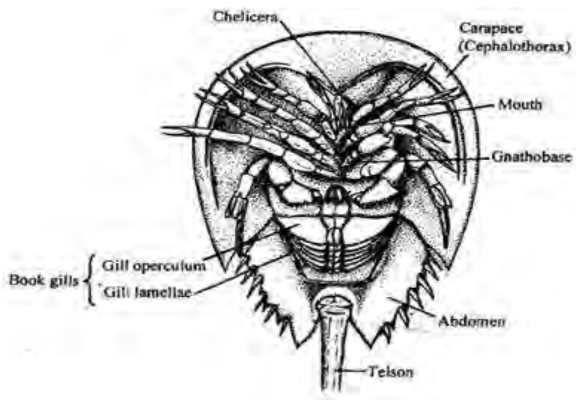


Fig. 8.3. Ventral view of book gills in Limulus crab

In Crustacea the gills or branchiae are arranged as lateral extensions along the central axis. Gills may be of three types:

8.1.2.1. PHYLLOBRANCHS

A type of decapod gill bearing a double series of platelike or leaflike branches from the axis. These are simple, leaf-like lobes that are set on either side of a main axis that bears a series of broad, flattened, leaf-like branches.

8.1.2.2. TRIOCHOBRANCHS

Triochobranchs are modified phyllobranchs with filaments arranged around a central axis and each lateral lobe subdivided. Gills have a supply of haemocoelomic channels. A continuous supply of water is maintained in the gill chamber. This ensures proper gas exchange.

8.1.2.3. Dendrobranchs

These are modified phyllobranchs with each lateral lobe being subdivided. Gills have a supply of haemocoelomic channels. A continuous supply of water is maintained in the gill chamber. This ensures proper gas exchange.

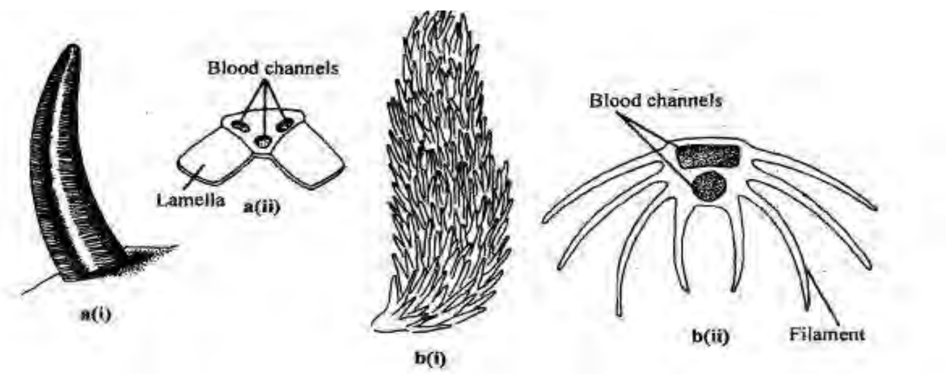


Fig.8.4. Gill types in crustaceans. a) Phyllobranch b) Triochobranch c) Dendrobranch,

8.1.3. GILLS IN MOLLUSCA

Mostly, molluscs are aquatic and respire by means of gills which are called Ctenidia. These are situated in the mantle cavity. The gills of mollusca are a homologous organ.

8.1.3.1. STRUCTURE OF GILL IN MOLLUSCA

Ctenidia are projections of the mantle. Ctenidia are paired, symmetrical, ciliated and two rows of flattened gill filaments, arranged one on either side of a long, flattened axis, traversed by afferent and efferent vessels through which haemolymph flows. Ctenidia consist of a main axis or stem placed horizontally bearing a row of filaments or lamellae on one or both sides. These are delicate, flexible and numerous structures covered by cilia. The movement of cilia is responsible for maintaining water current in the mantle cavity. Narrow spaces are left between the gill filaments to permit free water flow between them but close enough so that cilia on adjacent filaments may operate together in generating water current. Blood enters Ctenidium via the alternate branchial vein and returns to the heart via the efferent branchial vein.

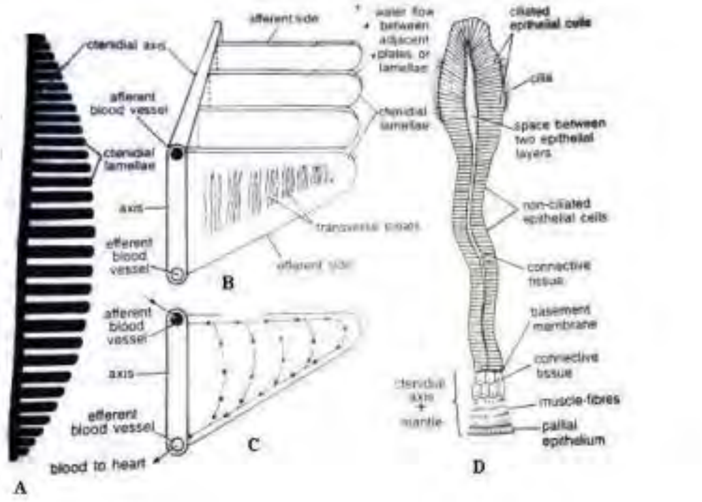


Fig.8.5. Gills in Pila: A-monopectinate ctenidium. B-stereogram to show water current through gill lamellae. C-single lamellae to show the flow of blood within it. D-A lamella in T.S.

8.1.3.2. TYPES OF CTENIDIA IN MOLLUSCA

Gills or ctenidia vary in number, form and position in mollusca. There are 5 pairs of unipectinate (monopectinate) gills composed of finger-like lamellae in the class monoplacophora. In class, Amphineura gills are true ctenidium. In Placophora, these are 6-80 in number and are arranged in two rows. Gills are absent in aplacophora, two large plumelike ctenidia were discovered, one on each side of the anus. In class Gastropoda, gills are shifted to the front of the body.

In prosobranchs, single pair gills are present. A single monopectinate gill is present on the left side of mesogastropoda and neogastropoda. Gills in opistnobranchia become shorter and more posterior. Single ctenidium is present on the right side. In pelecypoda, the gills are most complex. These serve for nutrition (filter feeding) and brood pouches. In sub class, protobranchia gills are smaller and situated at the back of the mantle cavity. In filobranchia, gill filaments become elongated and thread like. In pseudolamellibranchia, gills have more cohesion than in filibranchia.

In class septibranchia, gills degenerate and are replaced by horizontal, muscular and perforated septum. Septa moves up and down to maintain water current and respiratory gas exchange is entirely done by mantle. Gills in the class Cephalopoda are simple and bipectinate. Lamellae are leaf like, delicate and arranged in a row on the axis or stem. An important point to be noted here is that cilia are absent. Water current is produced and maintained by coordinated action of muscular mantle, funnel and inlet valves. This is an advanced feature of evolutionary importance.

8.1.4. ADAPTIVE OR SECONDARY GILLS AND INTEGUMENT

In certain members of the phylum Mollusca, ctenidia are absent and respiratory functions are carried by other morphological structures. These are called adaptive gills. There are mainly three types:

8.1.4.1. ANAL GILLS

Anal gills are a rosette of delicate and retractile gills around the anus at the posterior end of the body. Anal gills act as respiratory organs. 'Gills', or anal papillae, of mosquito larvae serve for respiration. Example: Doris. In Chactoderma, a pair of symmetrical lateral gills is present on each side of the cloaca.

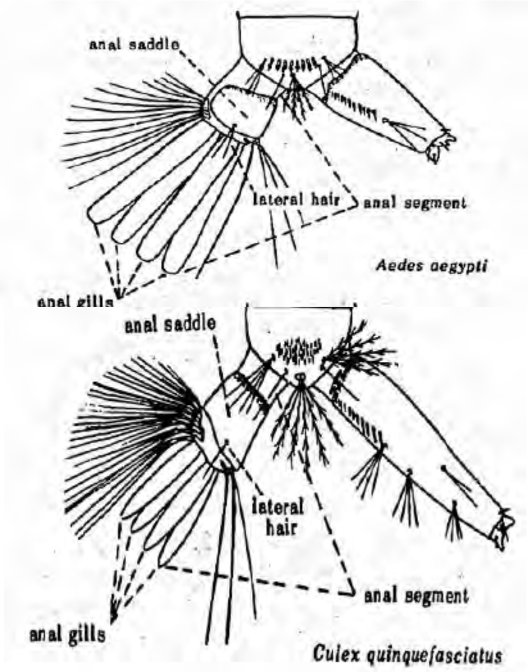


Fig.8.6. Structure of anal gill

8.1.4.2. PALLIAL GILLS

Secondary external gills develop in certain basommatophore pulmonates due to enlargement of the pallial lobe just outside the pneumostome and hey lack cilia. These are present in the form of a row in the pellial groove on each lateral side of it. Limpets (Patella), for example, have got several gill filaments in the pallial groove between the foot, mantle and shell.

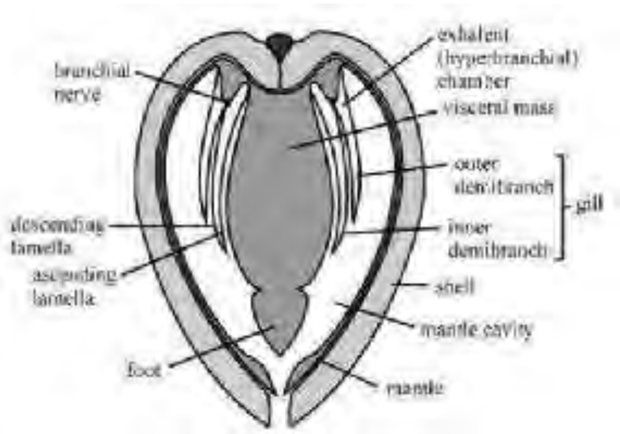


Fig.8.7. Structure of pallial gills

8.1.4.3. CERATA

In many opisthobranches the dorsum bears highly vascular appendages called cerata. They may be simple and club-shaped (Aeolis), dendritic (Dendronotus) or multi-lobed resembling a bunch of grapes (Dotochica). The word ceras comes from the Greek word "keratos", meaning "horn", a reference to the shape of these structures. These are many simple or branched structures situated on the dorsal surface of the body. These are richly vascularized and have regulative capacity. All aeolids have these dorsal and lateral outgrowths of the body. It is a blood-filled tube which contains a duct of the digestive gland. Most aeolids have a sac called the cnidosac at the tip of the ceras, such as Aeolis.

Cerata comes in many different shapes. While most are tapering and tubular, those of *Eubranchus* are very inflated, and others, such as in *Phyllodesmium longicirrum,* are large and flattened. One remarkable example, *Cuthona kuiteri,* has secondary papillae to make it look like a hydroid polyp. The digestive gland duct is an unbranched duct lined with digestive gland cells in most species, but in a few cases, particularly in the genus Phyllodesmium, the digestive gland duct is heavily branched.

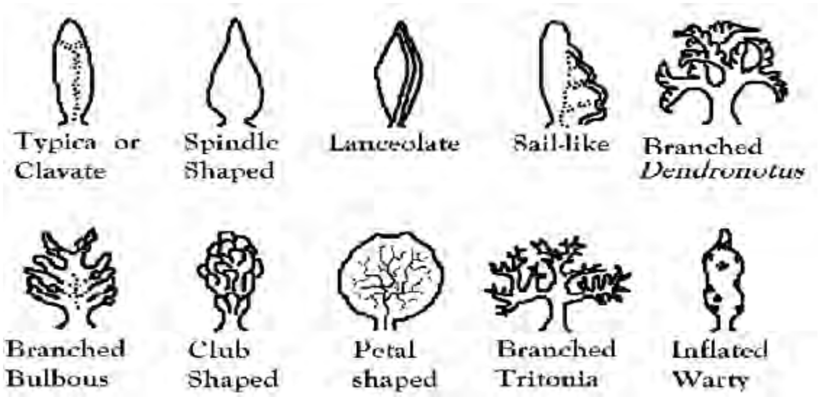


Fig.8.8. Cerata in various species

8.1.4.4. PLEURAL GILLS

In Pleurophyllida, rows of branchial leaflets are situated beneath the mantle.

8.1.5. CTENIDIA TYPES BASED ON TOPOGRAPHY

The ctenidia found in mollusks can be classified into the following groups based on their topography:

8.1.5.1. HOLOBRANCHIATE TYPE

A complete gill is known as a holobranch. It consists of bony or cartilaginous arches. The anterior and posterior part of each gill arch possesses plate-like gill filaments. Each holobranch consists of an anterior (oral) and a posterior (aboral) hemi-branch. This type of arrangement of ctenidia is found in Polyplacophora. Ctenidia cover the entire body in this form. The number of ctenidia ranges from fourteen to seventy pairs, with some species having as many as eighty pairs, such as Acanthopleura.

In Patella (Gastropoda), a circlet of gill lamellae extends completely around the margin of the mantle. It has a striking resemblance to the Chiton, prompting Cuvier to group Patella and Chitons into a single class, Cyclobranchia. In Chiton the ctenidia are present along the margin of the body excepting the head and anus, but in Patella the ctenidia are extended throughout the body.

Fig.8.9. Holobranch

8.1.5.2. MEROBRANCHIATE TYPE

The ctenidia are restricted to a particular area of the body, it is called the merobranchiate type.

8.1.6. TYPES OF CTENIDIA BASED ON THE THE ARRANGEMENT OF LEAFLETS

Depending on the arrangement of leaflets in the gills, they have been subdivided into four types;

8.1.6.1. PLICATE TYPE

This type of gill comprises in simple, flat, transversely folded, projecting integumentary laminae constitute the gill. In Neomania a tuft of filaments arise from the cloacal wall.

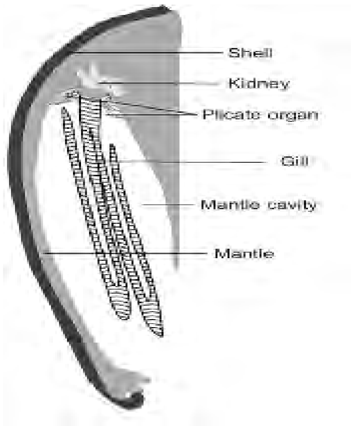


Fig.8.10. Pelicate gill of Mytilus

8.1.6.2. MONOPECTINATE TYPE

This type of ctenidia consists of flattened gill filaments arranged on only a single side of the ctenidial axis as observed in Pila, Triton.

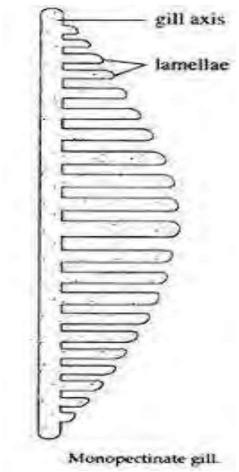


Fig.8.11. Monopectinate gill

8.1.6.3. BIPECTINATE TYPE

This type of ctenidium has flattened gill filaments arranged in two rows.

They may be of two types:

(a) Unequal

When both of them are present, but the right one is smaller as observed in Fissurella, Haliotis.

(b) Equal:

Both of them are of the same size. This is the characteristic of the Bivalves. They become variously modified among Bivalves. Nucula possesses short flat leaflets. In some forms, long filamentous leaflets are present.

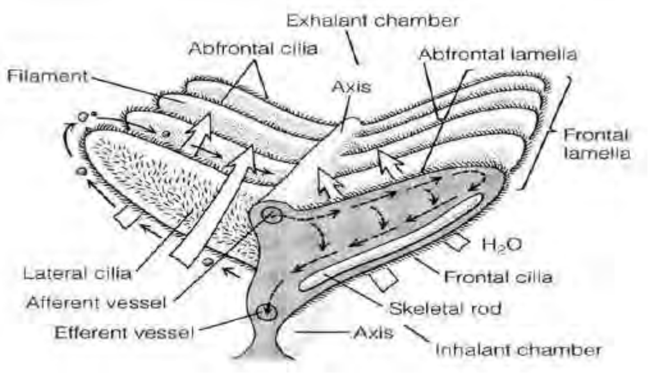


Fig.8.12. Structure of bipectinate gill

8.1.6.4. FEATHERED TYPE

The shape of a gill is like a feather. Example: Cephalopods.

Fig.8.13. Feather shaped gill of cephalopod

8.1.7. CTENIDIA IN DIFFERENT GROUPS OF MOLLUSCS

8.1.7.1. MONOPLACOPHORA

The pallial groove contains five to six pairs of unipectinate gills.

Example: Neopalina.

8.1.7.2. POLYPLACOPHORA

Ctenidia bipectinate found in the mantle groove:

(a) The number of ctenidia varies from 14 (Lepidopleura) to 80 (Acanthopleura).

(b) Gill rows can be holobranchiate, with the exception of two merobranchial rows. Examples: Chiton laeves, Chiton pall as ii.

8.1.7.3. APLACHOPHORA

The gills are reduced to a paired, feather-shaped structure situated near the cloacal cavity, one on each side. The gills are merobranchiate. Example: Chaetoderma.

8.1.7.4. GASTROPODA

The gills vary widely in number and position in this group

(i) Prosobranchia

Ctenidia lie in front of the heart.

(ii) Diatocardia

The arrangement is the most primitive. The gills are two, long, feathered, on each side and lie symmetrically to the middle line. Example: Fissurella.

(iii) Monotocardia

The arrangement of the gills is remarkably uniform. A single gill, feathered on one side and united to the mantle along its whole length. Example: Triton.

(iv) Opisthobranches

The gills are partially enclosed in the mantle cavity (Tectibranchiata). The true ctenidium, when present, is little developed and located on the right side of the body.

Example: Aplysia.

8.1.7.5. Bivalvia

The gills are bipectinate, equal on both sides, and usually very large, having taken on a food collecting function in addition to gas exchange in most species.

i. **Protobranchiata**

   Gills are the smallest and lie behind the foot at the back of the mantle cavity. In Nucula the gill filaments are triangular.

ii. **Filibranchiata**

   In section, each gill forms a 'W' with long, narrow limbs. The gill axis lies at the middle angle of the W. Examples: Area, Mytilus, Anomia.

iii. **Pseudolamellibranchiata**

   The reflected dorsal tips of the gill filaments have coalesced laterally with the mantle and mesially with the base of the foot. The gill has greater cohesion than that in the filibranchs. The surface of the gills is plicate or thrown into folds and grooves, making

iv. **Eulamellibranchiata**

The adjacent filaments of gills are united by vascular cross connections, leaving narrow openings, the Ostia between them. The two lamellae of each demi-branch are attached back to back in the same way. Examples: Cardiacea, Myacea.

v. **Septibranchiata**

The ctenidia do not exist in their original form, but have been transformed into a horizontal muscular septum that runs from the base of the foot to the mantle and extends all the way back to the siphons. Example: Poromya.

8.1.7.6. CEPHALOPODA

The gills are large, paired, bipectinate, and suspended on either side of the rectum by their afferent edges rather than their efferent edges, as in gastropods, and the water current is driven from afferent to efferent side.

A. The gill filaments are firm and fleshy, non-ciliated, and thrown into primary and secondary folds to increase respiratory surface. In Nautilus, the gills are two pairs.

B. A pulsatile accessory branchial heart, located at the base of the gill in the course of the afferent ctenidial vessel and placed in an annexe of the pericardium, aids the flow of haemolymph through each gill.

C. Pallial contractions drive water between the gill filaments at great pressure.

8.1.8. GILLS RESPIRATION IN ARTHROPODA

Gills or branchiae in arthropoda are evident in class Crustacea. These may vary in number, position and details of anatomical structure, but made on a similar fundamental plan. On the basis of their origin and attachment, there are three types:

8.1.8.1. PODOBRANCH OR FOOT GILL

Podobranch (Greek: poos, foot; branch, gill), A decapod gill from the anterior side is a podo branch which remains attached to the coxa of the second maxillipede attached to the coxa of an appendage. In Macrobrachium (Palaemon), Penaeus the podobranchs are one pair and remain attached to the second maxillipedes.

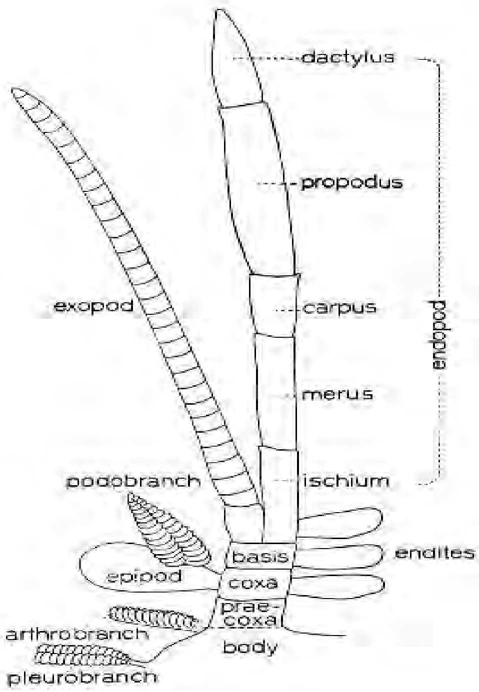


Fig.8.14. Structure of foot gill

8.1.8.2. ARTHROBRANCH OR JOINT GILL

Gill attached to the articular membrane between the body wall and coxa of an appendage, (Taxon-specific: Order Decapoda). Type of gill attached to the point of articulation (articular membrane) between thoracopod and body wall. A gill is attached to the articulating membrane of the basal joint of a thoracic appendage with the body in some crustaceans. In Palaemon, the arthrobranchs are two attached to the arthroidal membrane of the third maxillipede.

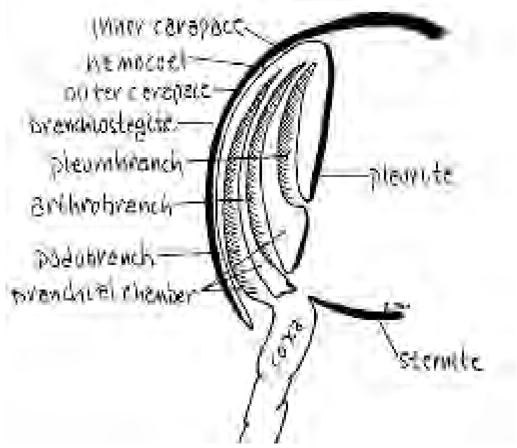


Fig.8.15. Arthrobranchs of Penaeus

8.1.8.3. PLEUROBRANCH OR SIDE GILL

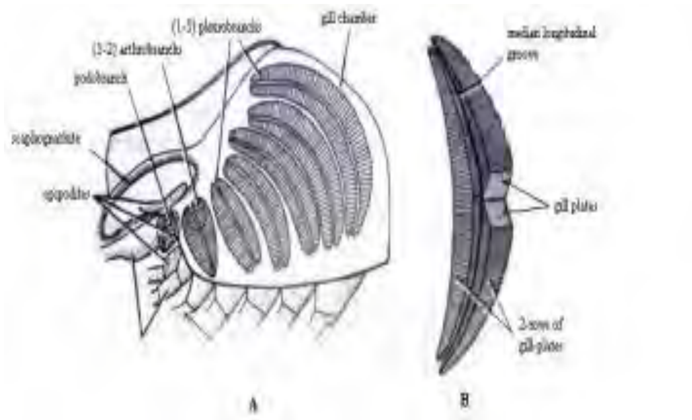
A decapod gill, that develops from the lateral body wall of the thoracic pleura. It is attached to the lateral wall of the body segment containing the limb. For example, in Palaemon there are five pleurobranchs, attached to the lateral side of the thorax. In Penaeus, there are six pairs of pleurobranchs attached to the last six pairs of thoracic appendages.

Fig.8.16. Structure of Pleurobranch

8.1.9. MODIFICATION OF GILLS IN ARTHROPODA

The gills are variously modified in Crustaceans and other Arthropods. In Phyllocarida, broad epipodites of the thoracic appendages work as gills. Similar gills are seen in Cumacea. Gills are plate-like in Amphipoda and flattened in a Decapod, Palinurus.

In Euphausiacea, the tufted podobranchs are not covered by carapace. The gills appear as a row of small branchial lamellae on each side of Cyprididae. In Phyllopoda, the leaf-like pleopods work as gills. Among the Crustaceans, only Stomatopods and Isopods have abdominal gills.



8.1.9.1. TRACHEAL GILLS

In insects, tracheal gills are usually outgrowths of the tracheal system. They are finger-shaped or leaf-shaped. They are covered by a thin layer of cuticle that is permeable to both oxygen and carbon dioxide. In the aquatic larvae of many insects, a series of simple and divided external processes are attached to the abdominal segments. These are richly supplied with tracheae and are called the tracheal gills.

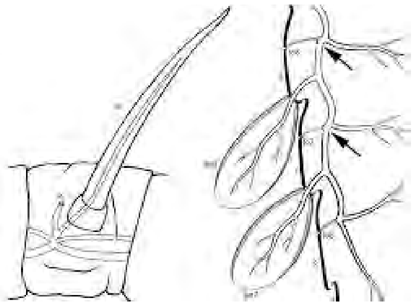


Fig.8.17. Structure of tracheal gills

8.1.9.2. BLOOD GILLS

The term `blood gill' is restricted to organs which have a spacious lumen but in which trachea are poorly developed or totally absent. The tracheae are replaced in certain aquatic insect larvae (primarily chironomidae) by branching tubular outgrowths containing blood vessels, which are known as blood gills.

8.1.9.3. RECTAL GILLS

The rectal gills are located on the inner surface of the rectum. They are a form of soft lamellae. Rectal gills project into the rectum in six longitudinal rows, forming the bronchial basket. Rectal gills are important for the uptake of salt, as well as for respiration. In the nymphs of several insects, the inner surface of the rectum bears gills. Rectal gills are found in dragonfly naiads and are used to draw in and expel water.

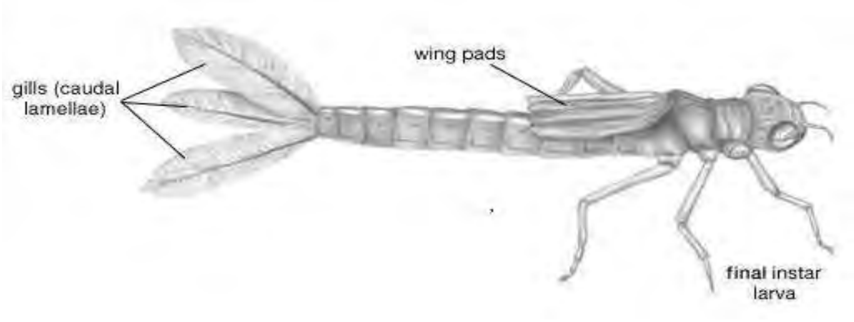


Fig.8.18. Structure of rectal gills

8.1.9.4. BOOK GILLS

The most specialized gills are seen in Xiphosurids, where the abdominal appendages bear plate-like book gills. These gills are formed by the evagination of the posterior borders of opisthosoma in segments from ninth to thirteenth. Each gill contains nearly 150 lamellae, which look like the delicate leaves of a book. Book-gills are book-like gills. These are the respiratory organs of Limulus. Limulus has 5 pairs of bookgills. They are found attached to the last five pairs of appendages. Each book gill is formed of 150 to 200 leaf-like lamellae and are richly supplied with blood.

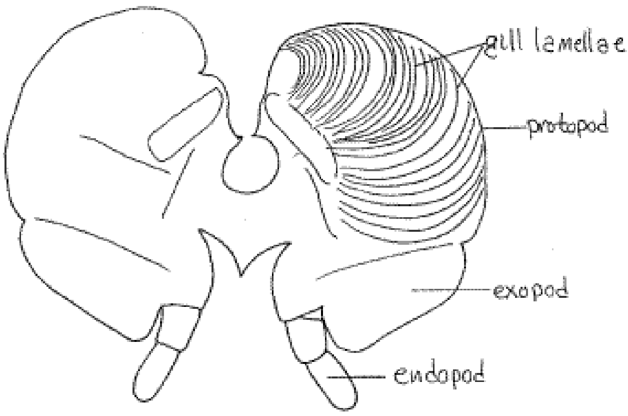


Fig.8.19. Structure of book gills

8.1.10. STRUCTURE OF A TYPICAL GILL

Each gill has a curved structure and is connected to the thorax by a small root like structure called gill root. A. gill consists of two rows of thin leaf like gill plates. If these are arranged like the leaves of a book, the gills are called Phylobranch. Gill plates are arranged at right angles to the longitudinal axis or base of the gill. Gill plates are largest in the middle and gradually become smaller towards the two ends. Each gill is made of a double layer of cuticle enclosing a single layer of cells within itself. There are two types of cells; (a) pigmented cells and (b) transparent cells. The gills are supplied with three longitudinal blood channels running around the base or axis of the gill. An afferent branchial channel transports blood and an efferent branchial channel removes it. Water current is brought in by the vibrating movement of appendages. Gaseous exchange takes place by simple diffusion of gill plates between water and underlying blood.

8.1.11. HYDROFUGE HAIRS AND RESPIRATORY SIPHON

In many water-bugs and water beetles there are tufts of waterproof hairs on different parts of the body. The air trapped among these hairs is used for breathing. In the water-beetle Dytiscus, the air is enclosed between the body and the forewings (elytra). The adults of water-bug Nepa or the larvae of Eristalis (Diptera) possess a long respiratory siphon, which remains in contact with the air.

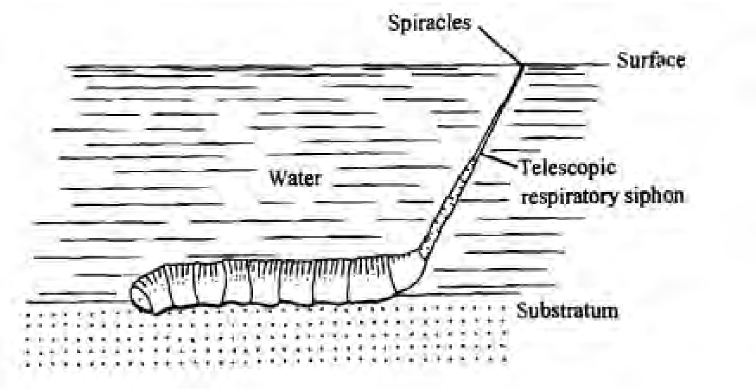


Fig.8.20. Hydrofuge hair and respiratory siphon of water beetle

8.1.12. LOPHOPHORES

A Lophophore is a hollow tentacle like structure, which serves as a respiratory organ. This is a distinguishing feature of three minor phyla: Phoronida, Bryozoa, and Brachiopoda.In these phyla, it is a circular or horse shoe shaped fold of the body wall that encircles the mouth and bears numerous ciliated, hollow tentacles. Each contains an extension of coelom. The ciliary tracts of tentacles drive a current of water through the lophophore. This water current serves two functions; collection and sorting of food particles and planktons; and gaseous exchange for respiration by providing a large surface area.

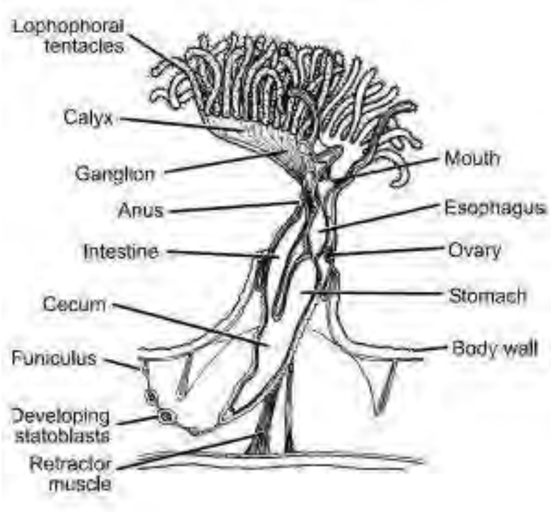


Fig.8.21. Structure of hollow tentacle like respiratory structure

8.1.13. AERIAL RESPIRATION IN ARTHROPODA

Aerial respiration involves the utilization of oxygen present in the air. Aerial respiration occurs in terrestrial arthropods. The respiratory organs for aerial respiration are the following:

8.1.13.1. LUNGS

Lungs are hollow structures possessed by air-breathing animals. These are hollow structures, elastic having fine branches of air pipes or tubules ending in air sacs, when vascular elements can exchange gases (O_2 & CO_2) by simple diffusion. The lung is found in amphibious gastropod mollusks. This is developed as an adaptation to aquatic or amphibious habits. *Lymnaea truncatula* has a lung for aerial life in marshy habitats. In the terrestrial coconut crab Birgus, the upper part of the gillah ber is separated from the rest as an almost closed air-filled cavit lung. Aerial respiration is carried out by highly vascular epithelial folds that hang from the roof of this.

In terrestrial forms (e.g. limax) the mantle cavity is transformed into a pulmonary sac or lung. This organ is used as an organ for aerial respiration. The Pulmonary sac's roof is richly supplied with 'blood vessels'. The 'breathing' (air intake and release) is done by alternate contraction and relaxation of muscles of the mantle floor. Gaseous exchange takes place through a semi permeable wall of mantle.

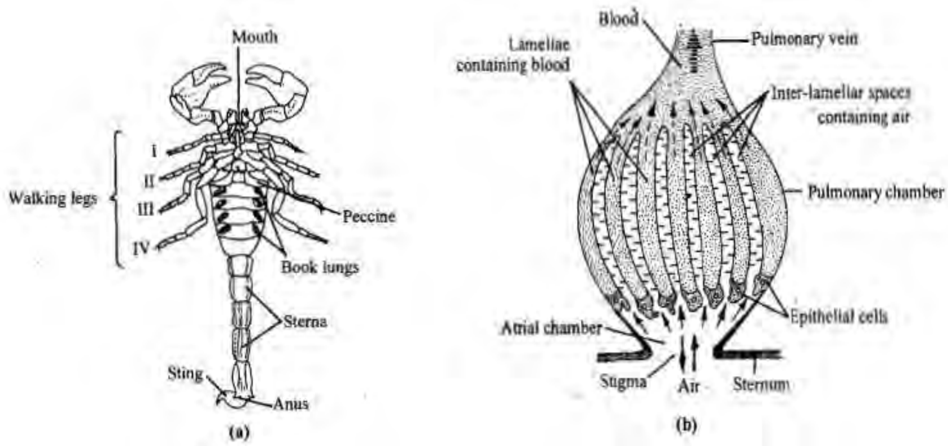
In Pila, the mantle cavity is divided by an incomplete septum called epitaenia, into a left pulmonary chamber and a right ctenidial chamber. The pulmonary chamber is used to breathe in air, whereas the ctenidial chamber is used to breathe in water or pulmonary chamber of Pila opens outside through a large and oblique pulmonary aperture. The left nuchal lobe acts as a siphon through which air enters into the pulmonary sac. After gas exchange, air returns along the same path. Alternate contraction and relaxation of pulmonary sac muscles ensure the flow of air in and out of the mantle cavity.

8.1.13.2. BOOK LUNGS

In land-dwelling Arthropoda respiration is effected either by book-lungs (Arachnids) or by tracheae (Myriapoda and Insecta). The book-lungs seem to have been modified from the book-gills of the ancestral arachnids, the Merostomata. Scorpions possess four pairs of book-lungs. They are found in the 3^{rd}, 4^{th}, 5^{th} and the 6^{th} segments of the mesosoma, one pair in each segment. Each book-lung lique slit is called stigma. The cavity of each book is a thin cuticle which is formed into numerous folds called lamellae. The lamellae are arranged parallel to one another, giving the appearance of the leaves of a book. There are about 150 lamellae. They are hollow containing blood.

Each stigma leads into a small chamber called the atrial chamber. The atrial chamber leads into a large pulmonary chamber in which the lamellae are arranged. Air from outside enters the chamber and passes into the spaces between the leaves. The blood flows continuously in the space inside the lamellae while the inter lamellaar spaces are filled with air so that exchange of gases takes place through the thin walls of the lamellae. Each book-lung receives impure blood from the ventral sinus. The blood is aerated in the lamellae, the pulmonary vein collects aerated blood and opens into the pericardial sinus, while the ventral and the atrial muscles control air expiration in the book-lungs.

Fig.8.22. (a) Ventral surface of scorpion showing spiracle of book-lungs, (b). Vertical section of a book lungs.



8.1.13.3. TRACHEAL SYSTEM

The tracheal system is found in insects, centepedes, millipedes and many rachnids. It is a system of tubes ramifying the body. The Trachea is primarily an air-breathing organ. Trachea are ectodermal structures, formed by ingrowth from the surface. As a result, these are lined by cuticles called intima. The intima is thickened and forms spinal or ring shaped ridges. These thickenings are called taenidia that serve to maintain an open lumen to ensure the passage of air (gases). It opens outside by means of opening called spiracles. Typically, these are found in the thorax and abdomen, situated on the pleura.

The trachea, which is found in Arthropods such as Myriapoda and Insecta, evolved a completely unique system for oxygen transport in the body. In aquatic insects, the tracheal system is little altered and the spiracles are open. But these insects acquire various modifications to renew the supply of fresh air. The Odonata and mosquito larvae periodically come to the water surface to take in fresh ones. The essential features of a well developed tracheal system are that it transports oxygen to the tissue by tracheal tubes, that branch to reach all parts of the body. The tracheal system consists of spiracles, tracheae, tracheoles and air sacs.

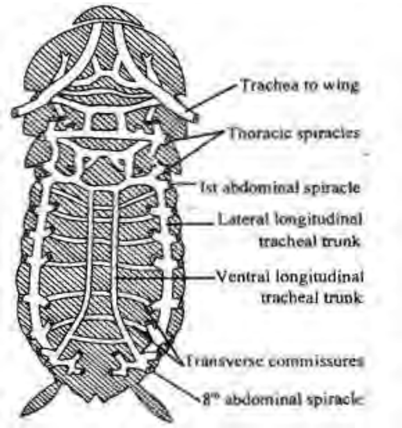


Fig.8.23. Tracheal system in insects

i.Spiracles:

These are the openings of the tracheal system to the exterior. They are also called stigmata. They are located on the sides of the thorax. Insects have 9 or 10 pairs of spiracles. Of these, two pairs are located on the sides of the thorax and the remaining pairs are located on the sides of the abdomen. In most insects, the spiracle opens into a cavity called the atrium from which the trachea arises. The atrium is provided with an air filtering apparatus. The filtering apparatus keeps away the dust and parasites. A valve is also present in the atrium. The valve can close the spiracle when required.

ii. Tracheae:

Tracheae are highly branched tubes. The trachea is formed of three layers, namely an inner intima, a medium of epithelium and an outer layer of basement membrane. Taenidia are spiral thread-like thickenings produced

iii. Tracheoles**:**

The tracheoles are the tracheae's smallest branches. Taenidia are not found in the tracheoles. They result in tid sues.Tracheole fluid is a fluid that fills the terminal ends of tracheoles.

iv. Air sacs:

The tracheae are dilated in certain places to form air sacs. They help to store air and to circulate air in the tracheal system.

8.1.14. TYPES OF TRACHEAL SYSTEM

There are three main types of tracheal system, namely polypneustic, oligopneustic and apneustic tracheal systems. In a polypneustic tracheal system, eight or more pairs of spiracles are functional. In oligopneustic, type one or two spiracles are functional. In the apneustic type, there is no functional spiracle.

8.1.14.1. MECHANISM OF TRACHEAL RESPIRATION

Air is drawn into and forced out of the tracheal system through the spiracle by alternate expansion and contraction of the body. The tracheoles are filled with air. The tracheole fluid absorbs oxygen. This oxygen diffuses into the tissue. Similarly, CO, from the tissues diffuses into the tracheoles.

i) Air-tubes

The terrestrial crustacean Oniscus contains trachea-like resni tory tubes in its abdominal appendages for aerial respiration.

ii) Spiracular gills

Spiracular gills are ectodermal outgrowths enclosing air space they are linked to the tracheae. They occur in the larvae of Teich mza and in the pupae of Simulium.

iii) Plastron

Certain aquatic beetles, such as Haemonia and Phytobius, have a type of air store in the spiracle region. This air store is called plastron. It is covered with hydrofuge hair. It is communicating with the spiracle. This air-store helps the insect to remain under water for a long time.

iv) Respiratory tubes

Respiratory tubes are found in the water-scorpions Nepa and Ranatra. They are located at the posterior end of the abdomen. Each respiratory tube is formed by two cerci. The water scorpions come to the surface and fill the respiratory tube with atmospheric air. This air can be used for respiration when the scorpions are under water. The mosquito larva also has a respiratory tube at the posterior end.

Let Us Sum Up

In this unit, we studied about the respiration and respiratory organs in invertebrates. Under this unit, we focused on the structure and functions of gills, aquatic respiration by gills, gills in Mollusca, adaptive or secondary gills and integument, types of ctenidia based on the topography, types of ctenidia based on the arrangement of leaflets, ctenidia in different groups of mollusc, gill respiration in Arthropoda, modification of gills in Arthropoda, structure of typical gill, hydrofuge hairs and respiratory siphon, lophophores, aerial respiration in Arthropoda and types of tracheal system.

Check Your Progress

1) __________ involves gaseous exchange with the environment with intake O2 and release CO2.
2) Depending upon the habitat, the respiration is classified into two types, they are __________ and __________.
3) There are __________ types of gills present in molluscs.
4) Molluscs are aquatic and respire by means of gills which are called __________.
5) In many opisthobranches the dorsum bears highly vascular appendages called __________.

Glossaries

Integument : Tough protective layer

Ctenidia : Comb like structure present in respiratory organ like gill

Plicate : Folded or crumpled.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Organs of respiration in invertebrates https://youtu.be/TFz5xJMd8Ns

Respiration by lungs https://youtu.be/sbGAtcPUzVU

Answers to check Your Progress

1) Respiration
2) Aquatic and terrestrial
3) Three
4) Ctenidia
5) Cerata

UNIT – 9

Respiratory Pigments

Structure

Objectives

After studying this unit, the students will be able to

- Explain the respiratory pigments in invertebrates
- List out and explain the types of respiratory pigments in invertebrates

Overview

In this unit, we will study about the respiratory pigments in invertebrates. Here, we will focus on the respiratory pigments such as, haemoglobin, hemocyanin, chlorocruorin and hemerythrin.

9.0. RESPIRATORY PIGMENTS IN INVERTEBRATES

In order to facilitate the transport of oxygen to different parts of the body, most animals have developed respiratory pigments. In general, respiratory pigments are coloured proteins that contain a metallic element in their constitution and have the property of forming loose combination with oxygen and sometimes with carbon dioxide. Four different (biochemically) respiratory pigments are recognized; haemoglobin, chlorocruorin, haemocyanin, and haemerythrin. Even in the same phylum, there may be several distinct pigments, and more than one distribution of four pigments in the animal pigment may exist in the same animal.

Hemoglobin is purple in colour, it becomes orange-red with oxygen. Chlorocruorins is green in colour, it becomes red with oxygen. Hemocyanins are colorless, it becomes blue with oxygen and hemerythrins is colorless, it becomes red with oxygen.

9.1. HAEMOGLOBIN

It is the most efficient respiratory pigment. It is widely distributed in the animal kingdom, starting from some protozoa like Paramoecium to almost all vertebrates except eel larvae and some Antarctic fishes. Some invertebrate phyla, such as Porifera, Cnidaria, and Ctenophora, are completely devoid of Haemoglobin. In invertebrates, it may remain dissolved in blood plasma, (e.g. Oligochaetes, Hirudinea, Arenicola, Nereis etc.) or may be contained inside erythroid coelomocytes (e.g., Holothurians, some polychaetes like Capitella, Glycera etc.).

Haemoglobin is composed of an iron porphyrin compound, haeme, which is linked to a protein (globin) and ranges from 17,000 D to 3,000,000 D (annelids). Haemoglobin It is composed of two pairs of polypeptide chains (α and β-Hb). It contains four heme groups, each of which can combine with one O_2 molecule. Haeme is composed of four pyrrole rings linked by methenyl-bridges to form a super-ring with an atom of ferrous iron in the centre attached to the pyrrole. When all four heme groups are complexed with O_2, the molecule is said to be fully saturated. Haemoglobin is dark red in the deoxygenated state, bright red in the oxygenated state.

The haeme component is a constant structural feature of all haemoglobins, but the globin portion varies in different species. In addition, varying numbers of haemoglobin units unite to form polymers of different sizes.

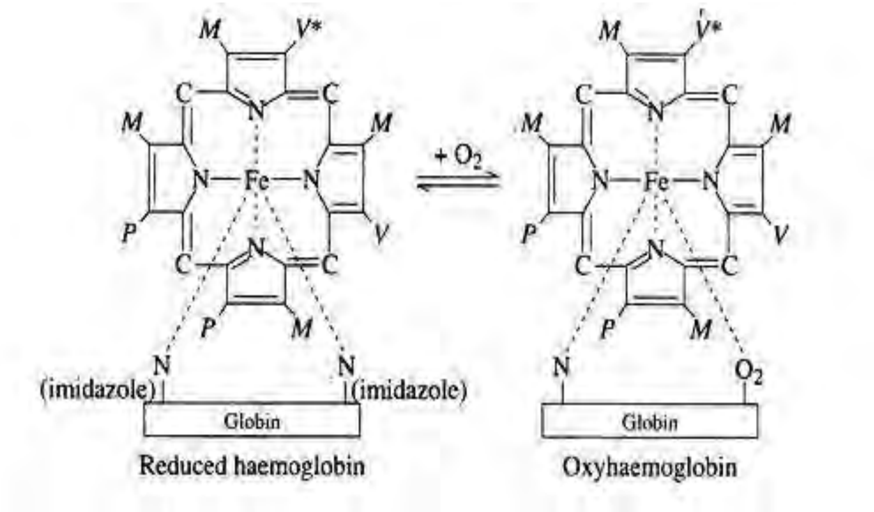
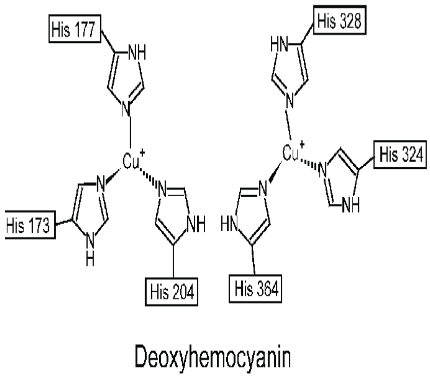


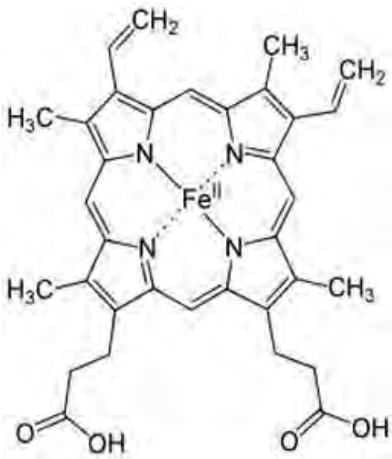
Fig.9.1. Structure of hemoglobin

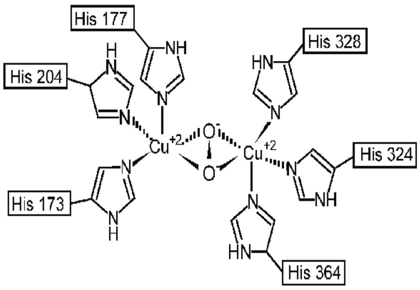
In all cases, the atoms of ferrous ion remain associated with one molecule of oxygen to form oxyhaemoglobin. The reaction is readily reversible and the non-oxygenated compound is referred to as reduced haemoglobin. Haemoglobin is red in colour both in oxygenated and non-oxygenated states. The association of haemoglobin with oxygen depends not only on the availability of oxygen but also on the pH and ionic content of the solution.

9.2. HAEMOCYANIN

It is found in Chitons, some gastropods and cephalopods amongst the molluscs and in crustaceans and Limulus amongst the arthropods. It is a Cu-containing protein. One hemocyanin molecule contains two Cu atoms and can combine with 1 O_2 molecule. Only haemocyanin can reversibly combine with oxygen and, thus, serves as a transport pigment. It always remains dissolved in the plasma. The molecular weight is very high, varying from 4,00,000 Daltons in some crustaceans to 13,00,00,000 Daltons in some gastropods. The number of subunits varies from a few to many in haemocyanin.







Oxyhemocyanin

Fig.9.2. Structures of hemocyanin

Molluscan haemocyanins are generally larger than arthropodan pigments. Haemocyanin has no porphyrin. In this metalloprotein, the metallic part is copper (Cu^{++}), which remains directly linked to the protein part. The molecules of haemocyanin are buildup of units consisting of one copper atom associated with a peptide chain of just over 200 amino acids. During oxygenation, two atoms of copper are reversibly oxidized to the cupric form.

In de-oxyhaemocyanin, the copper is in the cuprous form. Haemocyanin is colourless in deoxygenated form but bluish in an oxygenated state. This pigment gets saturated with oxygen at different concentrations in different species. The value of partial pressure of oxygen ranges between 15-35 mm Hg in Mollusca and 50-20 mm Hg in arthropods. The oxygen transporting capacity of haemocyanin is less than that of haemoglobin.

9.3. CHLOROCRUORIN

This green coloured metalloprotein is found in the plasma of certain polychaet families, viz., Sabellidae, Serpulidae etc. It is a Fe-containing protein. The molecular weight is about 3 million D. It is similar to hemoglobin structure. The metalloporphyrin is similar to heme of haemoglobin except that one vinyl ($CH = CH_2$) group is replaced by formyl (0=CH) group in chlorocruorin. The porphyrin is called chlorocruoheme. As with hemoglobin, one O_2 molecule combines with each of the 4 heme groups. Chlorocruorin is green in both deoxygenated and oxygenated states. These occur in suspension in blood.

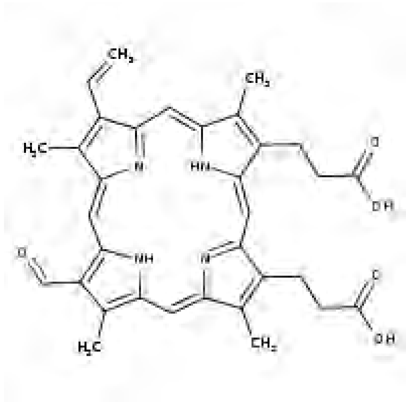


Fig.9.3. Chemical structure of chlorocruorin

9.4. HAEMERYTHRIN

This violet coloured pigment is found inside the corpuscles of animals belonging to the phyla Sipunculida, Priapuloidea and Brachiopoda, and also in the polychaete worm Magelona. It is also an iron containing metalloprotein but has no porphyrin. It is an Fe-containing protein with a molecular weight of approximately 100,000 D.One hemerythrin molecule contains several Fe atoms and each O_2 molecule can combine with 2 or 3 Fe atoms. It is brownish in the deoxygenated state, purple in the oxygenated state. Present within coelomocytes that circulate within the coelomic fluid.

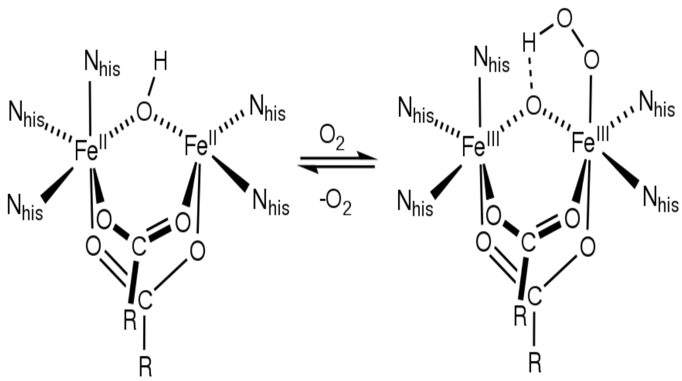


Fig.9.4. Chemical structure of haemerythrin

Let Us Sum Up

In this unit, we studied about the respiratory pigments in invertebrates. Under this unit, we focused on the respiratory pigments such as, haemoglobin, hemocyanin, chlorocruorin and hemerythrin.

Check Your Progress

1) There are __________ types of respiratory pigments present in invertebrates.
2) __________ is the most efficient respiratory pigment.
3) __________respiratory pigment present in chiton and some gastropods.
4) The green coloured metalloprotein is found in the plasma of certain polychaete family is __________.
5) __________ is also an iron containing metalloprotein but has no porphyrin.

Glossaries

Haemerythrin	:	It is a non-heme iron protein used by invertebrates for oxygen transfer.
Gastropod	:	It is the snails or slugs.
Haemocyanin	:	It is a protein containing copper, responsible for transporting oxygen in the blood plasma or arthropod and molluscs.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Respiratory pigments https://youtu.be/M5ohZR2fkAw

Answers to check Your Progress

1) 4
2) Haemoglobin
3) Haemocyanin
4) Chlorocruorin
5) Haemerythrin

UNIT- 10

Mechanism of Respiration

Structure

Objectives

After studying this unit, the students will be able to

- Explain the organs of respiration in invertebrates
- Describe in detail about the mechanism of respiration in invertebrates

Overview

In this unit, we will study about the mechanism of respiration in invertebrates. Here, we will focus on the transport of gases, transport of oxygen and transport of carbon dioxide.

10.0. MECHANISM OF RESPIRATION

10.1. TRANSPORT OF GASES

Blood is the medium of transport for O_2 and CO_2. About 97 per cent of O_2 is transported by RBCs in the blood. The remaining 3 per cent of O_2 is carried in a dissolved state through the plasma. Nearly 20-25 per cent of CO_2 is transported by RBCs whereas 70 per cent of it is carried as bicarbonate. About 7 per cent of CO_2 is carried in a dissolved state through plasma.

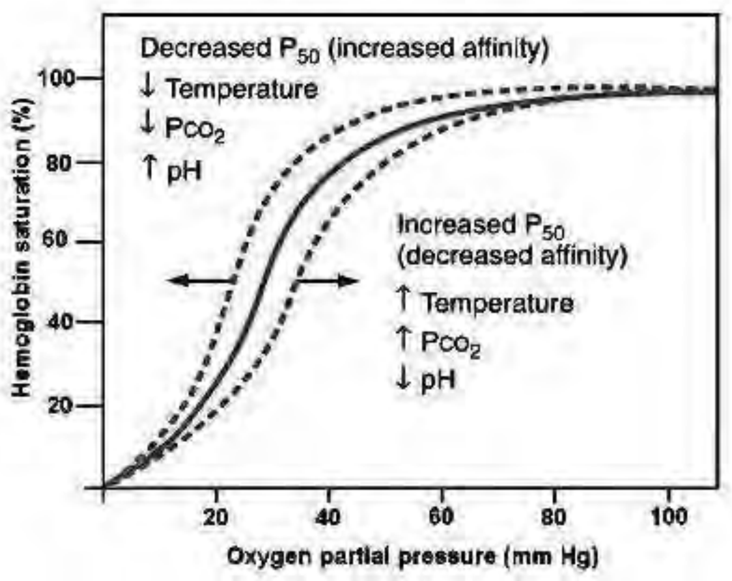

Fig.10.1. Oxygen dissociation curve

10.2. TRANSPORT OF OXYGEN

Haemoglobin is a red coloured iron containing pigment present in the RBCs. O_2 can bind with haemoglobin in a reversible manner to form oxyhaemoglobin. Each haemoglobin molecule can carry a maximum of four molecules of O_2. Binding of oxygen with haemoglobin is primarily related to partial pressure of O_2. Partial pressure of CO_2, hydrogen ion concentration and temperature are the other factors which can interfere with this binding. A sigmoid curve is obtained when percentage saturation of haemoglobin with O_2 is plotted against the pO_2. This curve is called the oxygen dissociation curve.

The Oxygen dissociation curve is highly useful in studying the effect of factors like pCO_2, H^+ concentration, etc., on binding of O_2 with haemoglobin. High pO_2, low pCO_2, lower H^+ concentration and lower temperature factors are all favourable for the formation of oxyhaemoglobin, whereas in the tissues, where low pO_2, high pCO_2, high H^+ concentration and higher temperature exist, the conditions are favourable for dissociation of oxygen from the oxyhaemoglobin. This clearly indicates that O_2 gets bound to haemoglobin and gets dissociated in the tissues. Every 100 ml of oxygenated blood can deliver around 5 ml of O_2 to the tissues under normal physiological conditions.

10.3. TRANSPORT OF CARBON DIOXIDE

CO_2 is carried by haemoglobin as carbamino-haemoglobin (about 20-25 per cent). This binding is related to the partial pressure of CO_2. pO_2 is a major factor which could affect this binding. When pCO_2 is high and pO_2 is low in the tissues, more binding of carbon dioxide occurs, whereas, when pCO_2 is low and pO_2 is high in the tissue/alveoi, a dissociation curve of CO_2 from carbamino-haemoglobin takes place, i.e., CO_2 which is bound to haemoglobin from the tissues is delivered. At the tissue site where partial pressure of CO_2 is high due to catabolism, CO_2 diffuses into blood (RBCs and plasma) and forms HCO_3 – and H^+,. At the alveolar site where pCO_2 is low, the reaction proceeds in the opposite direction, leading to the formation of CO_2 and H_2O. Thus, CO_2 trapped as bicarbonate at the tissue level and transported to the alveoli is released as CO_2.

Let Us Sum Up

In this unit, we studied about the mechanism of respiration in invertebrates. Under this unit, we focused on the transport of gases, transport of oxygen and transport of carbon dioxide.

Check Your Progress

1) __________ is red coloured iron containing pigment present in the RBC's.
2) CO2 is carried by haemoglobin.

Glossaries

Dissociation : It is the process of disconnection.

Catabolism : It is the set of metabolic pathways that breaks down molecules into smaller units.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

Weblink

Mechanism of respiration in invertebrates
https://youtu.be/No_LUOGIFWY

Answers to check Your Progress

1) Haemoglobin
2) Carbamino-haemoglobin

UNIT- 11

Excretion and Excretory Organs

Objectives

After studying this unit, the students will be able to

- Explain excretion in invertebrates
- List out and describe the organs of excretion in invertebrates
- Briefly explain the process of excretion

Overview

In this unit, we will study about the excretion in invertebrates. Here, we will focus on the excretory organs in Platyhelminthes such as, flame cells, excretory organs in aschelminths, excretory organs in Annelida such as, protonephridia, metanephridia, micronephridia, meganephridia, meronephridia, tufted nephridia, nephridia in earthworm, exo and enteronephridia, coelomoducts, nephromixia such as, protonephromixium, metenephromixium and myxonephridium, chloragogen cells, botryoidal tissue, ciliated organs, excretory organs in arthropods such as, nephridia, green gland, coxal gland, shell gland, hepatopancreas, nephrocytes, crural glands, malphigian tubules and miscellaneous organs, excretory organs in molluscs such as, nephridia, renal sac, organs of bojanus, kebers organ and coelomoducts, and excretory organs in Echinodermata such as, axial gland and coelomocytes.

11.0. EXCRETION

The removal of metabolic waste products such as CO2, water, and nitrogenous waste substances are essential in an organism.

Respiration helps in the removal of CO_2 and, to some extent, water. Certain other substances like salt, water and fat derivatives etc are excreted through the skin by an organism. Ammonia, Urea and Uric acid are the major nitrogenous wastes that are highly toxic to the body. Removal of these nitrogenous waste products is commonly known as excretion. The specialized organs that help the excretory function are known as excretory organs.

11.1. EXCRETORY ORGANS

There is a great diversity noticed with reference to the excretory organs along with the diversity of organisms in the animal kingdom. The diversity of excretory organs is based on the environment, habitat, and mode of life. The structural diversity of excretory organs is noticed among the same order or class or phylum but not restricted to different phyla. In Protozoa, Porifera and Coelenterata, no special organelles are present for excretion. Nitrogenous wastes (mainly ammonia) is excreted by diffusion from the general body surface into the surrounding water. The excretory organs in some important invertebrates, such as Platyhelminthes, Aschelminthes, Annelida, Arthropoda, Mollusca and Echinodermata are described in this unit.

11.1.1. CONTRACTILE VACUOLES OF PROTOZOANS

Some protozoan animals possess an organelle in the form of an internal sac, or vacuole, which enlarges by the accumulation of a clear fluid and then discharges its contents to the exterior. The cycle of filling and emptying may be repeated as frequently as every half minute. The chief role of the contractile vacuole appears to be in osmotic regulation, not in nitrogen excretion.

Contractile vacuoles occur more frequently and are more active in freshwater species than in closely related marine species. In fresh water, the concentration of dissolved substances in the cell is greater than in the external medium, and the cell takes in water by osmosis. If the contractile vacuole is put out of action, the cell increases in volume. If the concentration of salts in the medium increases, which would have the effect of decreasing the rate of osmosis, the rate of output by the contractile vacuole diminishes. The fluid eliminated by the vacuole is more dilute than the cytoplasm.

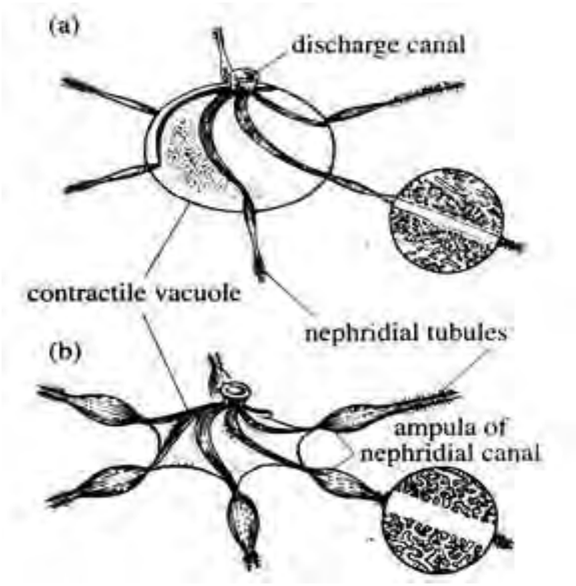

Fig.11.1. Three-dimensional representation of a contractile vacuole in diastole and systole in paramecium.

11.2. EXCRETORY ORGANS IN PLATYHELMINTHES

EXCRETORY SYSTEM

A system of vessels, water vessels, sends ramifications through all parts of the body. There are two main, considerably coiled, pairs of longitudinal trunks, right and left, which open externally on the dorsal surface by means of several pairs of minute pores; in front they are connected together by a transverse vessel. The vessels of each pair often join and separate again. Each main trunk gives origin to a number of branches, which in turn give off a system of extremely fine capillary vessels, many of which terminate in flame cells. By the activity of the flame cells, the fluid contained in the vessels is moved on towards the excretory pores.

In *Fasciola hepatica*, the excretory system comprises a large number of flame cells or protonephridia, connected with an intricate system of excretory ducts of various orders.

11.2.1. FLAME CELLS

Each flame cell has an intracellular lumen or cavity, in which hang a few long cilia, each arising from a basal granule situated in the cytoplasm. Planaria are flatworms. Their excretory system consists of two tubules connected to a highly-branched duct system that leads to pores located all along the sides of the body.

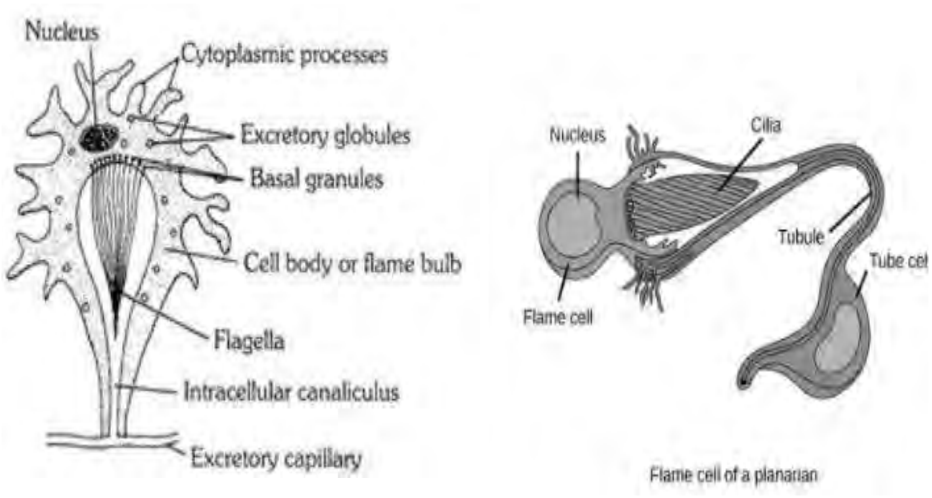

Fig.11.2. Structure of flame cells

The filtrate is secreted through these pores. The cells in the tubules are called flame cells (or protonephridia) because they have a cluster of cilia that looks like a flickering flame when viewed under the microscope. Flame cells function like a kidney, removing waste materials through filtration.

The lumen of the flame cell is continuous with a microscopic capillary duct. Capillary ducts from a few protonephridia open into a narrow collecting tubule. Several such tubules open into larger twigs, which in turn open into vessels. Excretory vessels of the anterior part of the body open into four trunks, two dorsal and two ventral, which unite posterior to form a single median longitudinal excretory canal. It extends up to the posterior end of the body where it opens out through the single excretory pore situated somewhat ventrally. Excretory vessels of the posterior part of the body open directly in the longitudinal excretory canal. All the ducts except the single median longitudinal canal are lined with cilia.

The cilia propel waste matter down the tubules and out of the body through excretory pores that open on the body surface; cilia also draw water from the interstitial fluid, allowing for filtration. After excretion, any useful metabolites are reabsorbed by the cell. Flame cells are found in freshwater invertebrates, such as flatworms, including parasitic tapeworms and free-living planaria.

Physiology of excretion

The main excretory products of fluke are fatty acids, carbon dioxide and ammonia. These substances diffuse into protonephridia from the surrounding mesenchyme. Excretory fluids are kept moving through tubules by the action of cilia and finally squeezed out through the excretory pore by contractions of the body. The enzyme alkaline phosphatase, found in flame cells and collecting tubules, serves in the selective transfer of chemical substances. Some nitrogenous wastes are also passed to the exterior through the surface tegument. The protonephridial system is excretory as well as osmoregulatory, since it controls the amount of fluid (water) in the body.

11.3. EXCRETORY ORGANS IN ASCHELMINTHES

In Ascaris lumbricoides, the excretory system consists of gland cell, or of canals or of both. Ascaris has an 'H' shaped excretory system of canals and a complicated "giant cell" called "renette cell". It consists of two lateral longitudinal excretory canals, right and left, connected anteriorly below the pharynx, by a transverse canalicular network. Each longitudinal canal extends posteriorly along the entire body length through a lateral epidermal chord and is closed at both ends. Externally, their location is marked by the two lateral lines. The left canal is slightly wider than the right. Anterior limbs of H are reduced. The canal’s lumen is cilia-free. A short terminal excretory duct extends from the left side of the transverse canalicular network to the excretory pore situated mid-ventrally, a little behind the anterior tip. The nucleus of the excretory cell lies anteriorly on the left longitudinal canal. Two smaller nuclei have also been located, one on the terminal duct and one on the transverse canalicular network, indicating that the canal system has evolved probably by more than one cell.

Physiology of excretion

The excretory products of Ascaris are mainly urea, thus it is a ureotelic animal. Excretory canals collect the excretory products from different parts of the body. Pressure of pseudocoelomic fluid helps in ultrafiltration. Excretory products are eliminated through the excretory pore. Some ammonia and urea are also passed out with faeces through the anus.

11.4. EXCRETORY ORGANS IN ANNELIDA

Annelida is a vast assemblage of segmented worms. Their excretory system has evolved in varied ways and still follows a similar basic principle. Annelids are primarily Ammonotelic in nature. However, Earthworms show a blending of Ureotelism with Ammonotelism. The excretory organs of Annelida are as follows,

11.4.1. NEPHRIDIA

A nephridium is a fine tubule formed by invagination of surface ectoderm. Its lumen is believed to form by hollowing out of ectodermal cells. The point of invagination persists as Nephridiopore. However, the tubule has undergone varied specializations in different groups. They are segmentally arranged coiled ciliated tubes. The following basic types are recognized,

11.4.2. TYPES OF NEPHRIDIA

The following are the important types of nephridia found in annelids:

11.4.2.1. PROTONEPHRIDIA

Protonephridium is a primitive type of nephridium. It is found in Alciopa, Phylodoce and Glycera etc. This nephridium terminates blindly in the body cavity. Hence, it is known as a closed type nephridium. However, it bears Solenocytes. Such nephridia are called Protonephridia. Solencocytes are variables of flame cells of Helminthes. These have a round body projecting into body fluid and a long cytoplasmic canal with a long flagellum. The canal is attached to the nephridial duct system. The flagellum beats constantly which appears as a flickering of flames. The cell is sometimes applied to blood vessels. It opens exteriorly by nephridiopore.

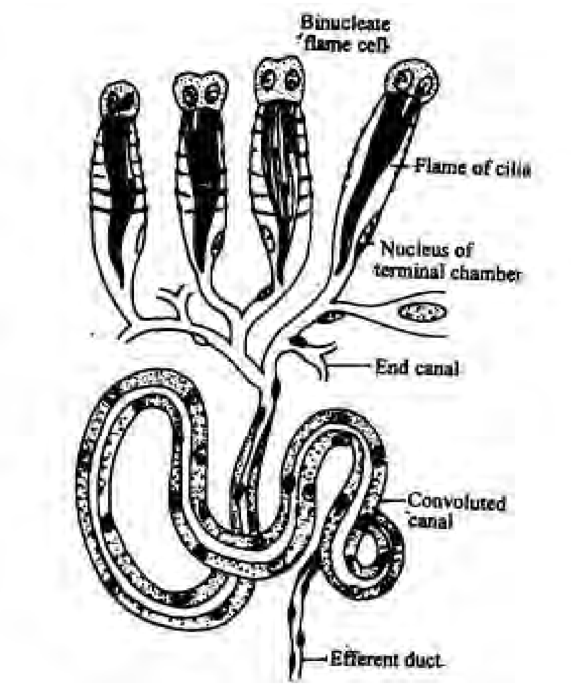

Fig.11.3. A single protonephridium of flat worm

11.4.2.2. METANEPHRIDIUM

The nephridium has evolved a ciliated opening into the coelom. It is called the Nephrostome. It has two openings. One of the ends of Metanephridium opens into coelom by a funnel and the other end opens outside the body through nephridiopore. Metanephridium is found in Dravida, Nereis etc.

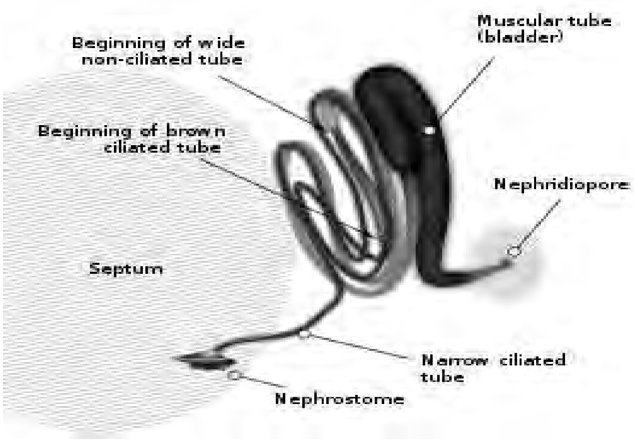

Fig.11.4. Structure of metanephridium

In Neries, a pair of metanephridia is arranged in each segment. In the mass of syncytial cytoplasm, a coiled tube like metanephridia is embedded. The nephrostome is a ciliated funnel that connects one end of the nephridial tube to the coelom. Below the nephrostome, the short neck is present and it leads into a coiled nephridial tube. It opens outside the body through nephridiopore.

The coiled nephrodial tube is divided into three distinct regions: (i) the anterior ciliated region near the neck, (ii) the middle glandular region, and (iii) the posterior muscular region. Each nephridium has a horse shoe-shape. This part is known as the main lobe and it has two limbs. (i) Anterior limb and (ii) Posterior limb. The inner lobe is present between the anterior and posterior limbs. The posterior limb continues forward as an apical lobe which looks like a walking stick. A hollow long tube that coils around the apical lobe is known as the initial lobe. In the case of testicular nephridia, one of the initial lobes merges into the main lobe, while the other ends blindly into the testis sac. A duct known as the vesicle duct emerges from the inner end of the anterior limb and leads into a bad known as the vesicle or bladder. A short excretory duct arises from this bladder and opens outside by a nephridiopore.

Nephridia are present in most of the Annelids, including Polychaetes. However, it may be differentiated as follows.

11.4.2.3. MICRONEPHRIDIA

These are small and confined to a segment. Ex. Oligochaetes.

11.4.2.4. MEGANEPHRIDIA

These are larger and extend between two or more segments. Ex.Polychaetes.

11.4.2.5. MERONEPHRIDIA

It refers to a multiple of nephridiua arising from the subdivision of a single embryonic cord.

11.4.2.6. TUFTED OF BRANCHED NEPHRIDIA

It contains a Nephridium with up to 100 brances.

11.5. NEPHRIDIA IN EARTHWORMS

The nephridia in some Earthworms are localized as Pharyngeal, Integumentary & Septal Nephridia. Besides, some of the nephridia secondarily terminate in the gut (Enteronephric) while others open outside (Exonephric).

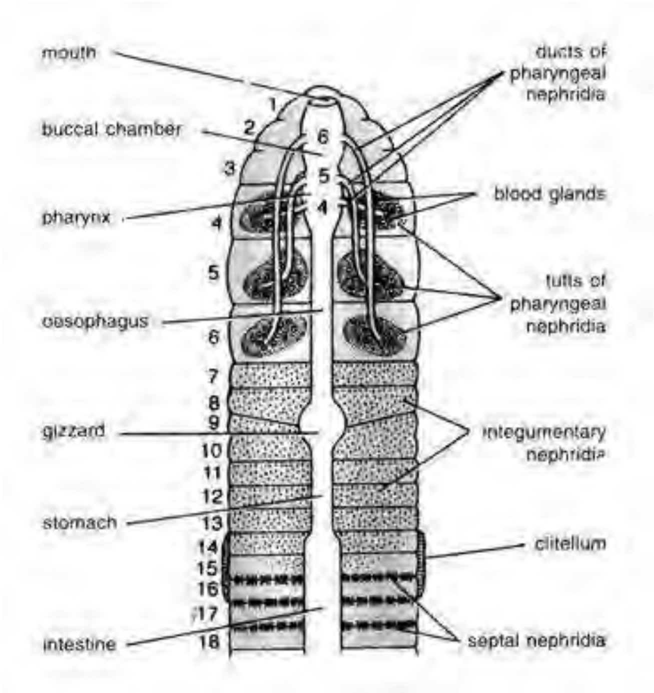

Fig.11.5. Different types of nephridium in *Pheretima*

In Neries, a pair of metanephridia is arranged in each segment. In the mass of syncytial cytoplasm, a coiled tube like metanephridia is embedded. The nephrostome is a ciliated funnel that connects one end of the nephridial tube to the coelom Below the nephrostome, the short neck is present and it leads into a coiled nephridial tube. It opens outside the body through nephridiopore.

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The nephridia in some earthworms are localized as pharyngeal, Integumentary & septal nephridia. Besides, some of the nephridia secondarily terminate in the gut (Enteronephric) while others open outside (Exonephric).

11.5.3. SEPTAL NEPHRIDIA

These are found situated on the inter-segmental septum between the 15^{th} and 16^{th} segments of the posterior side of the body. Each septum bears nephridia on both the surfaces arranged in semicircles around the intestine, two rows in front of the septum and two behind it. Each septum has about 40 to 50 nephridia in front and the same number behind; so that each segment possesses 80 to 100 septal nephridia accept the 15th segment which has only 40 to 50 nephridia. These are not found in the segments up to the 14th. Each septal nephridium consists of a nephrostome, neck, body of nephridium and the terminal duct.

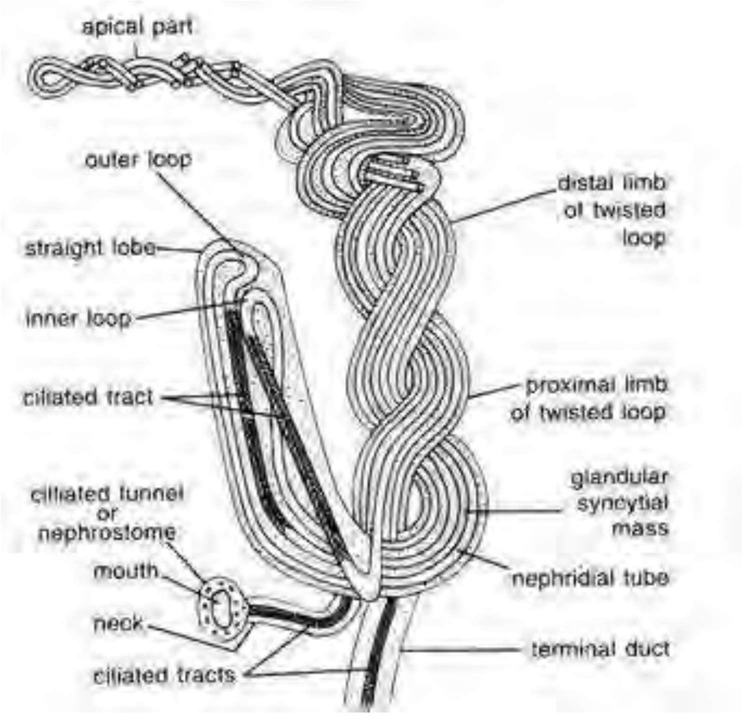


Fig.11.6. Septal nephridium of *Pheretima*

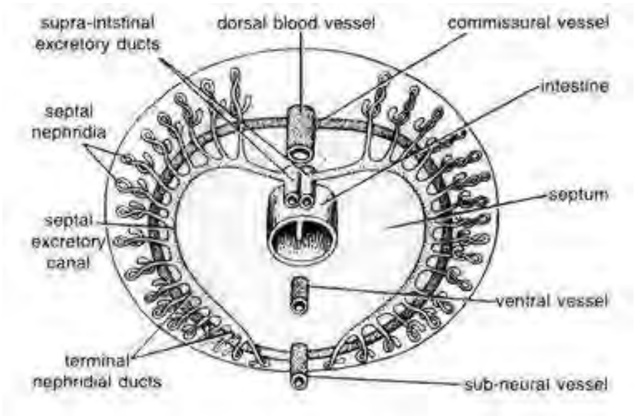


Fig.11.7. Arrangement of septal nephridial system in relation to the intestine

i). Nephrostome

It is also known as ciliated funnel or nephridiostome. It is the proximal flattened funnel-shaped structure of the nephridium lying in the coelom. It has an elliptical mouth-like opening leading into an intracellular canal of the large central cell. The margins of the opening are surrounded by a large upper lip and a smaller lower lip. The lips are provided with several rows of small ciliated marginal cells and the central canal is also ciliated.

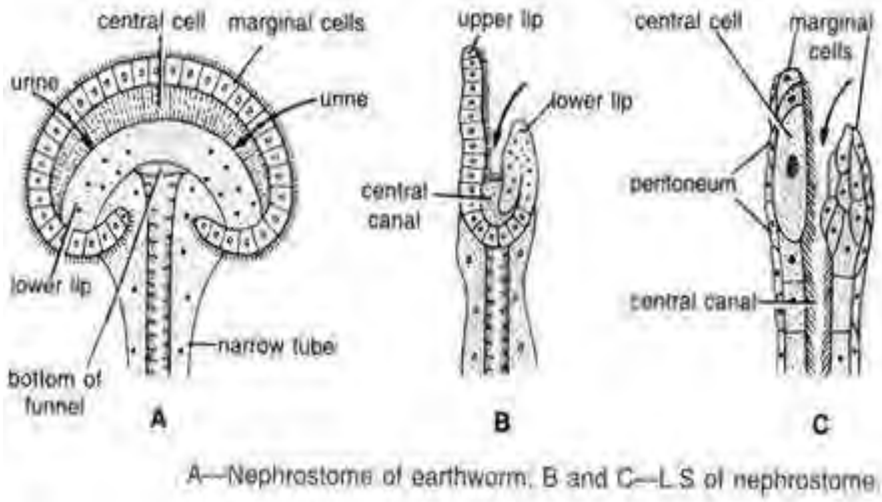


Fig.11.8. Nephrostome of earthworm

ii) Neck

The nephrostome leads into a short and narrow ciliated canal forming the neck. It joins the nephrostome to the body of nephridium.

iii) Body of nephridium

The body of nephridium has two parts: a short straight lobe and a long twisted loop. The loop is formed by two limbs, the proximal limb and the distal limb. Both these limbs are twisted spirally around each other; the number of twists varies from nine to thirteen. The neck of nephridium and the terminal duct join together and remain connected with the proximal limb of the twisted loop, while the distal limb becomes the straight lobe.

Internally, the nephridium is made of a connective tissue matrix having long coiled nephridial duct forming loops. There are four such canals in the straight lobe, three in the lower part and two in the upper part of the limbs of the twisted loop. Two canals of the straight lobe out of the four are ciliated like the ciliated canal of the neck.

iv) Terminal duct

It is short and narrow with a terminal excretory duct. It joins the nephridium with the septal excretory canal.

11.5.4. PHYSIOLOGY OF EXCRETION IN EARTHWORMS

In earthworms, the protein catabolism results in the formation of nitrogenous waste substances like certain amino acids, ammonia and urea. An earthworm excretes nitrogenous waste in the form of urine which generally contains urea, water, traces of ammonia and creatinine. Nephridia excrete these substances from the body of earthworm. The various excretory wastes from the coelomic fluid are drawn into the nephrostomes of septal nephridia or into the excretory canals of other nephridia along with some other useful substances.

These products are either discharged into the intestine (by enteronephric nephridia) or outside by the nephridiopores (by exonephric nephridia). The body of nephridia also absorbs some waste. However, the useful substances are reabsorbed and the passing out waste remains concentrated on various nitrogenous compounds. The excreted waste substances are removed from the body with faeces. In addition to excretory function, the nephridia also have osmoregulatory function.

The nephridia help in conserving water by reabsorption from the excreted products during summers and winters, so they pass hypertonic urine in relation to blood. During the rainy season, the urine is diluted due to less reabsorption of water. The enteronephric nature of nephridia provides another device for conserving water.

11.6. EXO AND ENTERONEPHRIDIA

If nephridia opens directly into the exterior through nephridiopore, then they are known as Exonephric or Ectonephric nephridia. Ex. Meganephridia of Nereis, Hirudinaria and Lumbricus and integumentaly microhephridia of Pheretima. If nephridiopores are absent and the nephridia open directly into excretory canals or alimentary canals, such nephridia are called Enteronephric nephridia. Ex. Pharyngeal or septal nephridia of Pheretima.

11.7. COELOMODUCTS

These originated from mesoderm and were arranged segmentally. Coelmoducts are large tubes that formed as out pushings or evaginations from the coelom into the outside world. Coelmoducts open into coelom on one side via a relatively large ciliated funnel known as the Coelomostome. It can be easily distinguished from the small-sized ciliated funnel called the Nephrostome of nephridia. The genital pore at the second end of the coelomoduct allows access to the outside world. Coelomoducts primarily act as gonoducts. The genital products developed on the wall of coelom are conveyed to the outside of the body by these coelomoducts. Hence, coelomoducts are confined only to a few segments in which reproductive organs are present. However, in certain cases, coelomoducts as a secondary function act as excretory ducts.

11.8. NEPHROMIXIA

In more primitive Poltchaeta and Hirudinea, Oligocaeta, the coelomoducts and nephridia are separate. However, in some Polychaeta, the coelomoducts not remain independent but fused partially or wholly with the nephridium and results in the formation of a compound segmental organs called Nephromixia. Thus, they originate both from ectoderm and mesoderm. Similarly, they serve for both the purposes of excretion and the function of the reproductive system in carrying out of the body, the gametes. Different types of nephromixia are identified based on the degree of fusion of both nephridia and coelomoducts in the formation of Nephromixia. They may share only one external opening, or their fusion may be so close that they share the majority of the same duct. Annelids have four different types of nephromixia.

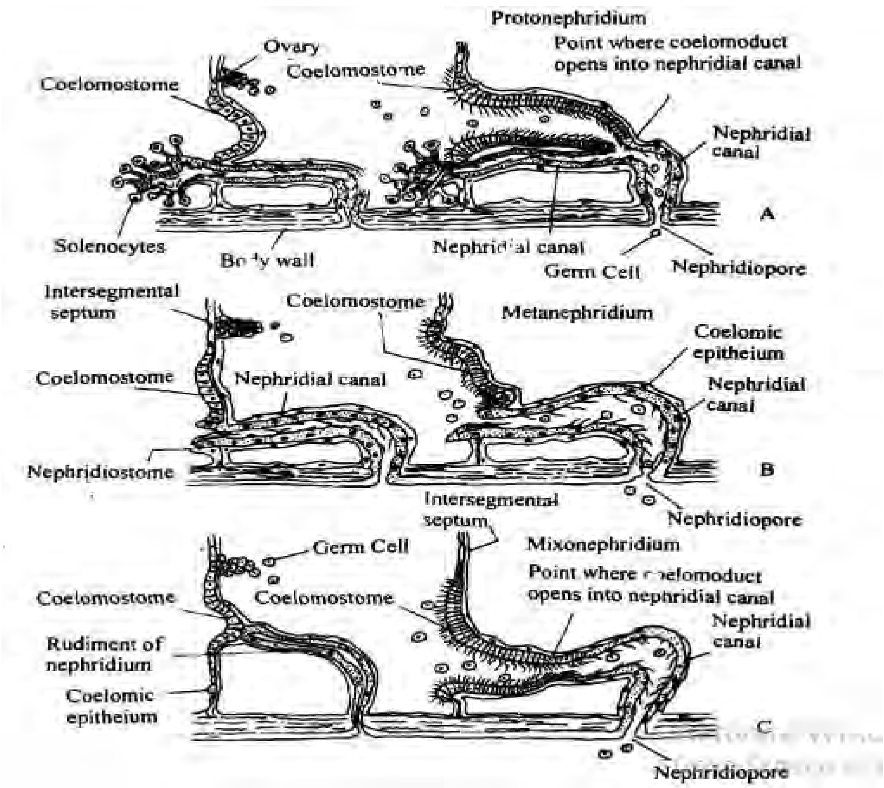


Fig.11.9. Nephridia in Polychaetes. (A) Protonephromixium (B) metanephromixium (C) Mixonephridium.

11.8.1. PROTONEPHROMIXIUM

It is formed due to the fusion of a coelomoduct with a protonephridium. It conveys both excretory and reproductive products to the outside of the body. Protonephromixium is found in Phyllodoce.

11.8.2. METANEPHROMIXIUM

It is formed by the union of coelomoduct with Metanephridium. It is found in Capitellids, Hesione etc.

11.8.3. MYXONEPHRIDIUM

Nephridium and coelomoduct are very intimately fused to form a single composite organ. The coelomoduct forms a funnel, and the nephridia forms myxonephridial ducts. They are found in Arenicola.

11.9. CHLORAGOGEN CELLS

Chloragogen cells, also called as yellow (Y) cells, are found in annelids. They are star shaped that function is similar to the liver in vertebrates. These cells are derived from the inner coelomic epithelium, and help in excretory functions in earthworms. These are most commonly found in the coelomic fluid of earthworms. They collect nitrogenous waste products from the blood capillaries of the gut. Later, these nitrogenous wastes are deposited as yellow granules i.e. guanine in their cytoplasm. When nitrogenous waste products are fully deposited in the cytoplasm, the chlorogogen cells detach from the gut wall and drop into the coelomic fluid. Finally, they are eliminated through septal nephridia or dorsal pores in Pheretima. These chlorogogen cells released freely into the coelom are called Eleocytes. Semal-van Gensen said these degenerative chlorogogen cells are eliminated by phagocytic coelomocytes.

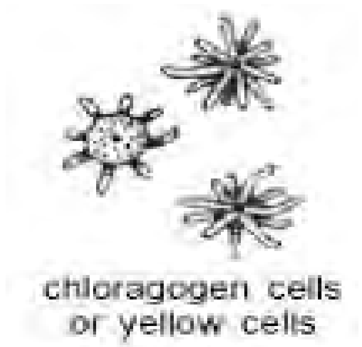


Fig.11.10. Chloragogen cells

Another opinion is that the detached and degenerating chlorogogen cells serve as storehouse of reserve food materials in the form of glycogen and fat. Chlorogogen cells are found with deamination of proteins, formation of ammonia and synthesis of urea. Thus, chlorogogen cells are vital in the organization of intermediary metabolism in earthworms.

11.10. BOTRYOIDAL TISSUE

It is found in Leech. The entire coelom is filled with botryoidal tissue. From beneath the longitudinal muscles of the body wall to the surrounding of the alimentary canal, the botryoidal tissue occupies the space in the coelom. Botryoidal tissue is composed of a network of large branching tubular cells arranged end to end. Except for a few spances, such as haemocoelomic spances, it fills the entire coelom. The walls of the botryoidal cells are loaded with dark brown pigment. Their intracellular canals are filled with red haemocoelomic fluid. It has an excretory function like that of Chlorogogen cells.

11.11. CILIATED ORGANS

In some annelids, coeomoducts are reduced to maximum size as simple Ciliated Organs. Ciliated organs in nereis are attached to the dorso-lateral longitudinal muscles. They open directly outside the body. In Leech, a paired peculiar ciliated organ is present. They have a central reservoir and a large number of funnels. Each funnel is a ciliated organ that has a distinct connection with the nephridium. However, this connection is lost in the case of adults. At the same time, excretory function is also lost and it becomes a part of the haemocoelic system and produces coelomic corpuscles or coelomocytes.

11.12. EXCRETORY ORGANS IN ARTHROPODA

The main excretory products in Arthropods are ammonia and uric acid. Hence, the organisms which excrete ammonia are called ammonotelic organisms. Ex. Crustaceans. The organisms which excrete uric acid are called Uricotelic organisms, eg Insects. The Arthropod excretory system is as complex as other aspects of the organization of this phylum. In these arthropods, the characteristic excretory organ is basically a tubular structure. However, because earlier misnomers are still prevalent and in use, they may refer to them as nephridia. As a detailed discussion is not required for this title, we are presenting the different varieties of excretory organs present in this phylum, Arthropoda, are as follows:-

1. Nephridia
2. Green Glands

3. Coxal Glands
4. Shell glands
5. Hepatopancreas
6. Nephrocytes
7. Crural Gland
8. Malphigian Tubules
9. Miscellaneous Organs:
    i. Ectodermal Gland
    ii. Integument
    iii. Midgut Epithelium
    iv. Intestinal Caeca
    v. Lymphatic Organs
    vi. Fat Body Cells
    vii. Uricose gland

11.12.1. NEPHRIDIA

These are present in the Peripatus and are situated on the lateral side of the segmented body cavity. The numbers of these paired organs correspond to the number of the segments of the trunk. Each nephridium is made up of a terminal vesicle with one end open to the outside and the other connected to a coiled loop. This loop is known as the nephridial canal and it opens inside the body cavity. Its internal lining is ciliated.

11.12.2. GREEN GLAND

It is also known as the antennal gland or maxillary gland. In some species, the organs are also called green gland or antennal gland because of their colour and location (e.g., Astacus). In some freshwater crustacean species, the organs are situated near the maxillary segments and are called maxillary glands. It is a simple structure. The green glands have a round bulbous end sac, a long coiled tube like labyrinth and a bulbous bladder opening outside by excretory pore. The green gland of cray fish starts with the end sac, which is demarcated as sacculus and cortex. The cortex is connected with the labyrinth. The labyrinth resembles a long tube and is connected to a large sac known as the bladder, which opens to the outside via an excretory pore. The labyrinth is the proper excretory gland. It is found in Malacostraca (excepting Isopods) and larval forms of all Crustaceans, especially in Entomostracan larvae.

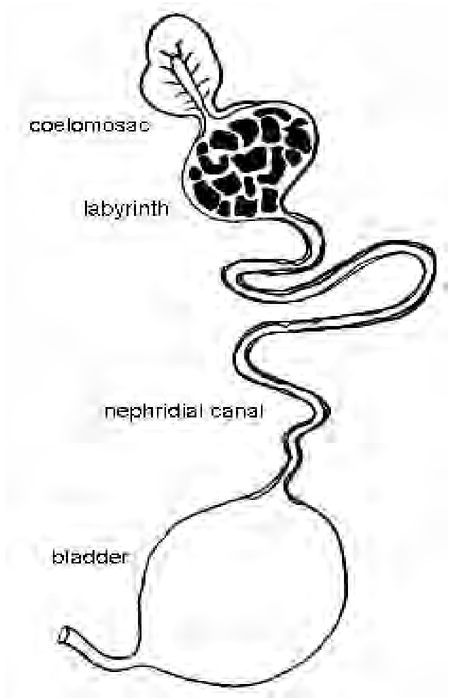


Fig.11.11. Structure of green gland

Physiology of excretion

Like a vertebrate kidney, antennary glands have dual functions, i.e. excretion and osmoregulation. By ultra filtration, water and dissolved substances are separated from the blood and later passed into the end sac. End sac excretes ammonia. Uric acid and other nitrogenous compounds are excreted by other parts of the antennary glands. The labyrinth collects useful substances by selectively reabsorption and returns them to the blood. The excretory fluid or urine flows into the bladder. The entire excretory products are thrown out through the renal pore after collecting excretory fluid from the renal sac into the bladders.

11.12.3. COXAL GLANDS

These glands are present only in Arachnida and their structures and positions vary. Each coxal gland is made up of convoluted tubules known as labyrinths and a sac known as the labyrinth sac. It opens externally by a short tube. A pair of shining white coxal glands is attached to the coax of the third pair of walking legs. Coxal glands are derived from coelomoducts and in adult coelomoducts of the fifth segment persist in the form of coxal gland. Each coxal gland has three parts: (i) large excretory sacculate or end sac, (ii) a coiled tube or labyrinth and (iii) a swollen reservoir or bladder. This bladder opens exteriorly by a small orifice. Urate crystals were found in coxal glands when carmine was injected into the body cavity.

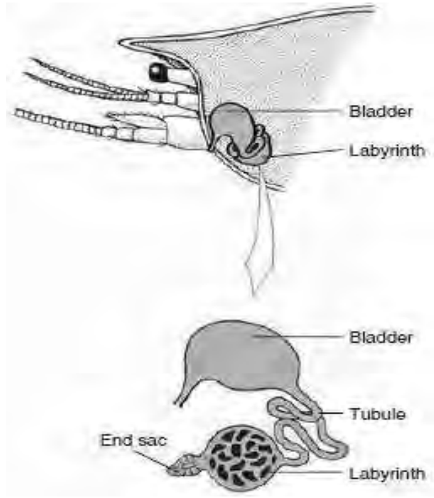


Fig.11.12. Structure of coxal gland

Structure and position of coxal glands in arachnids

Examples	Position	Labyrinth sac	Labyrinth	Exit
Solifugae	2nd or 3rd segment	Short	Very extensively coiled	On pedipalpi
Amblypygi and Uropygi	3rd segment		Much coiled between 5th and 6th segments	1st leg.
Scorpionidae	5th segment		Do	3rd leg.
Araneida	3rd and 6th segments			1st and 3rd legs
Palpigradi	2nd segment	Very long, extends up to 8th segment	Short and sac-like	On pedipalpi.

11.12.4. SHELL GLANDS

These glands are also known as maxillary glands and are present in the coxopodites of second maxillae in Branchiopoda, Ostracoda, Copepoda, Cirripedia and larval forms of all Crustaceans.

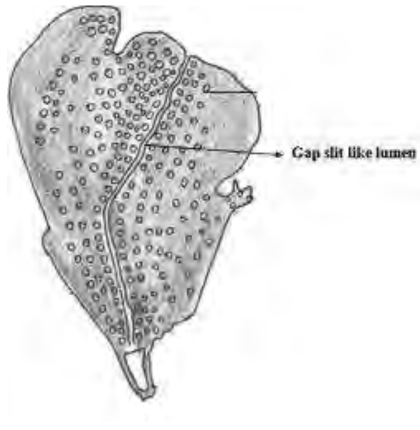


Fig.11.13. Structure of shell glands

11.12.5. HEPATOPANCREAS

In Limulus, absorptive cells are present in the hepatopancreas. These cells shed large amounts of calcium phosphate as an excretory product into the intestine through which it is eliminated along with faeces.

11.12.6. NEPHROCYTES

These are migratory cells, present in groups within the haemocoel of insects. These are regarded as modified fat body cells and are said to absorb unwanted colloidal particles from the blood.

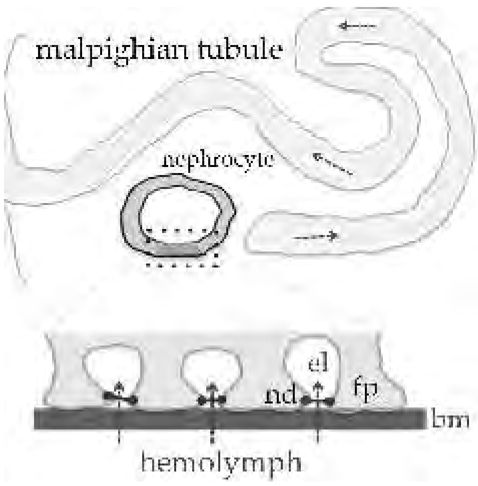


Fig.11.14. Structure of nephrocytes

11.12.7. CRURAL GLANDS

They are seen in peripatus and are supposed to have excretory function. A series of paired, grandular thin wall vasicular structures are known as crural glands that lie laterally in the body cavity of males only. They open to the outside at the bottoms of the legs. These are also called coxal glands by some of the authors. The external opening of crural glands lies just outside the nephridiopore.

11.12.8. MALPHIGIAN TUBULES

Malphigian tubules are the excretory organs in Chelicerata, Mandibulata subphyla of Arthropoda. In 1969, Malphighi discovered the tubules and they are named after him as Malphighian tubules. These are long filamentous bodies with or without lumen and are made up of ciliated or cubical epithelium. These tubules usually originate from the region of the gut which denotes the beginning of hindgut. Among the Crustaceans, the Amphipods possess one pair of tubules which originate as diverticula of the alimentary canal.

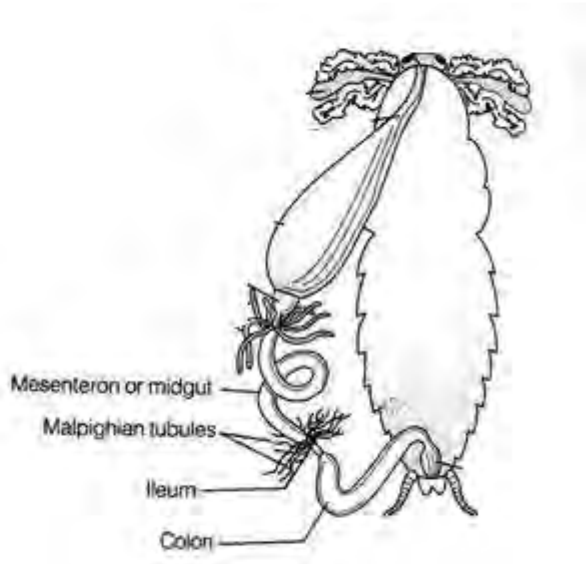
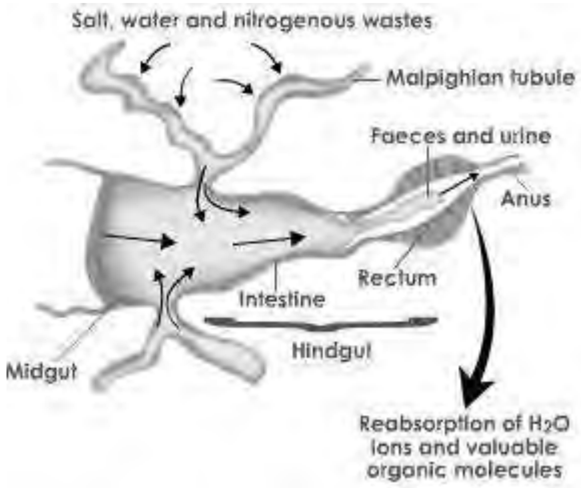


Fig.11.15. Structure of malpighian tubules of cockroach

These develop from the undifferentiated region between the midgut and hindgut in insects, and the number ranges from 2 to 150 Malpighian tubules occur in all insects except in Collembola, some of the Thysanura and the Aphids. The tubules often occur in two or multiples of two.

Malphighian tubules, which are yellow or cream-colored unbranched blind tubes, are well developed in cockroaches. They open into the anterior end of the hind gut or proctodaeum. Basically, they are the outgrowths and around 60-150 malphighian tubules are arranged in 6-8 bundles. Each malphighian tubule measures 25mm in length and 0.05mm in diameter. They are lined by a granular epithelium with a brush border towards the internal lumen. They float in the haemolymph.



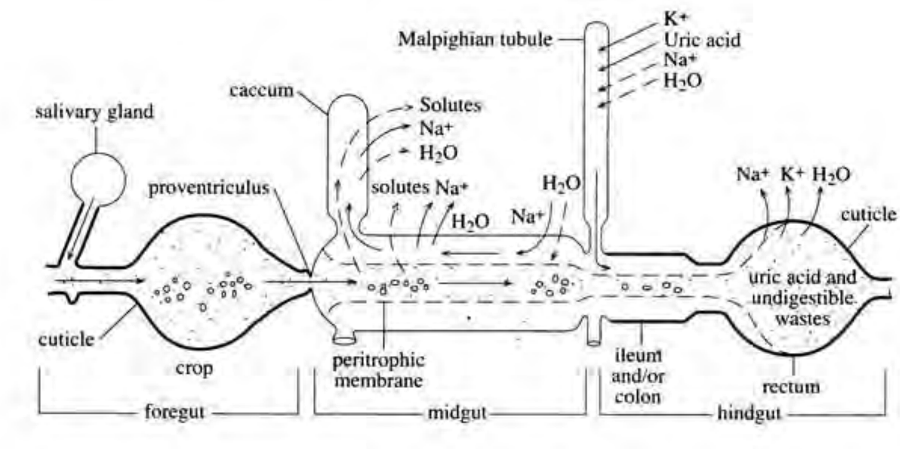


Fig.11.16. Functional diagram of the digestive tract of cockroach showing the passage of food (small circles) through the gut, the absorption of food products in the caeca and the secretion of wastes in the Malpighian tubule. Active transport of salts (solid arrows) leads to passive diffution of water and other substances (dashed arrows).

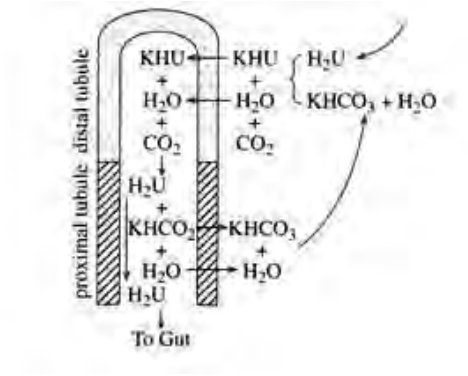


Fig.11.17. Different parts of Malpighian tubule of Periplaneta Americana. Showing their role in excretion.

The Malphighian tubules have two functional parts. Glandular cells of the distal secretory part extract nitrogenous waste (mostly in the form of salts of uric acid, e.g., potassium urate) and water from haemolymph, forming a solution called urine. The urine flows towards the proximal absorptive part of the tubule which reabsorbs certain salts, such as potassium bicarbonates, and some water, resulting in precipitation of uric acid. Uric acid already present in haemolymph combines with reabsorbed potassium bicarbonate and water to form the relatively soluble potassium urate which again becomes available to be actively transported from haemolumph into the lumen of the distal portion of malphighian tubules. Uric acid moves from malphighian tubules into the ileum by gentle peristaltic waves. More water is reabsorbed in the colon and rectum, resulting in the elimination of more or less solid uric acid with feces via the anus.

11.12.8.1. TYPES OF MALPIGHIAN TUBULES

The Malpighian tubules may be divided into 4 main types,

(a) In the simplest type, the tubules join at the junction of midgut and hindgut. The distal ends of the tubules remain free and terminate blindly. The contents of the tubules are usually fluid, but crystals can be found when the insects, such as Orthoptera, Dermoptera, and Coleoptera, are found in arid conditions.

(b) In the second type, the distal ends of the tubules are attached to the hindgut. The condition of these is known as cryptonephridial or cryptonephridic or Cryptosolenic. This condition is seen among many Coleoptera and most Lepidoptera. Cryptonephridial condition is seen in insects when they live in a drier environment and that helps the insects to conserve water by absorbing it from the faeces.

(c) The Malpighian tubules of the third type remain free at the distal ends and connect proximally with the gut through ampullae, and are found in Hemiptera.

(d) The fourth type of Malpighian tubules is found in the Lepidoptera and this type is a combination of the second and third types. Two to four pairs of tubules are found in Myriapods and Arachnids and in the latter the tubules are endodermal in origin.

11.12.9. MISCELLANEOUS ORGANS

In Arthropods, there are few other miscellaneous organs that carry out excretory functions. Sometimes they may have excretory function as a secondary adaptation. They are as follows,

11.12.9.1. ECTODERMAL GLAND

In Nebalia, eight pairs of ectofermal glands are present between the folds of the shell in the antennal region. They are considered as excretory organs.

11.12.9.2. EXOSKELETON

In crustaceans and insects, the cells of the hypodermis secrete nitrogenous substances which remain deposited within the exoskeleton. These are eliminated at the time of ecdysis.

11.12.9.3. MIDGUT EPITHELIUM

In Nauplius larvae of Crustacea, the cells surrounding the midgut carry out excretory function.

11.12.9.4. INTESTINAL CAECA

The rectum of Squilla (Class: Crustacea) bears a pair of intestinal caeca with a comb-like internal wall. These are believed to be excretory in function.

11.12.9.5. LYMPHATIC ORGANS

Lymphatic tissue and organs are found in Scorpions as specialized structures. Lymphatic tissue is found beneath the body wall, especially in the area of mesosoma. A pair of lymphatic organs are connected with the coxal glands. They are internally filled with lymphatic tissue, phagocytic cells and connective tissue. Hence, lymphatic organs and tissues are considered to have phagocytic and excretory function in Scorpion.

11.12.9.6. FAT BODY CELLS

In Insecta, Myriapoda and Onychophora, the fat bodies are made up of polygonal cells. The cells, as they grow old, become filled up with minute urate crystals. Fat body cells are found in insects, ex. Cockroach. In adults, they fill up most of the area of haemocoelom. Excretory products such as uric acid and urates are deposited in urate cells throughout life. This type of excretion is called storage excretion.

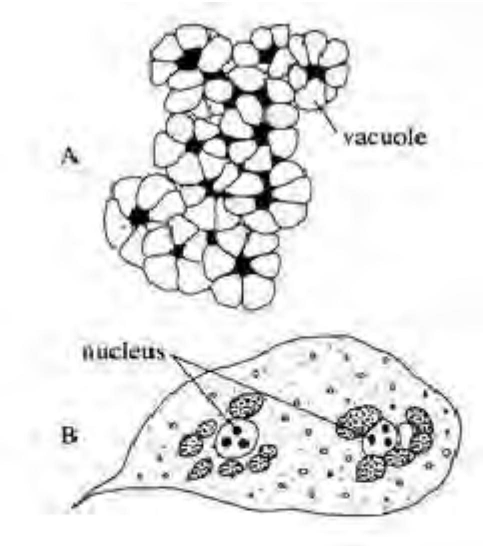


Fig.11.18. Fat body cells

11.12.9.7. URICOSE GLANDS

They can also be found in insects such as cockroaches. The mushroom gland of the male cockroach possesses long, blind, peripheral tubules known as Uricose gland or Urriviuli majors. It stores uric acid as a part of the storage excretion method. This excretory product is discharged over spermatophore during copulation.

11.12.9.8. OENOCYTES

In insects and myriapods, certain cells are found in groups around the abdominal spiracles. These cells originate from the surface epithelium and are believed to be both excretory and circulatory in functions. The excretory system is well-developed in land-living arthropods, which are concerned with the problem of water loss. In them, the excretory organs work in such a way that very little water is lost from the body.

11.12.9.9. PERICARDIAL CELLS

In insects, some cells around the heart and the pericardial membrane are excretory in function.

11.13. EXECRETORY ORGANS IN MOLLUSCA

Even though diversity is present among various organisms in the phylum Mollusca, the group preserves a good deal of uniformity in the excretory system, despite the variety of forms shown by other organs such as ctenidium and foot. The important excretory organs are listed below:

11.13.1. NEPHRIDIA OR SAC LIKE KIDNEY

They are also known as renal organs. On each side of the body, six pairs of nephridia are present in Neopilina belonging to class Monoplacophora. Each nephridium has a central sac giving out several secretor lobules and diverticula. Nephridia have short ducts that open laterally by nephridiopores into pallial groove. In Chiton, belonging to class Amphineura, there are two slender and symmetrical kidneys or nephridia are present. Each has an elongated Y-shaped canal. The unpaired limb of Y-runs longitudinally on each side of the body, terminating blindly in the anterior. The ventral or external branch of the paired limb of Y, opens to the exterior through nephridiopore. This opens inward into the mantle cavity's posterior part. The dorsal or internal branch of the paired limb of Y – opens into the pericardium through a ciliated renopericardial aperture or funnel. Thus, both pericardial and external apertures of the kidney in this way lie near one another at hinder end. The excretory area or surface is increased due to numerous branched caeca or lobed canals. These caeca open into all the 3 limbs of kidney especially in anterior region. Cubical or ciliated epithelium is present in the three limbs.

11.13.2. KIDNEY OR RENAL SAC

In Sepia, the excretory system has a kidney as an excretory organ. It includes a kidney or renal sac consisting of three thin walled chambers, two ventral and one mid dorsal, which communicate with one another. Two ventral chambers open at one end, to the exterior by renal apertures placed on renal papillae, lying one on either side of the rectum, and at the other, communicate with the pericardium by renopreicardial apertures. Through each ventral chamber passes the corresponding branchial vein, formed by the bifurcation of the venacava. The excretory glandular epithelium that covers the vein extracts nitrogenous waste products from the blood. Chamber encloses the pancreatic follicles covering the end opening into the ducts of the digestive gland. They are richly vascular and are said to serve an excretory function. Nitrogenous excretory substance has been detected in the cavities of the renal sac in the form of Guanine which is discharged into the mental cavity.

11.13.3. RENAL ORGAN OR KIDNEY

The excretory organ in *Pila lobose* is a large kidney or renal organ similar to the gill, with the organ on the left side having disappeared or being modified into the gonoduct. It communicates with the outside on the one hand and with the pericardial cavity representing coelom on the other, making it a coelomoduct. It consists of two chambers, a right anterior and a left posterior.

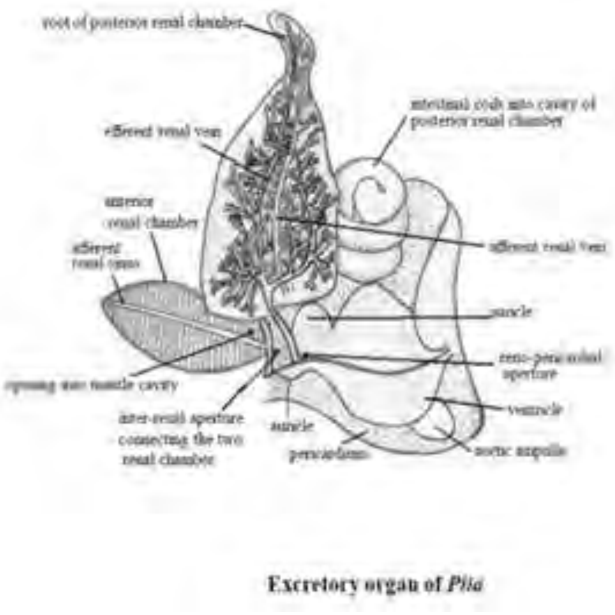


Fig.11.19. Excretory organ of pila

a) Exterior Renal chamber:

It is more or less an oval organ, reddish in colour and lies enterior to the pericardium. It opens into the branchial chamber of the mental cavity through a slip like opening near the epitaenia. At the other end, it communicates with the posterior renal chamber through an internal opening. Internal cavity of the anterior chamber is very much reduced due to the presence of much triangular leaf like processes or lamellae, those arising from the roof alternating with those from the floor. Dorsal surface of the chamber is marked by numerous transverse grooves, corresponding to these internal lamellae. Lamellae on the roof are arranged on either side of a median longitudinal axis, or the efferent renal sinus. Lamellae on the floor are arranged on either side of a similar median axis, the afferent renal sinus, which is the right branch of the peri intestinal sinus. It breaks up into numerous branches to supply the lamellae on both the sides.

b) Posterior renal chamber

It is a broad, brownish to grey and hook- shaped chamber, situated behind the anterior renal chamber, in between the rectum on the right and the pericardium and the digestive gland on the left. Its large internal cavity encloses a part of the genital duct and a few coils of the intestine. At one end, it communicates with the anterior renal chamber through an aperture, and at the other with the pericardium through an elongated slit like renopericardial aperture, perforating a thin vertical renopericardial septum, separating the two afferent and efferent renal vessels profusely branch in the roof of this chamber.

Physiology of Excretion

Two renal chambers are richly supplied with blood from which the nitrogenous waste products are separated. Excretory fluid from the posterior chamber is also transferred to the anterior chamber, from where it is discharged through the external renal aperture into the mantle cavity and finally passed out of the body through the right nichal lobe along with the outflowing water. Excretory fluid contains mostly ammonia and some ammonium compounds, urea and uric acid. Pila shows an adaptation for water conservation during terrestrial phase by converting ammonia into the insoluble uric acid. During aquatic phase, Pila excretes ammonia, but during terrestrial phase, it excretes uric acid. So it is both ammonotelic as well as uricotelic.

11.13.4. ORGANS OF BOJANUS

Excretory organs in Unio are (i) a pair of kidneys or organs of Bojanus, and (ii) Keber's organ or Pericardial gland. The two kidneys or nephridia are often termed the organs of Bojanus after the name of their discoverer. They are situated beneath the floor of the pericardial cavity, one on each side of the vena cava. They are derived from the true coelom (urocoels). Each kidney is a long, dark and glandular tube open at both ends. It is bent upon itself like a broad U-shaped tube, with the loop posterior, the two ends anterior and the two limbs lying parallel and one above the other. The lower arm is brown, spongy, glandular and thick walled, forming the kidney proper, which opens anteriorly into the fluid filled pericardial cavity by a small ciliated renopericardial aperture. The dorsal arm is small, non glandular, lined by ciliated epithelium and a thin wall known as the ureter or urinary bladder, which opens anteriorly into the supra branchial chamber of the inner gill lamina by a small renal aperture. The bladders of both kidneys intercommunicate by an oval apertute.

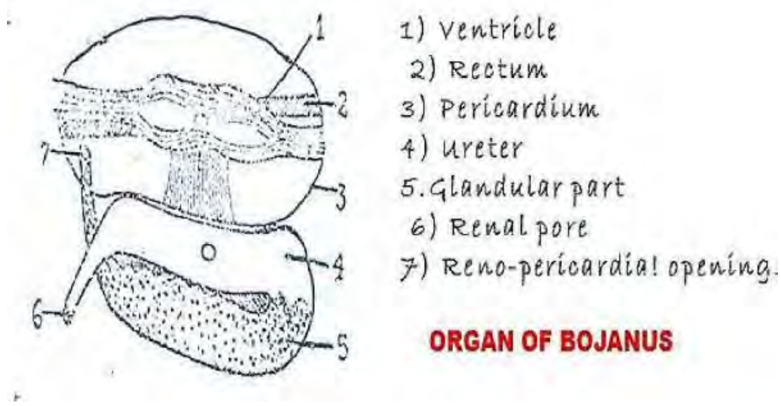


Fig.11.20. Organ of Bojanus

11.13.5. KEBERS ORGANS

It is also known as pericardial gland. It is placed in front of the pericardium as a large, reddish brown, glandular mass. Keber's organ discharges nitrogenous waste products into pericardial fluid through reno-pericardial aperture; nitrogenous wastes enter the kidneys proper from Keber's organ. The glandular part of the kidney proper also filters nitrogenous waste products from the blood. Then the kidneys, proper excretory fluid enters the urinary bladder and then the supra branchial chamber. The outgoing water takes away the nitrogenous waste from the supra branchial chamber along with its outflow. The excretory organs, in addition to excretrion, aid in osmoregulation.

11.13.6. COELOMODUCTS OF MOLLUSCS

Nephridia are absent in Molluscs, as they are in crustacea. But certain of the larval pulmonates do possess protonephridia, suggesting that they have been secondarily lost in molluscs. The excretory system is more or less similar in all the groups of molluscs. In molluscs, it is assumed that the two coelomic cavities meet dorsally to enclose the heart and their walls proliferate into germ cells. Their cavities by further differentiation give rise to gonad anteriorly, pericardial canal centrally and gonoduct posteriorly. The last segment, in addition, had an excretory function. In Aplacophora, the coelomoducts of adults consist of a pair of tubular structures, leading from the coelomic cavity to the outside and primitively constitute the genital ducts. However, in other mollusks, modifications have occurred along the following lines:

i) There is the development of a certain degree of asymmetry.

ii) There is a separation of genital and excretory organs.

The coelomoducts split in the region of the coelomostome in Polyplacophora, and the gonadal cavities become closed off from the pericardial coelom. The excretory coelom remains connected with pericardial coelom. The coelomic complex is markedly asymmetric in gastropods. The left gonad disappears and the right gonad opens into a coelomoduct that has lost its renal function and its connection with the pericardial coelom. The excretory organ is only present on one side (left kidney), and it is large and thick-walled. In prosobranchs, the excretory opening is in the posterior part of the mantle cavity and in pulmonates it opens outside the mantle cavity. In lamellibranchs, though the complications of asymmetry in gastropods do not exist, the genital and renal ducts get separated. In the primitive group protobranchs, the entire coelomoduct has an excretory function. The gametes are discharged into renal organs.

The coelomoduct in filibranchs is bent into a "U" shape, with the lower limb glandular and the more distal upper limb forming a bladder. The connection has shifted to the posterior end of the kidney. In eulamellibranchs, the two organs have developed separate openings. Nutrition, Excretion and Osmoregulation the separation of genital and excretroy components of the coelomic complex has been accomplished in cephalopods. The genital duct runs separately from the renopericardial canal and kidney.

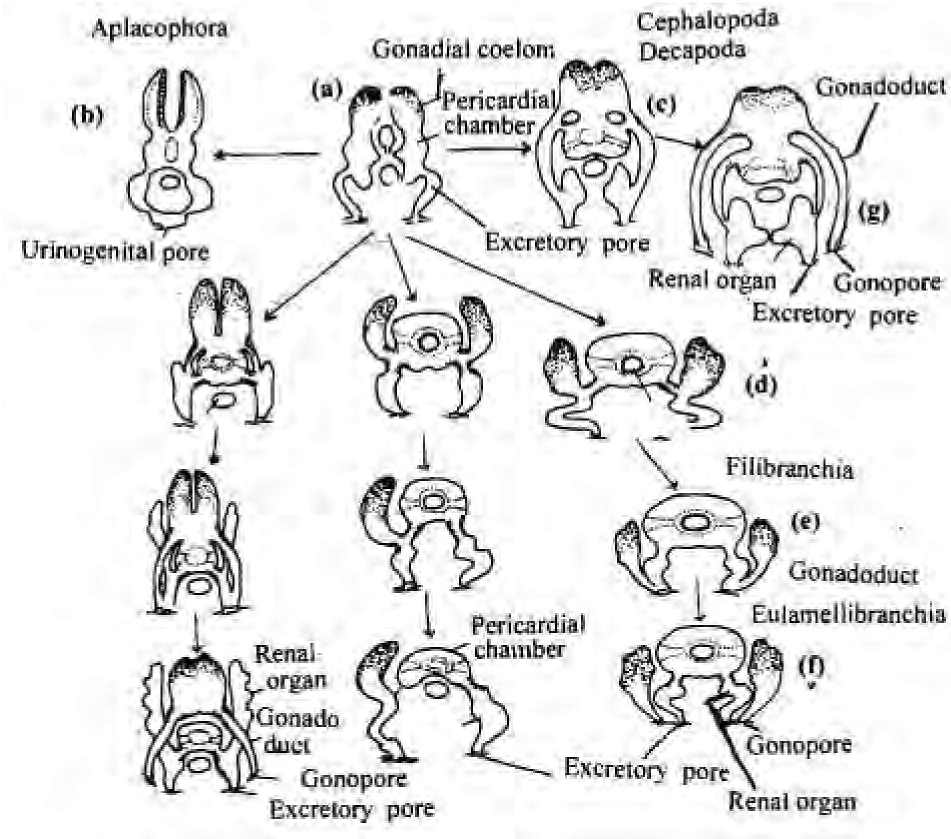


Fig.11.21. Coelom and coelornoducts in Mollusca: (a) primitive mollusc, (b) Aplacophora, (c) Polyplacophora, (d) protobranch, (e) filibranch, (1) eulamellibranch, (g) Cephalopod

11.14. EXCRETORY ORGANS IN ECHINODERMATA

In the phylum Echinodermata, axial organs in Asteroids and Echinoids may have excretory function. The other structures that play an important role in serving excretory function in the entire phylum of Echinodermata are Coelomocytes.

11.14.1. AXIAL GLAND

The axial gland was also known as the axial organ or ovoid gland, or dorsal organ or septal organ or brown gland etc. It is a part of the axial complex. It has three parts: (a) an axial sinus, a thin walled tubular coelomic cavity containing, (b) a stone canal and (c) an axial gland or organ. The Stone canal and axial gland are very closely attached to its walls by mesenteries. The axial gland is an elongated fusiform spongy body. The axial organ is externally clothed by coelomic epithelium and internally with several strands of lacunar tissue, i.e. irregular spaces containing coelomocytes and bounded by connective tissue. The oral end of the axial gland terminates in the septum dividing the hyponeural ring sinus. Axial gland aboral end gives out a head process surrounded by terminal sac or dorsal sac or madreporic vesicle.

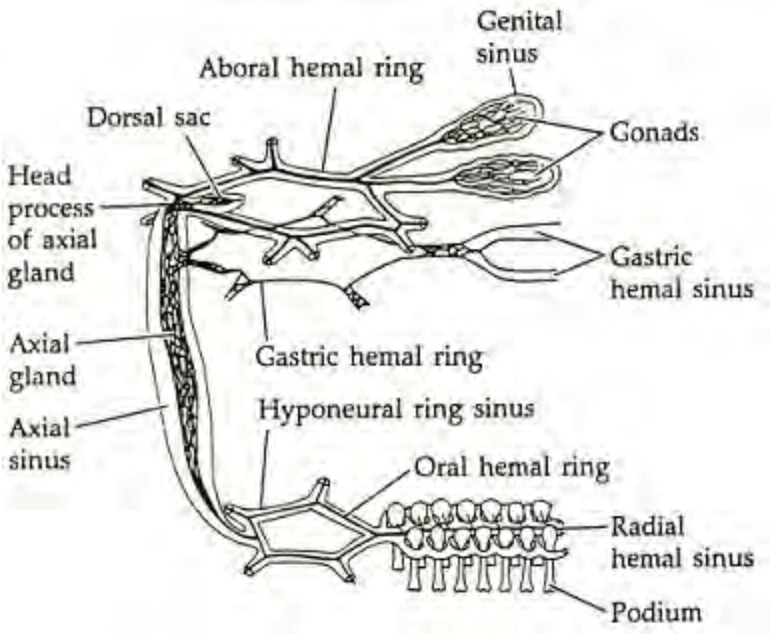


Fig.11.22. Structure of axial gland

11.14.2. COELOMOCYTES

In Echinoderms, the coelom is filled with coelomic fluid. It is similar to sea water with less alkalinity. The coelomocytes are present in the coelomic fluid. These coelomocytes are formed by the axial gland. Coelomocytes are also known as amoeboid coelomocytes or amoebocytes. There are two types:

a) Amoebocytes with slender pseudopodia,

b) Amoebocytes with petaloid pseudopodia.

These coelomocytes are highly phagocytic on foreign substances such as bacteria, pigments, and collagen, among others. They act like leucocytes or white blood corpuscles of blood and serve to ingest and remove foreign bodies from coelom and the other parts of the organism. Coelomocytes help in excretion as they ingest the waste matter and send it out of the body through the walls of dermal papulae or branchiae.

Let Us Sum Up

In this unit, we studied about the excretion in invertebrates. Under this unit, we focused on the excretory organs in Platyhelminthes such as, flame cells, excretory organs in aschelminths, excretory organs in Annelida such as, protonephridia, metanephridia, micronephridia, meganephridia, meronephridia, tufted nephridia, nephridia in earthworm, exo and enteronephridia, coelomoducts, nephromixia such as, protonephromixium, metenephromixium and myxonephridium, chloragogen cells, botryoidal tissue, ciliated organs, excretory organs in arthropods such as, nephridia, green gland, coxal gland, shell gland, hepatopancreas, nephrocytes, crural glands, malpighian tubules and miscellaneous organs, excretory organs in molluscs such as, nephridia, renal sac, organs of bojanus, kebers organ and coelomoducts, and excretory organs in Echinodermata such as, axial gland and coelomocytes.

Check Your Progress

1) The removal of metabolic waste products is known as ___________.
2) The specialized organs that help the excretory functions are known as ___________.
3) There are ___________ types of nephridia are present.
4) The nephrostome is known as a ___________.
5) ___________ cells are yellow cells, which are found in annelids.
6) The malpighian tubules may be divided into ___________main types.

Glossaries

Flame cells : It is a specialized excretory cell found in invertebrates.

Nephridia : It is a tubule open to the exterior which acts as an organ of excretion or osmoregulation.

Nephridiopore : It is the external opening of nephridia.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

Weblink

Organs of excretion in invertebrates https://youtu.be/tQ6oLtQYVKk

Nephridial excretion https://youtu.be/u_qqLLsgymo

Malphagian tubules https://youtu.be/bv-pEHnEIxI

Answers to check Your Progress

1) Excretion
2) Excretory organ
3) 6
4) Ciliated funnel
5) Chloragogen cells
6) 4

Unit-12

Mechanism of Excretion

Objectives

After studying this unit, the students will be able to

- Explain the basic organs of excretion in invertebrates
- Illustrate and explain in detail the mechanism of excretion in invertebrates

Overview

In this unit, we will study about the mechanism of excretion. Here, we will focus on the detailed account of excretory action in the species of phylum invertebrates.

12.0. MECHANISM OF EXCRETION

Aquatic invertebrates excrete ammonia by diffusion through the surface of their bodies, while terrestrial invertebrates first convert ammonia to uric acid, which is then disposed off. In annelids like earthworms, leeches, lugworms, and bristle worms, waste is excreted through structures called metanephridia. The physiological process by which an organism disposes of its nitrogenous by-products is called excretion. The mechanisms for that process constitute the excretory systems. In invertebrates, the excretory structures are classified into three types, including contractile vacuoles in protozoa, nephridia (flame cell system) in most invertebrate animals and Malpighian tubules (arthropod).

Invertebrates in general conform to the principles applied to all animals, namely, that aquatic forms get rid of ammonia by diffusion through the surface of the body; terrestrial forms convert ammonia to uric acid. This implies that in aquatic forms the excretory organ is principally of importance for the composition of their body fluids. Normally, the body fluids of marine invertebrates have the same concentration as seawater; they usually differ, however, in the proportions of ions, with relatively more potassium and less magnesium than seawater. Furthermore, their urine normally has the same concentration as seawater, but correspondingly it contains less potassium and more magnesium. In freshwater invertebrates the urine is commonly, though not invariably, more dilute than the body fluids. By producing dilute urine, a freshwater invertebrate conserve the salt content of its body while eliminating the water that enters its body by osmosis through its water-permeable surface.

Some invertebrates, notably echinoderms, cnidarians, and sponges, have no organs to which an excretory function can be confidently ascribed. Since all of these animals are aquatic, it is reasonable to suppose that they excrete nitrogen (as ammonia) by simple diffusion. Their body fluids (where present) are closely similar to seawater in composition, and it may be presumed that regulation operates only at the cellular level.

Although the earthworm is considered a terrestrial animal, its relationships with its environment are characteristically those of a freshwater animal. The nephridium of the earthworm is longer and more complex than that of marine annelids, four regions being distinguishable. Body fluid enters the nephridium via an internal opening called the nephridiostome. As the fluid passes along the tubule, probably driven by cilia, its composition is modified. In the two lower regions of the tubule, the fluid becomes progressively more dilute, presumably as a result of the reabsorption of salts. Finally, a very dilute urine passes into the bladder (an enlarged portion of the tubule) and then to the exterior through the external opening, or nephridiopore. The rate of urine flow for an earthworm may be as much as 60 percent of its body weight in a period of 24 hours.

In all molluscs so far investigated, the primary process in urine production appears to be filtration of the blood. This may take place through the wall of the heart into the pericardium, or from blood vessels that supply the glandular part of the renal gland. The composition of the primary urine may be altered by reabsorption or secretion, or both. Salts are reabsorbed in the glandular tube and the wide tubule of freshwater mollusks, and the final urine is more dilute than the blood. The rate of urine flow is high, up to 45 percent of the body weight per day in the freshwater mussel. In marine mollusks the urine has the same concentration as the blood, but its ionic composition is different.

In freshwater crayfishes, urine has the same concentration until it reaches the end of the labyrinth; after that, reabsorption occurs in the canal and the urine exits the body as a very dilute solution. The addition of the canal to the system demonstrates one way crustaceans have adapted to life in fresh water. But this is not the only way in which the regulatory problem is solved in freshwater crustaceans. In freshwater crabs, for example, there is a great decrease in the water permeability of the surface (principally the gills) so that water enters by osmosis quite slowly. In contrast to the rate of urine flow in a freshwater crayfish (about 5 percent of the body weight per day), that of the freshwater crab is 100 times less (about 0.05 percent). In the crab, the urine has the same concentration as the blood, but because the flow is so small, the salt loss via the urine is negligible. A few semi-terrestrial crabs are known to produce urine more concentrated than blood.

In all crustaceans for which analyses are available, the concentrations of ions in blood and urine differ. At a urine flow of 5 percent of the body weight per day, the activities of the antennal glands are certainly capable of effecting changes in the composition of the blood. These activities are somehow coordinated with salt uptake by the cells of the body's surface so as to sub serve homeostasis. The role of the antennal glands in nitrogenous excretion seems to be unimportant.

The insect excretory system therefore comprises the malpighian tubules and the rectum acting together. The malpighian tubules are bathed in the insect’s blood, but since they are not rigid, it is impossible for any hydrostatic pressure to be developed across their walls, such as could bring about filtration. The primary urine is formed by a process of secretion in the following way: Potassium ions are actively transported from the blood into the cavity of the tubule and are necessarily followed by negatively charged ions so as to maintain electro neutrality. In turn, water follows the ions, probably by osmosis, and various other substances, sugars, amino acids, and urate ions also enter the primary urine by diffusion from the blood.

The primary urine, together with soluble products of digestion and insoluble indigestible matter from the midgut, then passes to the rectum. There (or in some insects at an earlier stage) the urine is acidified and the soluble urate is thereby converted to insoluble uric acid, which comes out of solution. Water is then reabsorbed together with the soluble products of digestion and other useful substances, including the bulk of the ions that enter the primary urine. In insects that live in dry surroundings, the rectum has remarkable powers of reabsorption, its contents finally being voided as hard, dry pellets containing solid uric acid.

Let Us Sum Up

In this unit, we studied about the mechanism of excretion. Under this unit, we focused on the detailed account of excretory action in the species of phylum invertebrates.

Check Your Progress

1) Aquatic invertebrates excrete by __________ diffusion through the surface of their bodies.
2) The excretory structure are classified into __________ types.
3) The body fluid enters the nephridium via internal opening called the __________.

Glossaries

Metanephridia : It is a type of excretory gland found in many types of invertebrates.

Pellets : It is a usually small rounded, spherical indigestible material.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Mechanism of excretion in invertebrates https://youtu.be/2JeS9vkgq64

Answers to check Your Progress

1) Ammonia
2) 3
3) Nephridiostome

Unit- 13

Excretion an Osmoregulation

Objectives

After studying this unit, the students will be able to

- Explain the process of excretion in invertebrates
- Describe the process of osmoregulation in the invertebrates

Overview

In this unit, we will study about the basic of excretion and osmoregulation in invertebrates. Here, we will focus on the osmoconformers, osmoregulators and a detailed study on osmoregulatory mechanism in invertebrates.

13.0. EXCRETION AND OSMOREGULATION

Osmoregulation refers to the process by which living organisms maintain the constant osmotic conditions in the body. It entails regulating the concentrations of water and solutes in body fluids such as potassium, sodium, and chlorides so that their body fluids remain within homeostatic limits. In order for the cells in the body of an organism to function effectively, the body fluids such as the cell contents as well as fluids outside cells such as tissue fluids, lymph and blood plasma must remain constant.

Fresh water, marine and terrestrial organisms consist of varying modes of adaptations for Osmoregulation that meet the challenges of these diverse environments. The balance of water and ions is partly linked to excretion, the removal of metabolic wastes from the body. The environment of an organism influences the process of Osmoregulation and the nature of excretion because Osmoregulation involves the same body structures as nitrogenous wastes. This is attributed to the fact that the elimination of nitrogen wastes is usually associated with the problem of losing and gaining water. Different organisms live in various environments, including fresh water and the marine environment, as well as the terrestrial environment. In all these environments, organisms employ specific patterns of controlling the concentration of water and salt so that their body fluids do not become too dilute or too concentrated throughout their environment as a medium.

13.1. OSMOCONFORMERS AND OSMOREGULATORS

Some marine animals such as sea stars are osmoconformers; their body fluids are similar to seawater in osmolarity, so they gain and lose water at equal rates and have no need to expend energy expelling water or salt from the body. However, if they are placed in water more or less concentrated than seawater, their tissues shrink or swell, their organelles and cell membranes are damaged, and they die. This is why echinoderms are not found in estuaries, or river mouths where fresh and salt water meet and the salinity fluctuates greatly.

Osmoconformers are stenohaline (steno means "narrow range," and hal means "salt"), unable to tolerate much variation in environmental salinity. Osmoregulators, on the other hand, maintain a more or less stable internal osmolarity by physiological means. Terrestrial animals must osmoregulate because they unavoidably lose water by evaporation and excretion, and replacement water is not always immediately available. Marine osmoregulators maintain an internal salinity lower than that of seawater, and freshwater osmoregulators maintain an internal salinity higher than that of fresh water. Euryhaline (eury means "broad") animals, those able to tolerate a broad range of environmental salinity, must be good osmoregulators. The blue crab, *Callinectes sapidus*, for example, thrives in estuaries and requires efficient osmoregulation to survive there.

13.2. EXCRETION AND OSMOREGULATORY MECHANISMS

Water can not be actively transported across cell membranes because there are no carrier proteins capable of binding and transporting it. Water can, however, pass directly through membranes in response to changes in ion concentration. Water movement is therefore controlled indirectly, by pumping ions such as sodium and potassium across cell membranes, creating a concentration gradient that causes water to follow by osmosis. If sodium is excreted from the body, for example, water tends to follow it. The rate of water loss can thus be regulated by hormones that control the rate of sodium excretion or the water permeability of the excretory ducts. Osmoregulation is usually achieved by excretory organs that serve for the disposal of metabolic wastes. Thus, urination is a mechanism of both waste excretion and osmoregulation. Organelles and organs that carry out osmoregulation include contractile vacuoles, nephridia, antennal glands, and malpighian tubules of invertebrates.

Protonephridia of freshwater flatworms, metanephridia of annelids and coxal glands of crustaceans are other such water pumps that are capable of removing large amounts of fluids from the body. In fact, such organs' primary function is water balance rather than nitrogenous waste excretion.

In some animals, there are no special organs for the removal of water. Hydra is one such example. The regulation of both water and salt in Hydra is carried out by active transport of sodium. In the absence of calcium or sodium in the environment, the osmoregulatory process breaks down in Hydra. The pumping of sodium into the gut is followed by the passive flow of water along the osmotic gradient. The mesogloea functions like an extracellular fluid space. It is believed that two pumps may be operational in Hydra, one transporting Na into mesogloea and the second that transports it into the gut. Water is expelled through the mouth after being taken osmotically.

Active transport of sodium takes care of both osmotic and volume regulation. Thus, there is an influx of water into the body through the external surface, and the excess water is removed through the gastrovascular cavity, through the mouth. Fluid in the gastrovascular cavity is hypoosmotic to tissue fluid. The gastrovascular cavity is thus supposed to act like a contractile vacuole the ability to produce dilute urine has been demonstrated in animals belonging to more advanced phyla (arthropods, earthworms and fresh water molluscs). Using the techniques of micropuncture and clearance of tubular fluid in the metanephric tubules, both filtration and active transport have been demonstrated. For instance, in the antennal gland of fresh water crayfish, the end sac functions as the site of filtration. Chloride is reabsorbed as the filtered urine passes through the long tubule, resulting in conservation of salts and reabsorption of water.

Filtration in arthropods and molluscs is essentially carried out by the hydrostatic pressure of the blood. In arthropods, the wall of the coelomic sac is highly vascularised. In molluscs, the heart passes through the filtration cavity or pericardial sac. There is filtration through the wall of the heart, into the pericardial cavity. From the pericardial cavity, filtrate passes through the nephrostome into the kidney. Generally, the coelomic sac is located near the heart or near the region of high blood pressure. The observed dilution of urine in the distal tubule and ureter could be due to the addition of water or to the reabsorption of salts. But the use of metabolic poisons that arrest the active uptake has clearly demonstrated that absorption of solutes is responsible for the excretion of hypoosmotic urine.

In decapod crustaceans and cephalopods, ionic regulation may extend to every ion. Calcium and potassium, for example, are more concentrated in body fluids than in the external medium in these organisms, whereas magnesium, sulphate, and chloride are less concentrated. Reduction in anion concentration such as sulphate is compensated by an increase in sodium concentration. Thus, in marine invertebrates, including coelenterates, the internal medium has a specialised ionic composition quite distinct from that of the external medium. Excretory organs play a role in ionic regulation.

Insects are the largest group of metazoans that have most successfully invaded the terrestrial environment. Besides, most arachnids, myriapods and isopod crustaceans do not depend on the aquatic environment for their survival. Terrestrial arthropods owe their success to the presence of an impermeable cuticle that prevents water evaporation from the body. Their cuticle, a chitin-protein complex with a hydrophobic wax layer on the surface, is the water-proofing structure. The proximal region of the Malpighian tubules and, more importantly, the rectum play an important role in water resorption, excreting only dry faecal pellets containing insoluble uric acid as nitrogenous waste. Pulmonate molluscs which have taken to terrestrial habitats have a calcareous shell that prevents desiccation of the soft inner parts of the body. Aestivation, among other physiological adaptations, aids them in overcoming adverse climatic conditions.

Let Us Sum Up

In this unit, we studied about the basic of excretion and osmoregulation in invertebrates. Under this unit, we focused on the osmoconformers, osmoregulators and a detailed study on osmoregulatory mechanism in invertebrates.

Check Your Progress

1) __________refers to the process by which living organisms maintain the constant osmotic conditions in the body.
2) __________ are osmoconformers.
3) Urination is the mechanism of body waste __________ and __________.
4) Active transport of sodium takes place in both __________ and __________.
5) __________ are the largest group of metazoans in terrestrial environment.

Glossaries

Osmoregulation : It is the active regulation of the osmotic pressure of an organism's body fluid.

Osmoconformers : They are the marine organisms that maintain an internal environment which is isotonic to their external environment.

Suggested readings

1. **HIGHNAM, K.C.** and **HILL, L.** (1979). The Comparitive Endocrinology of Invertebrates, ELBS & Edward Amold (Publishers) Ltd., London.
2. **HYMAN, G.H** (1967) the invertebrates, Vol. I to VII, McGraw Hill Book Co., Inc., New York.

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Excretion and osmoregulation https://youtu.be/HgdF9f0JEL8

https://youtu.be/SCQPwPYOkBk

Answers to check Your Progress

1) Osmoregulation
2) Sea star
3) Excretion and osmoregulation
4) Osmotic and volume regulation
5) Insects