PREFACE

With its grounding in the "guiding pillars of Access, Equity, Equality, Affordability and Accountability," the New Education Policy (NEP 2020) envisions flexible curricular structures and creative combinations for studies across disciplines. Accordingly, the UGC has revised the CBCS with a new Curriculum and Credit Framework for Undergraduate Programmes (CCFUP) to further empower the flexible choice based credit system with a multidisciplinary approach and multiple/ lateral entry-exit options. It is held that this entire exercise shall leverage the potential of higher education in three-fold ways – learner's personal enlightenment; her/his constructive public engagement; productive social contribution. Cumulatively therefore, all academic endeavours taken up under the NEP 2020 framework are aimed at synergising individual attainments towards the enhancement of our national goals.

In this epochal moment of a paradigmatic transformation in the higher education scenario, the role of an Open University is crucial, not just in terms of improving the Gross Enrolment Ratio (GER) but also in upholding the qualitative parameters. It is time to acknowledge that the implementation of the National Higher Education Qualifications Framework (NHEQF), National Credit Framework (NCrF) and its syncing with the National Skills Qualification Framework (NSQF) are best optimised in the arena of Open and Distance Learning that is truly seamless in its horizons. As one of the largest Open Universities in Eastern India that has been accredited with 'A' grade by NAAC in 2021, has ranked second among Open Universities in the NIRF in 2024, and attained the much required UGC 12B status, Netaji Subhas Open University is committed to both quantity and quality in its mission to spread higher education. It was therefore imperative upon us to embrace NEP 2020, bring in dynamic revisions to our Undergraduate syllabi, and formulate these Self Learning Materials anew. Our new offering is synchronised with the CCFUP in integrating domain specific knowledge with multidisciplinary fields, honing of skills that are relevant to each domain, enhancement of abilities, and of course deep-diving into Indian Knowledge Systems.

Self Learning Materials (SLM's) are the mainstay of Student Support Services (SSS) of an Open University. It is with a futuristic thought that we now offer our learners the choice of print or e-slm's. From our mandate of offering quality higher education in the mother tongue, and from the logistic viewpoint of balancing scholastic needs, we strive to bring out learning materials in Bengali and English. All our faculty members are constantly engaged in this academic exercise that combines subject specific academic research with educational pedagogy. We are privileged in that the expertise of academics across institutions on a national level also comes together to augment our own faculty strength in developing these learning materials. We look forward to proactive feedback from all stakeholders whose participatory zeal in the teachinglearning process based on these study materials will enable us to only get better. On the whole it has been a very challenging task, and I congratulate everyone in the preparation of these SLM's.

I wish the venture all success.

Professor Indrajit Lahiri
Vice Chancellor

Netaji Subhas Open University

Four Year Undergraduate Degree Programme
Under National Higher Education Qualification Framework (NHEQF) &
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Course Title : Animal System and Function
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Course Title : Animal System and Function
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: Course Writer :
Dr. Sanjoy Mondal
Associate Professor, Department of Zoology
School of Sciences, NSOU

: Course Editor :
Dr. Sudipta Das
Associate Professor, Department of
Zoology School of Sciences, NSOU

: Format Editor :
Mr. Asif Ahamed
Assistant Professor of Zoology, NSOU

Notification

Ananya Mitra
Registrar (Additional Charge)

UG. Zoology
(HZO)

Netaji Subhas Open University

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Unit-1 ❑ Protozoan Biology : Locomotion in *Amoeba* and *Paramoecium* ; Asexual and Sexual modes of Reproduction in protista.

Structure

1.1 Objectives

This unit helps the learners to understand the animals belong to kigdom Protista and their certain developed functional mechanism like reproduction and locomotion. This unit also helps to know how the sexual reproduction is evolved and developed.

1.2 Introduction

The animal belongs to Protista is unicellular or acellular but these animals shows so many highly developed functional mechanism like different kinds of cell division, locomotion and reproduction etc.

1.3 Locomotion in *Amoeba*

1. The Amoeba moves from place to place by forming temporary finger-like projections called pseudopodia.
2. A pseudopodium may form at any place upon the surface of the body.
3. It appears as a blunt projection of ectoplasm.
4. The sheet of plasmagel at the root of the ectoplasmic protrusion slowly thins out and is converted into plasmasol.
5. The central granular part of the endoplasm, that is plasmasol, than flows into the ectoplasmic out growth by streaming movement through the gap in the plasmagel sheet.
6. Next to this, the stiff plasmagel at the opposite end of the animal is gradually converted into fluid plasmasol which rushes forward into the pseudopodium.
7. While returning back along the sides of the finger-like tube, the plasmasol is again converted into plasmagel.
8. Many pseudopodia appear simultaneously but usually one of them is extended and the others are retracted.
9. This sort of peculiar motion by thrusting out pseudopodia and then flowing into one of them is known as amoeboid movement.

10. Effective locomotion occurs only when the animal is in contact with the substratum and not when it is floating on the surface of the water.
11. The tip of the pseudopodium may adhere to the substratum by secreting a sticky juice and the entire animal glides forward into the pseudopodium.
12. The speed of locomotion usually ranges from 0-5 to 5 micra per second. In favourable condition the speed may be as high as 1 inch (25 mm.) per hour.
13. It varies with the temperature, increasing slowly up to a temperature of 30°C. Movement totally ceases at 33°C.

1.3.1 Types Of Pseudopodia

Pseudopodia is classified into two types based on numbers.

MONOPODIA

Only a single pseudopodia is formed on the surface of the body.
Eg: *Entamoeba histolytica*

POLYPODIA

Several pseudopodia formed on the surface of the body.
Eg: *Amoeba proteus*

But 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

LOBOPODIUM

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.*

FILOPODIUM

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.

RETICULOPODIUM OR RHIZOPODIUM

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.

AXOPODIUM OR ACTINOPODIUM

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.

1.3.2 Theories proposed to Explain the Locomotion in *Amoeba*

There are nine theories proposed till this date which are :-

1. Adhesion Theory :

According to this theory, locomotion in Amoeba is performed by adhesion similar to drop of water which spreads irregularly on uneven glass plate. The protoplasm flows, like the fluid of the drop, in the path of greater adhesion. Due to adhesive properties pseudopodia generally grow in the paths of adhesion. However, this explanation is not satisfactory and does not hold good as the pseudopodia are sometimes given out independently even without any contact with any surface.

2. Surface Tension Theory :

This theory was first of all advocated by Berthold (1886) and later supported by Butschli (1894) and Rhumbler (1898). According to this theory, protoplasm is a fluid, there must exist at the surface of the protoplasmic mass a tension (surface tension) acting to make the mass spherical. Wherever on such a sphere the surface tension is locally lowered by external or internal changes, the protoplasm flows out in the form of a projection, the pseudopodium. In such a projection, the protoplasm will flow forward in the centre and back along the sides. In other words, there is a fountain streaming of protoplasm in the pseudopodium. This theory is supported by the facts that drops of certain chemical mixtures will move in amoeboid fashion because of local decreases

in the surface tension and that in some amoeboid forms fountain streaming can be observed in active pseudopodia. However, majority of Amoebae do not exhibit fountain streaming in their pseudopodia.

Furthermore, most of the amoeboid forms have gelated surface instead of fluid as assumed by this theory. Therefore, surface tension theory may apply only to a few very fluid amoebae. This view is no longer supported now-a-days. It is believed that surface tension difference may cause change in the shape, but this does not account satisfactorily for the formation of pseudopodia.

3. Rolling Movement Theory :

Jennings (1904) worked on *Amoeba* verrucosa which has almost no pseudopodia.

If a particle of carmine is placed on the upper surface of a moving A. verrucosa, it is seen that the particle flows forward, rolls over the anterior edge, then it stops on the substratum until the entire direction of movement animal has passed over it, then the particle moves upwards at the posterior end and comes on the upper surface and moves forward. This is due to streaming movements of protoplasm of the animal accompanied by rolling action of the body and these two processes bring about locomotion. Jennings' observations may be correct for A. verrucosa, which is devoid of pseudopodia, but it cannot be applied to *Amoeba* proteus which moves with the pseudopodia. (Figure-1)

4. Contraction Theory :

Dellinger (1906) examined an *Amoeba* proteus not from the top, but from side view, exactly in front of the observer and came to the conclusion that a contractile substance present in the endoplasm is mainly responsible for the formation of pseudopodia. According to him, the *Amoeba* extends the anterior end to form a pseudopodium, then it lifts it and places it on the substratum, then it contracts this pseudopodium which causes the body to move forward. This process is repeated.

Thus, the animal is pulled from in front and pushed from behind due to contractions of a contractile substance located in the endoplasm as a coarse reticulum. In this way the *Amoeba* actually walks putting one foot out, then another. According to Dellinger, pseudopodia are formed by an exchange of water between the ectoplasm and endoplasm which causes alternate contractions and expansions.

5. Gel-Sol Theory :

Pantin (1923) studied the marine *Amoeba umax,* it forms a pseudopodium by swelling of protoplasm due to secretion of acid and absorption of water at that place. As the pseudopodium forms and extends in front, a gelatinous ectoplasmic tube is formed. At the posterior end, this ectoplasmic tube changes into endoplasm.

The ectoplasmic tube contracts and forces the endoplasm to stream to the front, this brings about locomotion. (Figure—2)

6. Sol-Gel Theory or Change of Viscosity Theory :

This theory was strongly advocated by Hyman (1917) and also adopted by Pantin (1923—1926) and Mast (1925). It is supposed to be the best to explain the locomotion in *Amoeba.* This theory is based on the reversible change of protoplasm from sol to gel state.

According to Mast, amoeboid movement is brought about by four processes :

(i) Attachment of *Amoeba* to the substratum,

(ii) Gelation of plasmasol at the anterior advancing pseudopodia,

(iii) Solation of plasmagel at the posterior end and receding pseudopodia,

(iv) Contraction of plasmagel tube at the posterior end to drive the plasmasol forwards.

As the plasmasol changes into plasmagel at the anterior end, the plasmagel tube extends forwards and is converted into plasmasol at the posterior end, the plasmagel tube drives the plasmasol forwards to form a pseudopodium. A thin plasmagel sheet persists intact at the anterior end and prevents the plasmasol from reaching the plasma lemma, but this sheet may break at times so that the plasmasol streams through filling the hyaline cap, but soon the plasmasol gelates to form a new plasmagel sheet.

Pseudopodia are formed because plasmagel is elastic and under tension, it is pushed out where the elastic strength is the lowest. During locomotion of Amoeba, the elastic strength of plasmagel is the highest at the sides, intermediate at the posterior end, and lowest at the anterior end; this results in an elongated shape of the animal and a forward extension of the anterior end to bring about locomotion.

7. Molecular Folding-Unfolding Theory :

Recently, Goldacre and Lorch (1950) have explained the phenomena of solation and gelation on the molecular basis. According to Goldacre and Lorch, the contraction of the plasmagel tube cannot supply enough force for moving the animal.

They state that all proteins gelate when their molecules unfold and they solate when their molecules fold. In the fluid endoplasm the protein molecules lie folded compactly, these molecules unfold at the tip of the advancing pseudopodia to form a layer of straightened and attached molecules. Posteriorly the protein molecules begin to fold again and they impart a contraction force. In *Amoeba,* the contraction is confined towards the posterior side which forces the contracted proteins towards the anterior end. As the animal moves, the plasmagel contracts at the posterior end, it changes into plasmasol which flows in front, and then by gelation, it forms the advancing pseudopod anteriorly. With further folding, these posterior molecules solute and pass forward in the endoplasm.

Such molecules attract substances from the sides of the *Amoeba* and release them on folding again to accumulate them at the posterior side of the animal to produce further contraction force. The rear part of the cell is squeezed like a tube of toothpaste, this drives the plasmasol to the front end where it forces out a pseudopod.

Attachment of the animal to the substratum is necessary for locomotion. It is supposed that the energy for the movement of *Amoeba,* folding and unfolding of protein molecules is provided by adenosine triphosphate (ATP), a substance which has stored chemical energy and which is-known to provide energy for contraction of muscles in Metazoa. This explanation of locomotion appears satisfactory since it shows that the mechanism of pseudopod formation and muscle contraction is similar.

8. Fountain-Zone Contraction Theory :

This theory was proposed by Allen (1962) that amoeboid movement is a slow contraction of molecules is based on the observation that endoplasmic molecules near the front end start moving before those at the posterior end. This shows that locomotion cannot be due to squeezing from behind forwards as claimed in some other theories. The endoplasm contains long protein chains which undergo contraction at the anterior end and here the plasmasol is converted into plasmagel.

In this plasmagel, the protein chains are folded by which the gel state results. It is believed that at the region near the tip of the forming pseudopodium the everting plasmasol changes into plasmagel to form a wall or fountain zone, and this anterior region develops tension which is transmitted to the hinder end of the endoplasm. At the posterior end, the protein chains unfold by which the plasmagel is converted into plasmasol. Thus, the animal is pulled forward by the contraction or tension at the anterior end. It is essential for the surface of the *Amoeba* to temporarily adhere to the substratum because internal streaming alone cannot cause locomotion.

9. Granule Movement theory (1963) :

Rinaldi and Jahn (1963) have analysed motion pictures of granule movements in advancing pseudopodia and observations given in support of theories of Mast (1925) and Allen (1962). They have strongly criticised the fountain-zone theory of Allen and supported the concept as proposed by Pantin and Mast.

They have advocated that during movement when plasmagel is converted into plasmasol at the posterior end, then due to contraction in the plasmagel a hydraulic pressure is exerted on the plasmasol. This pressure remains very less in the anterior end, moderate in the middle and very high in the posterior end of *Amoeba.* Due to this pressure the plasmagel in the anterior end breaks resulting into a forward flow of plasmasol which forms pseudopodium.

Since, there occurs constant conversion of plasmagel into plasmasol at the posterior end and the pressure remains less at the anterior end, the plasmasol flows forward and forms pseudopodium which brings about locomotion.

10. Views of Wolpert, Gingley and Garrod (1968) :

Wolpert, Gingley and Garrod (1968) have again confirmed the theory of Mast with the comment that the concept of amoeboid movement as suggested by Pantin and Mast is essentially correct. However, they have said that the plasmalemma of Amoeba is very elastic in nature which helps in the formation of pseudopodia to affect locomotion. Barrington (1967) has concluded that the biochemical principles involving in Amoeba's activity have something in common with those involved in other types of movements The energy needed for it comes form ATPs.

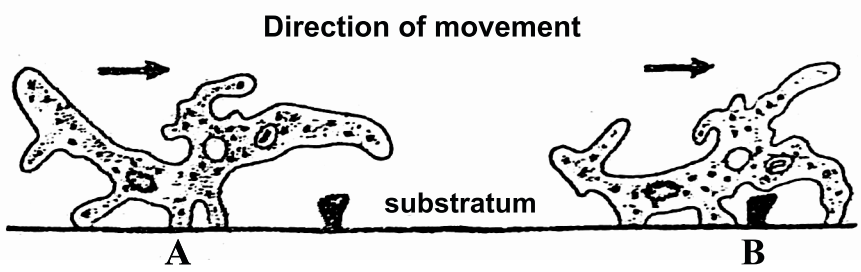


Figure-1 : **Rolling movement theory**

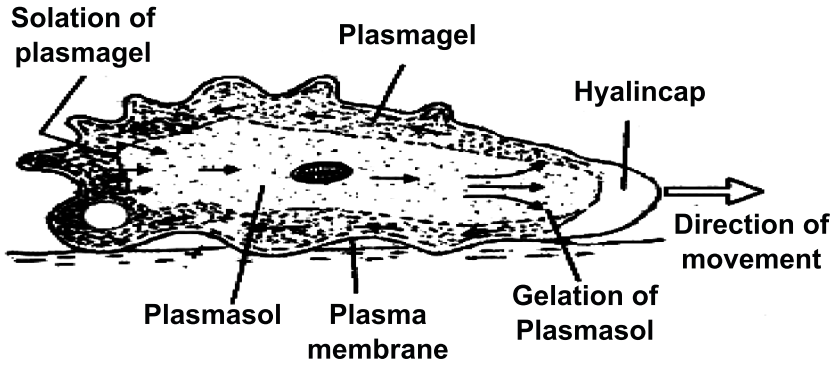


Figure-2 : **Sal-Gel theory in Amoeba**

1.4 Locomotion in Paramoecium

Paramecium has a streamlined body which helps it to swim in the water which less friction. The rapid swimming is facilitated by the beating of fine and hair-like cellular organelles called cilia. Cilia cover the entire body surface of this protozoan. *Paramecium* has around 4,000 motile cilia on its surface arranged in longitudinal rows, beating in waves to ensure movement and feeding.

Ciliary movement (Figure—3)

In *Paramecium* locomotion mainly occurs by movement of cilia. It can move forward and backward. While moving forward, cilia strongly move from anterior to posterior. Similarly, for backward movement cilia strongly move from posterior to anterior. All the cilia do not move at a time. Cilia of transverse row move at the same time. It is called synchronous rhythm, whereas cilia of longitudinal row move one after another. It is called Metachronous rhythm.

The back and forth movements of the cilia are also called as effective and recovery strokes respectively. Cilium moves just like a pendulum or a paddle. The cilium moves the water parallel to the surface of its attachment like that of paddle stroke movement. The movement of water is perpendicular to the longitudinal axis of cilium.

Effective stroke: During effective stroke, the cilium bends and beats against water thus bringing the body forward and sending the water backwards.

Recovery stroke: During recovery stroke, the cilium comes back to original position by its backward movement without any resistance. (Figure:-4)

Cilia shows two types of coordinated rhythms,

* **Synchronous rhythm,** where in the cilia beast simultaneously in a transverse row.

* **Metachronous rhythm,** where in cilia beat one after another in a longitudinal row. The metachronal waves pass from anterior to posterior end.

The beating of the cilia can be reversed to move backwards when a *Paramecium* encounters any undesirable object in its path. The ciliary movement is coordinated by infraciliary system though neuromotor center called as motorium present near the cytopharynx in the ciliates like *Paramecium*. The infraciliary system together with motorium form neuromotor system which helps in coordination of the beating of the cilia. Ciliary movement is the fastest locomotion in protozoans.

1.4.1 Role of Cilia in Locomotion :

Paramoecium exhibits the following types of movement by means of cilia

i. Swimming :

During swimming, each cilium moves in a whip-like motion. It first gives a forward active stroke in which the cilium is fully extended and beating against the surrounding liquid. It is followed by a recovery stroke, in which the cilium returns to its original position with an unrolling movement that minimizes the viscous drag. In Paramoecium, cilia do not beat simultaneously rather groups of cilia bend in a coordinated unidirectional waves. The movement of adjacent cilia occurs as a result of interference effect of the surrounding water layer. Thus, the hydrodynamic forces impose a co-ordination on the cilia.

ii. Creeping :

During creeping, Paramoecium uses its cilia of the oral surface as miniature legs and simply glides over the obstacles. As the pellicle is thin and elastic, the ciliate can easily bend and squeeze through gaps narrower than its own body diameter.

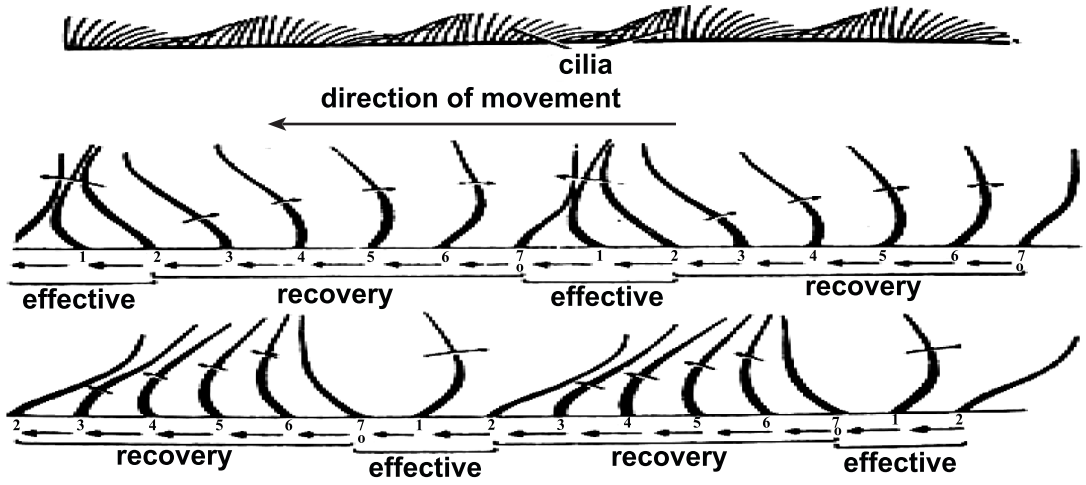


Figure-3 : **Cilliary movements**

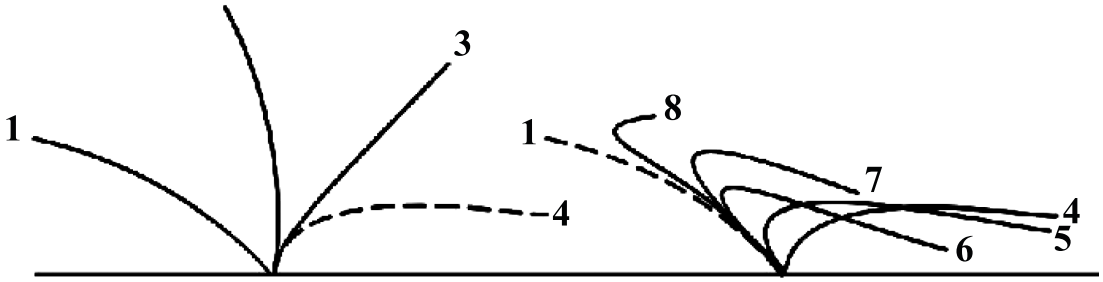


Figure-4 : **Movement of cilium : 1-4-effective stroke, 4-8-recovery stroke**

1.5 Asexual modes of reproduction in protozoa

The asexual mode of reproduction in which there is no union of gametes. In such a case, only one animal can produce new individuals. Protozoa usually reproduces asexually by binary fission and multiple fission.

1.5.1 Binary Fission :

The animal divides and two individuals are produced from one:

1. The micronucleus divides into two by a simplified form of mitosis.
2. The macronucleus divides into two by amitosis.

3. The cytoplasm divides into two equal halves by a constriction.
4. The daughter individuals can reconstruct the wanting structures which it does not obtain from the parent. Asymmetrical structures like gullet, peristome of Paramoecim cannot be equally shared by both the daughter individuals.

Binary fission is again of three types :

a. Transverse fission. The animal divides transversely into two. Examples: Amoeba, Paramoecium, etc.

b. Longitudinal fission. The animal splits into two along the long axis of the body. Examples: Euglena, Vorticella, etc.

c. Oblique binary fission. The plane of fission is oblique. Examples: Dinoflagellata, Ceratium, Cochliodinium,. etc.

1.5.2 Multiple Fission or Sporulation :

Many individuals are produced from one at a time. Examples: Some Amoebae, Euglena, Polystomella, etc.

1. The animal becomes encysted, the nucleus divides repeatedly and a large number of minute daughter nuclei are produced.

2. The cytoplasm fragments and a small bit of it surrounds each daughter nucleus and, thus, many minute animals are formed.

3. Under favourable circumstances the cyst bursts and these small animals come out and grow to the adult stage.

Multiple fission is common in sarcomastigophorans and apicomplexans. The process has been differently named according to the period and time of occurrence.

1.5.3 Following types of multiple fission are found in protozoa :

a. Gamogony :

Products are gametes. Examples: Monocytes.

b. Scizogony or agamogony occurs in asexual stages:

The resulting individuals are known as agametes or merozoites.

Example : Plasmodium.

c. Sporogony :

It occurs following sexual fusion. The products are surrounded by a cyst or a resistant covering and termed as spores. Motile spores are known as swarmer's or swarmospores.

The swarmospore are of two types :

i. Flagellospore. Spores bearing flagella.
ii. Pseudopodiospore or amoebospore. Spores beaning pseudopodia.

1.5.4 Plasmotomy :

The multinucleate individual divides into many small multinucleate offspring's by simple division of cytoplasm independent of nuclear division. The daughter individuals regain the normal size and the number of nuclei is restored by further nuclear division.

1.5.5 Budding :

New individuals are produced by separation of a portion of the cytoplasm of the parent organism with a daughter nucleus. It may be simple or multiple, exogenous or endogenous. Budding is common in suctorians. Examples: Noctiluca, etc.

1.6 Sexual modes of reproduction in protozoa

The modes of reproduction in which two gametes unite to form a new individual is known as sexual reproduction. The two units (male and female gametes) from two separate individuals unite by fusion of their cytoplasm, followed by the union of their nuclei. Most protists (protozoa) can continue to live, multiplying asexually for prolonged periods and may undergo sexual reproduction only at irregular intervals. However, there are many protozoans in which sexual reproduction is of regular occurrence. Sexual reproduction involves meiotic division reducing the chromosomes to haploid number. In majority, reduction division occurs shortly before syngamy. This is called gametic meiosis, in which gametes become haploid. But in some protozoans reduction division occurs in one of the subsequent divisions after formation of zygote. This is termed as zygotic meiosis, in which only zygote is diploid but rest of the life cycle is haploid.
Of different types of sexual reproduction in protozoans syngamy, conjugation, automyxis are important.

1.6.1 Syngamy or Sexual Fusion :

Syngamy is the complete and permanent union or fusion of two specialised protozoan individuals or gametes resulting in the formation of a fertilized cell or zygote or oospore. The nuclei of the gametes fuse to form the zygote nucleus or synkaryon. The zygotes develop into adult, either directly or through encystment and fission of various types.

Depending upon the degree of differentiation of the fusing gametes syngamy may be of the following types :

a. Autogamy :

The gametes derived from the same parent cell fuse. Examples: Actinophrys, Paramoecium aurelia, etc.

b. Paedogamy :

The fusing individuals are young. Example: Actinophrys

c. Hologamy :

The two mature individuals behave as gametes and fuse. Example: Copromonas

d. Merogamy :

The uniting individuals are smaller than the ordinary vegetative individuals, called merogametes.

e. Isogamy :

Union of the gametes of similar size and shape. The isogametes are produced by multiple or repeated binary fission. Isogamy has been reported in Foraminifera (Elphidium), and Gregarinida (Monocystis).

f. Anisogamy :

The two fusing gametes differ in size, shape and behaviour. The gametes are termed as heterogametes or anisogametes and their fusion is known as anisogamy or heterogamy. The formation of morphologically different gametes, is the first indication of sex differentiation in Protozoa. The smaller gametes, the microgametes, or male gametes, are active, motile, generally flagellated and more numerous. They are produced by multiple or repeated fissions. The fusion of two microgametes is called Micro-gamy. Example: Foraminifera, Arcella, etc.

The larger gametes, macrogametes, are immotile, voluminous, and referred to as female gametes. The fusion of two macrogametes is called Macro-gamy. Examples: Plasmodium, Eimeria, etc.

The syngamy brings about a combination of two different lines of hereditary characters. It increases the external differences in offspring's. It also renews the vigour which is lost due to repeated binary fissions. The fusion of two nuclei initiates the development of eggs.

1.6.2 Conjugation :

Conjugation is defined as the temporary union of two individuals which mutually exchange micronuclear material. It is unique type of a sexual process in which two organisms separate soon after exchange of nuclear material. Observations have been

made that usually paramecia neither conjugate with members of their own mating type nor with the other varieties, but only with the second mating type of their own variety. The mating types remain morphologically identical but they exhibit physiological differences. In *P. aurelia*, there are 14 syngens and 28 mating types, while in P. caudatum, there are 16 syngens and 32 mating types.

Process of Conjugation :

The process of conjugation differs in different species of Paramecium, following is the conjugation process of P. Caudatum :-

In conjugation two *Paramecium caudatum***(referred to as pre-conjugants)** of the opposite mating types of the same variety come together with their ventral surfaces and unite by their oral grooves; their cilia produce a substance on the surface of the body which causes adhesion of the two conjugating paramecia.

They stop feeding and their oral groove apparatus disappears. The pellicle and ectoplasm, at the point of contact, of both break down, and a protoplasmic bridge is formed between the two animals. Now, these individuals are called **conjugants.**

In this condition, the conjugating pair swim actively and simultaneously a series of nuclear changes take place in each conjugant as described below:

The macronucleus begins to disintegrate, it becomes loose in texture and forms a complex twisted skein, during the latter half of the conjugation period it will finally disappear being absorbed in the cytoplasm.

The micronucleus of each conjugant divides twice, one of them being a reduction division.Thus, four haploid daughter micronuclei are produced in each conjugant. Three of these four micronuclei degenerate in each, so that only one remains.

The remaining micronucleus of each conjugant divides mitotically into two unequal pronuclei or gametic nuclei forming a larger stationary female pro-nucleus and a smaller, active migratory male pro-nucleus.

The migratory pro-nucleus of one conjugant crosses over the protoplasmic bridge and fuses with the stationary pro-nucleus of other conjugant to form a synkaryon or conjugation nucleus in which the diploid number of chromosomes is restored and there has been an exchange of hereditary material.

The process has been compared with fertilisation in higher animals, but this is not fertilisation because no gametes are involved. The conjugants now (after about 12-48 hours) separate and are called ex-conjugants.

The synkaryon of each ex-conjugant divides three times to form eight micronuclei in each ex-conjugant. Four of the eight micronuclei enlarge and become macronuclei, and three of the other four micronuclei disappear.

The remaining micronucleus divides and at the same time the ex-conjugant divides by binary fission into two cells, each having two macronuclei and one micronucleus.

The cells and their micronuclei divide a second time to form four paramecia from each ex-conjugant, so that each has one macronucleus and one micronucleus.

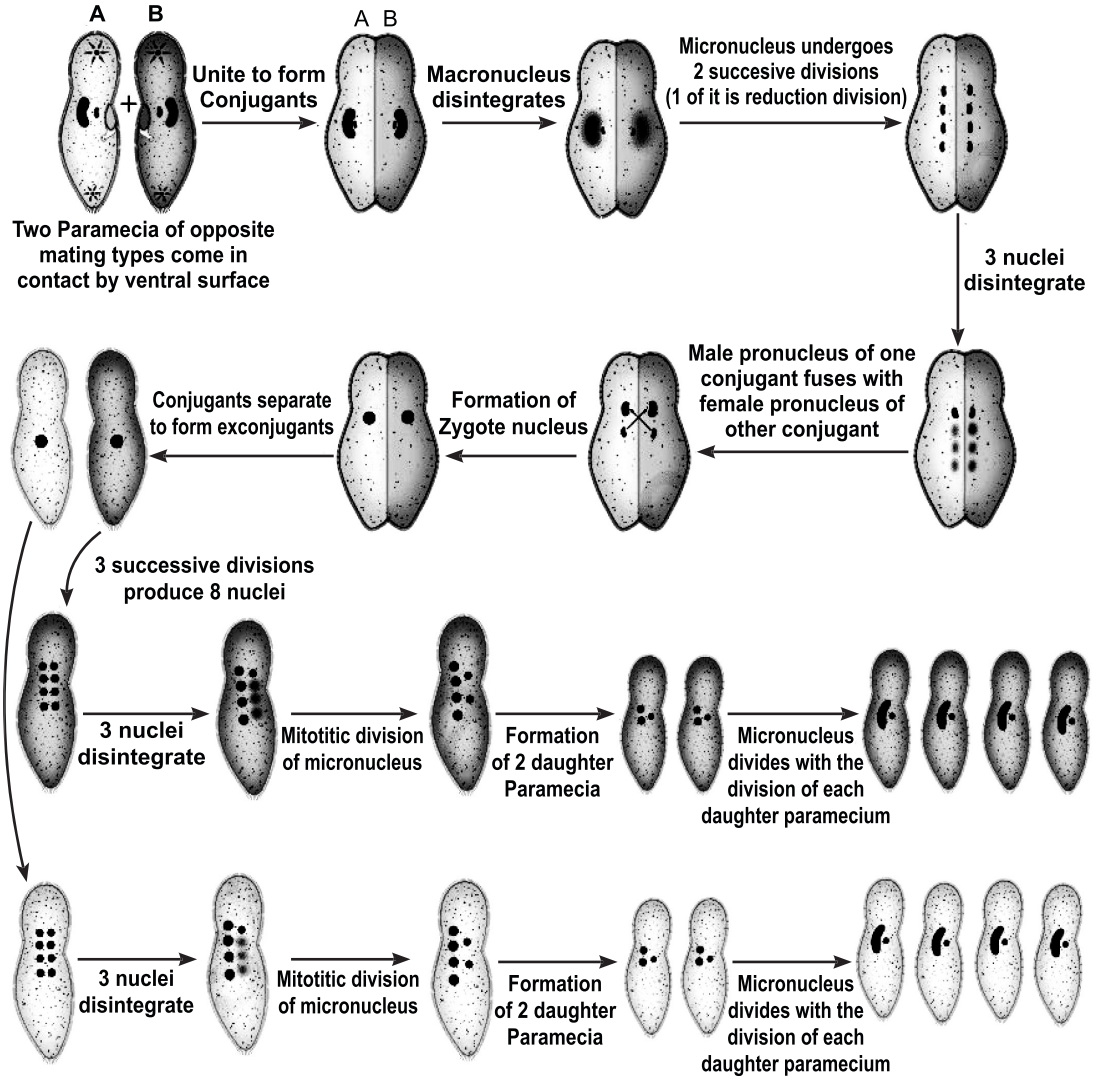
The new macronucleus, as also the micronucleus, have been made of new material.

These new nuclei probably contain new and different potential which is reflected in the healthy individuals.

1.6.2.1 Factors Inducing Conjugation :

The factors inducing conjugation vary from species to species.

1. Conjugation occurs usually under un-favourable living conditions; starvation or shortage of food and particular bacterial diet or certain chemicals are said to induce the process of conjugation in certain species of Paramecium.



STEP WISE REPRESENTATION OF CONJUGATION PROCESS IN PARAMECIUM

Figure-5 : **Conjugation process in Paramoecium sp**

2. Conjugation occurs after about 300 asexual generations of binary fission, or it alternates with binary fission at long intervals to rejuvenate the dying clone, i.e., it occurs in the individuals which must have passed through desirable number of asexual generations, said to be the period of immaturity, and then they become sexually mature to conjugate.

3. Conjugation occurs when there is a change in the physiological condition of paramecia, then it occurs between such individuals which are somewhat smaller in size (210 microns long) and they are at a stage which may be regarded as a period of unhealthy old age; the paramecia of this condition will die if not allowed to conjugate.

4. Sudden darkness in light conditions and low temperatures are said to induce the process of conjugation in some species.

5. Conjugation does not take place during night or darkness; it starts in early morning and continues till afternoon.

6. A proteinaceous substance in the cilia of mating type individuals is said to induce conjugation.

1.6.2.2 Significance of Conjugation :

A clone will die out if nuclear re-organisation does not occur, but the clone can be rejuvenated to regain its former vigour by nuclear rearrangement, this nuclear re-organisation is brought about by conjugation, thus, conjugation is essential for continued binary fission.

The significance of conjugation has been summarised below :

1. Conjugation serves as a process of rejuvenation and re-organisation by which the vitality of the race is restored. If conjugation does not occur for long periods, the paramecia weaken and die. (Woodruffs claim of keeping paramecia healthy for 22,000 generations without conjugation is disproved by Sonneborn, because he showed that all of Woodruffs paramecia belonged to the same mating type).

2. There is no distinction of sex in conjugants though only paramecia of two different mating types of the same variety will conjugate.

3. There is no distinction of sex, yet the active migratory pro-nucleus is regarded as male and the stationary pro-nucleus as the female.

4. Conjugation is only a temporary union, there is no fusion of cytoplasm and no zygote is produced, but the nucleus of each ex-conjugant contains hereditary material from two conjugating individuals.

5. Conjugation brings about replacement of the macronucleus with material from the synkaryon, this is an event of fundamental importance. In binary fission the chromosomes of the macronucleus were distributed at random to the daughter cells, continued binary fission had made the clone weak with some structural abnormalities.

6. Conjugation brings about the formation of the correct number of chromosomes in the macronucleus, so that the race is renewed in vigour. The role of the micronucleus is to restore a balanced chromosome and gene complex.

1.6.3 Automixis :

Automixis is the fusion of two gametic nuclei originating by the division of the single nucleus of an individual.

Automixis may be of the following types :

a. Autogamy :

The fusing nuclei come from the same cell as in Paramecium. All the steps in nuclear changes are similar to conjugation but the union occurs between the pronuclei of the same individual.

b. Paedogamy : (Figure-6)

The fusion occurs between two nuclei coming from two different cells of a parent. A single organism encysts and then divides into two or more gametocytes. The nuclei of these gametocytes undergo meiosis and the gametes thus produced unite in pairs forming the zygotes. Examples: Actinosphaerium, Actinophrys, myxosporidians, etc.

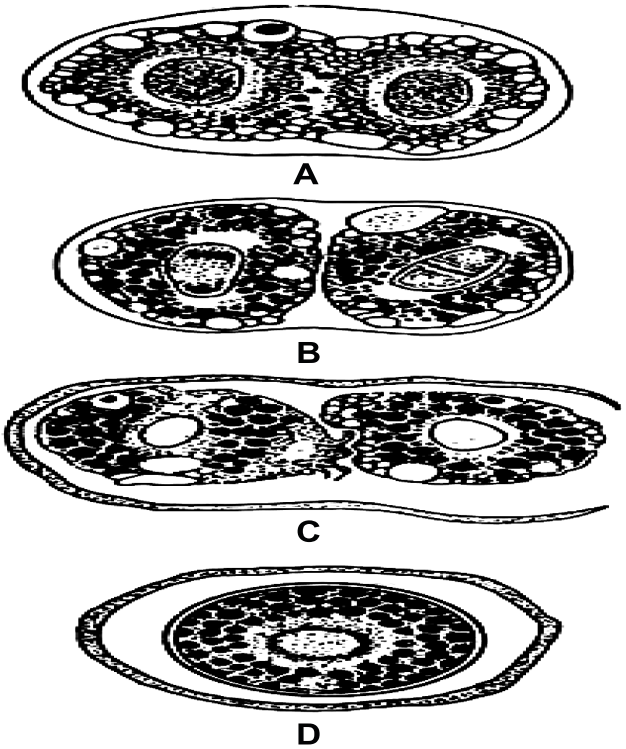


Figure-6 : **Paedogamy**

c. Cytogamy :

Cytogamy is said to be intermediate between conjugation and autogamy. In a number of species of *Paramoecium* the two individuals fuse with their oral surfaces. The nuclear changes occur as in conjugation but no nuclear exchange occurs. The two gametic nuclei in each individual fuse to form synkaryon.

d. Hemixis :

A reorganization process in various ciliated protozoans in which the macronucleus

breaks up and a new macronucleus is reconstituted from the fragments without accompanying micro nuclear changes compare endomixis.

1.6.4 Other modes of reproduction in Protozoa :

1. Plasmogamy :

Two or more individuals may fuse by their cytoplasm to form a plasmodium and separate out unchanged with their distinct nuclei. This sexual phenomenon is known as Plasmogamy and it occurs in certain Rhizopoda and Mycetozoa.

2. Regeneration :

The regeneration and replacement of lost parts among free-living and few parasitic protists is widespread. A proper proportion of cytoplasm and nucleus can regenerate into an entire individual.

3. Parthenogenesis :

The gametes which fail to fertilize start their further development parthenogenetically, i.e. development without fertilization , Examples: Actinophrys, etc.

1.7 Conclusion

Although protozoa includes only unicellular organism but some the organism like Paramoecium showed highly evolved functional attributes like reproduction,osmoregulation etc.Similarly locomotion in protozoa is another functional attributes which showed a complex mechanism.

1.8 Summary

Reproduction in protozoa is very complex and versetile in comparison to their body structure.

1.9 Glossary

Protista- A kingdom from six kingdom classification which contain only unicellular organism.

1.10 Further reading

Hyman, L.H (1965) The Invertebrates-Protozoa through ctenophora, McGraw Hill, NewYork.

Kotpal, R.L. (2012) Protozoa, Rastogi Publication, Merrut.

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1.11 Model Questions

Why conjugation in *Paramoecium* is considered as sexual reproduction ?
How many cell divisions occurs during the conjugation ?
What do you mean by syngen and mating type ?

Unit-2 ❑ Organization of canal system in Porifera and its function.

Structure

2.1 Objectives

This unit elaborates the mechanism of water circulation in the body of multicellular parazoon animals and how this canal system helps to transport different important materials within the body as well as from body to outside.

2.2 Introduction

The water circulatory system of sponges also called as canal system is the characteristic feature of the phylum Porifera. Canal system is also known as aquiferous system. The canal system of sponges helps in food acquisition, respiratory gas exchange and also in excretion.

2.3 Functions of the canal system

Water current plays the most vital role in the physiology of the sponges. The body wall of the sponges consists of two epitheloid layers the outer pinacoderm and the inner choanoderm. Pinacoderm consists of porocytes cells which bear openings called ostia. Choanoderm is composed of choanocytes or collar cells.

The choanocytes have collar of microvilli around the flagellum. The water current is caused by beating of flagella of the collar cells. The following are the functions of the water current which enters the body of the sponges through the canal system :

- All exchanges between sponge body and external medium are maintained by means of this current.
- Food and oxygen are brought into body through this water current.
- Also the excreta are taken out of the body with the help of this water current.
- The reproductive bodies are carried out and into the body of the sponges by the water current.

2.4 Types of canal systems

Different sponges have different arrangement and grades of complexity of internal channels and accordingly the canal system is been divided into the following three types :

2.4.1 Ascon type of canal system :

This canal system is the simples of all the three. It is found in asconoid type of sponges like Leucosolenia and also in some of the developmental stages of all the syconoid sponges.

The body surface of the asconoid type of sponges is pierced by a large number of minute openings called as incurrent pores or ostia. These pores are intracellular spaces within the tube like cells called porocytes.

These pores extend radially into mesenchyme and open directly into the spongocoel.

The spongocoel is the single largest spacious cavity in the body of the sponge. The spongocoel is lined by the flattened collar cells or choanocytes. Spongocoel opens outside through a narrow circular opening called as osculum located at the distal end and it is fringed with large monaxon spicules.

The surrounding sea water enters the canal system through the ostia. The flow of the water is maintained by the beating of the flagella of the collar cells. The rate of water flow is slow as the large spongocoel contains much water which cannot be pumped out through a single osculum.

Course of water current in Asconoid type canal system

Ingressing water ⟶ Ostia ⟶ Spongocoel ⟶ Osculum ⟶ Outside

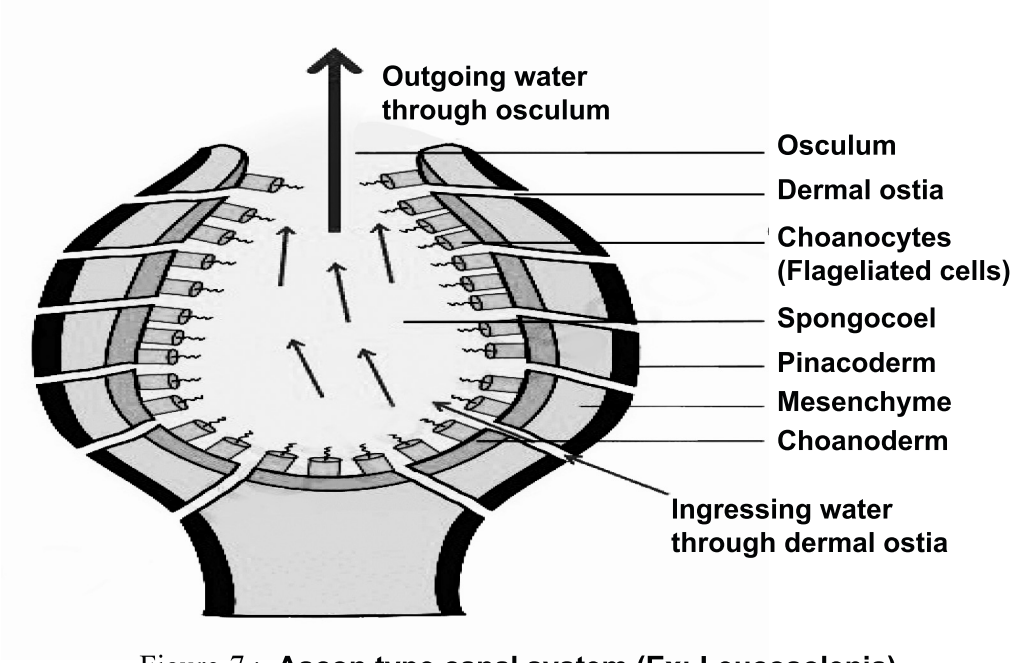


Figure-7 : **Ascon type canal system (Ex: Leucosolenia)**

2.4.2 Sycon type of canal system :

Sycon type of canal system is more complex compared to the ascon type. This type of canal system is the characteristic of syconoid sponges like Scypha.

Theoretically this canal system can be derived from asconoid type by horizontal folding of its walls. Also embryonic development of Scypha clearly shows the asconoid pattern being converted into syconoid pattern.

Body walls of syconoid sponges include two types of canals, the radial canals and the incurrent canals paralleling and alternating with each other.

Both these canals blindly end into the body wall but are interconnected by minute pores. Incurrent pores also known as dermal ostia are found on the outer surface of the body. These incurrent pores open into incurrent canals.

The incurrent canals are non-flagellated as they are lined by pinacocytes and not choanocytes. The incurrent canals leas into adjacent radial canals through the minute openings called prosopyles.

On the other hand radial canals are flagellated as they are lined by choanocytes. These canals open into the central spongocoel by internal ostia or apopyles.

In sycon type of canal system, spongocoel is a narrow, non-flagellated cavity lined by pinacocytes.

It opens to the exterior though an excurrent opening called osculum which is similar to that of the ascon type of canal system.

Course of water current in Syconoid type canal system

Ingressing water canal → Apopyles → Dermal ostia → Incurrent canal → Spongocoel → Osculum → Radial canals → Outside Prosopyles

Sycon canal system takes a more complex form in few species like Grantia, where the incurrent canals are irregular and branching forming large sub-dermal spaces. This is due to the development of cortex, involving pinacoderm and mesenchyme spreading over the entire outer surface of sponge.

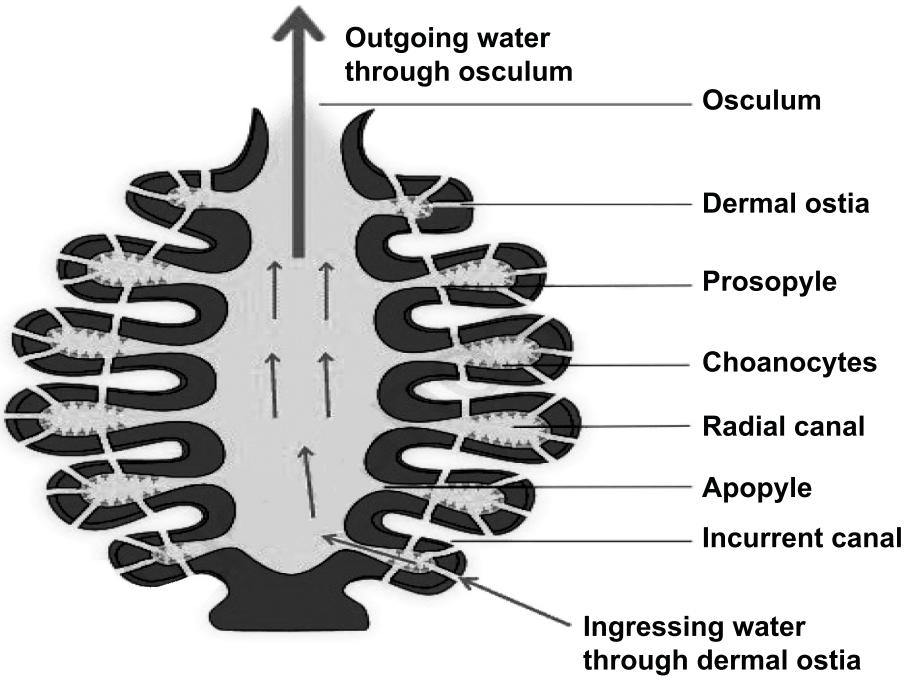


Figure-8 : **Sycon type canal system (Ex: Scypha)**

2.4.3 Leucon type of canal system :

This type of canal system results due to further folding of body wall of the sycon type of canal system. This canal system is the characteristic of the leuconoid type of sponges like Spongilla.

In this type the radial symmetry is lost due to the complexity of the canal system and this result in an irregular symmetry.

The flagellated chambers are small compared to that of the asconoid and syconoid type. These chambers are lined by choanocytes and are spherical in shape. All other spaces are lined by pinacocytes.

The incurrent canals open into flagellated chambers through prosopyles.

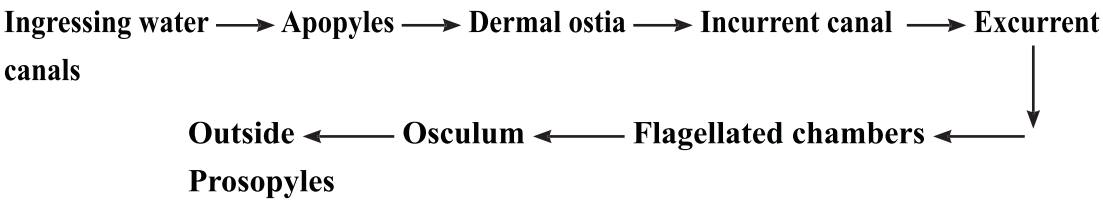
These flagellated chambers in turn communicate with the excurrent canals through apopyles.

The excurrent canals develop as a result of shrinkage and division of spongocoel.

The large and spacious spongocoel which is present in the asconoid and syconoid type of canal systems is absent here. Here the spongocoel is much reduced.

This excurrent canal finally communicates with the outside through the osculum.

Course of water current in Leuconoid type canal system



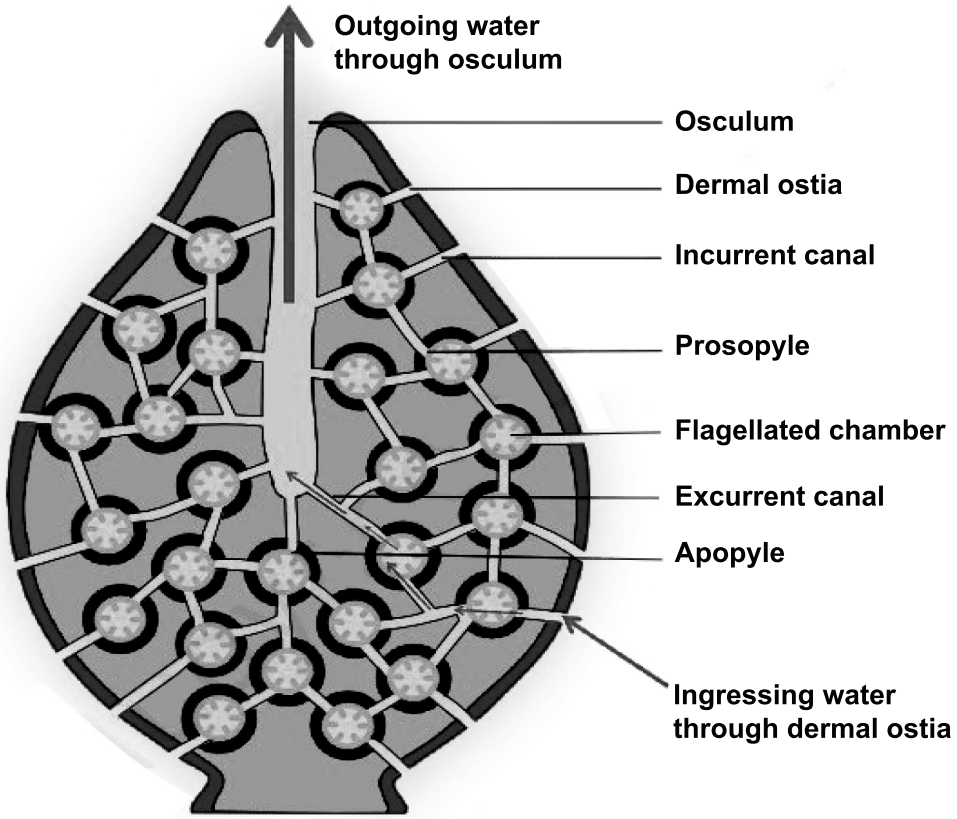


Figure-9 : **Leucon type canal system (Ex : Spongilla)**

Leucon type of canal system has the following three successive grades in its evolutionary pattern :

Eurypylous type :

This is the simplest and the most primitive type of leuconoid canal system. In this type the flagellated chambers directly communicate with the excurrent canal through broad apertures called the apopyles. Ex: *Plakina sp*

Aphodal type :

In this type of canal system the apopyles are drawn out as a narrow canal called aphodas.

This connects the flagellated chambers with the excurrent canals. Ex: *Geodia sp*

Diplodal type :

In some of the sponges, along with aphodas another narrow tube called prosodus is present between incurrent canal and flagellated chamber. This arrangement gives rise to diplodal type of canal system. Ex: *Spongilla sp*

1.4.4 Rgagon type system :

This type of canal system is found only in the larval form of Demospongae were the leuconoid canal system is originated. It is conical saped canal system and as a largest spongocoel.

2.5 Conclusion

1. The water circulatory system of sponges also called as canal system is the characteristic feature of the phylum Porifera.
2. The canal system of sponges helps in food acquisition, respiratory gas exchange and also in excretion.
3. The numerous perforations on the body surface of the sponges for ingression and egression of water current are the main constituents of the canal system.
4. Inside the body, the water current flows through a certain system of spaces where by the food is captured from the incoming water and the excretory material is sent out into the outgoing water.

2.6 Summary

The water circulatory system of sponges also called as canal system is the characteristic feature of the phylum Porifera. Canal system is also known as aquiferous system. The canal system of sponges helps in food acquisition, respiratory gas exchange and also in excretion. There are usually three types of canal system met within sponges, viz., asconoid type, syconoid type and leuconoid type.

2.7 Glossary

Dermal Ostia - Ostia is a pore present exteriorly on the body wall by which water enters inside first.

I**ncurrent Canal -** Incurrent Canal is the outer space present between two adjacent folds of the body wall here water comes after the entering from Ostia.

Prosopyle - Prosopyle is a pore that is helpful in the passing of water from Incurrent canal to the redial canal.

Radial Canal - Radial canal is a canal present on the body wall of the sponge which helps to collect water and release them into the spongocoel through apopyle.

Apopyle - It a pore-like structure that helps to pass the water from the redial canal to the spongocoel.

Spongocoel - Spongocoel is a hollow central portion of the sponge body which also helps the sponge in locomotion. It expelled water outside through the osculum.

Osculum - Osculum is the biggest pore on the body which releases water outside

2.8 Further reading

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2.9 Model Questions

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Unit-3 ❑ Polymorphism in Cnidaria; Biology of Coral reef formation.

Structure

3.1 Objective

This unit helps to understand the polymorphism because it occurs in biology in different forms lie Hydra . Obelia etc.It will also helps to learn how amongst the coelenterates, hydrozoans provide very good examples of polymorphism. It also helps to understand why this phenomenon is essentially for division of labour. Why division of labour is first seen in the cells of Hydra where the cells are specialized to perform different functions of individual as a whole.

In *Obelia* this specialization is earned still further. In it not only cells are specialized but individuals get specialized to perform different functions.

How the polyp performs different functions ?

The polyp performs vegetative function such as feeding, respiration, etc. and the free swimming medusae are reproductive nature.

3.2 Introduction

Polymorphism in biology occurs when two or more clearly different phenotypes exist in the same population of a species — in other words, the occurrence of more than one *form* or *morph*. In order to be classified as such, morphs must occupy the same habitat at the same time and belong to a panmictic population (one with random mating). Polymorphism is common in nature; it is related to biodiversity, genetic variation and adaptation; it usually functions to retain variety of form in a population living in a varied environment. The most common example is sexual dimorphism, which occurs in many organisms.

3.3 Cnidarian polymorphism

Some cnidarians are noted for their remarkable phenomenon of polymorphism.

This is associated with the division of labor.

Theoretically, members of Cnidaria have life cycles that alternate between two forms: Asexual *polyps* (generally sessile, with the body as a vase shaped form), which are nutritive in function; and sexual, free-swimming forms called *medusae* (singular medusa, the body in a bell-shaped form), which are reproductive in function.

In reality, not all cnidarians exhibit these two forms.

The Anthozoa (corals and sea anemones) live only as polyps and the Cubozoa (box jellyfish) live only as medusa.

Furthermore, the Scyphozoa (jellyfish) are mostly in the medusa form.

Most hydrozoans (Hydrozoa), such as *Obelia* and *Tubularia,* do show dimorphism.

But the siphonophores (an order of Hydrozoa) like *Physalia* exhibit the highest degree of polymorphism.

They have three kinds of polyploids (namely gastrozooids for nutrition, dactylozooids for defense, and gonozooids for the asexual production of medusae) and four types of medusoids (namely **pneumatophore** for floating, **nectophore** for swimming, **phyllozooid** for protection, and **gonophore** for bearing gonads).

3.4 Types of Cnidarian polymorphism

In case of Cnidarian polymorphism there are different types of polypoids and medusoids specialized for different functions. There are three types of polypoid and four types of medusoids individuals as given below :

A. Popypoid Zooids

1. Gastrozooids

The gastrozooids or the siphons are the nutritive or food-ingesting individuals of the colony. Each gastrozooid is a tubular or seccuLar structure with a large mouth. A single, long, contractile and hollow tentacle arises from the base of the gastrozooid. It bears numerous lateral contractile branches called the tentilla, each ending into a knob or coil of nematocytes.

2. Dactylozooids

These are the protective polyps of the colony and are variously known as palpons, tasters or feelers. Typically they resemble the gastrozooids except that they lack a mouth and their basal tentacle is unbranched. In Vallela and Porpita the dactylozooids arise from the margin of the colony in the form of long, hollow and tentacle-like fringing bodies called tentaculozooids. When associated with gonophores, the tentacle-like dactylozooids are known as gonopalpons. In Physalia the dactylozooids become excessively long.

3. Gonozooids

They are reproductive zooids which are also known as blastostyles. They are without mouth and tentacle. They reproduce asexually by budding and form medusae. In Vallela and Porpita, they resemble a gastrozooid and possess a mouth. Usually, the gonozooids take the form of branched stalks, called the gonodendra. These bear grape-like clusters of gonophores and are often provided with gonopalpons as in Physalia.

B. Medusoid Zooids

1. Swimming Bell

The swimming bells which are also known as nectocalyces, nectophores or nectozooids are medusoid form with a bell, velum, four radial canals and a ring canal. But these are devoid of mouth, manubrium, tentacles and sense organs. Its shape is variable and may be bilaterally symmetrical, prismatic, elongated or flattened. Due to well developed musculature, swimming bells act as excellent swimming organs and help in the locomotion of the colony.

2. Pneumatophores

The pneumatophores or the floats are bladder or vesicle-like structures filled with gas, and keep the colony floating. Each pneumatophore represents an inverted medusa bell, devoid of mesogloea and consisting of an external exumbrellar wall, pneumatocodon, and an internal subumbrellar wall, the pneumatosaccus or air-sac. The walls of both these are double-layered and are highly muscular. The space between the two walls is known as gastrovascular cavity.

3. Bracts

The bracts which are also known as the phyllozooids or hydrophyllia are thick, gelatinous and curved plates of mesogloea. These may be prism-like, leaf-like, shield-like or helmet like inappearance. They are unlike meduase and contain a simple or branched gastrovascular canal.

4. Gonophores

The gonophores or the reporductive medusoids occur singly on separate stalks or in clusters on polypoid gonozooids as in *Velella* or on simple or branched gonodendra. The gonophores may be medusa-like with bell, velum, radial canals and a manubrium bearing gonads. But the mouth, tentacles and sense organs are always absent. In number of hydrozoans e.g. *Physalia*, the female gonophores are medusa-like while the male ones are sac-like.

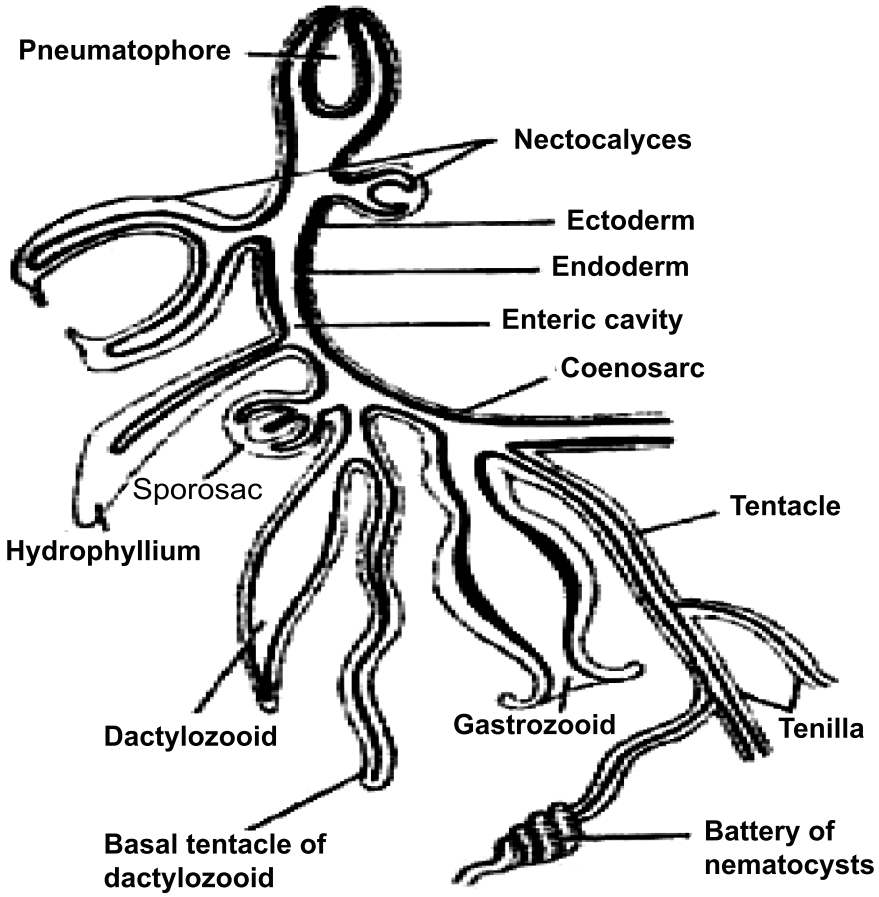


Figure-10 : **Structure of generalized Siphonophora**

3.5 Biology of Coral reef formation

What Are Corals?

Corals are related to sea anemones, and they all share the same simple structure, the polyp. The polyp is like a tin can open at just one end: the open end has a mouth surrounded by a ring of tentacles.

3.5.1 How are they formed?

Individual coral polyps within a reef are typically very small—usually less than half an inch (or ~1.5 cm) in diameter.

The largest polyps are found in mushroom corals, which can be more than 5 inches across. But because corals are colonial, the size of a colony can be much larger: big mounds can be the size of a small car, and a single branching colony can cover an entire reef.

Coral reefs are formed when the freely moving larvae of corals attach themselves to sedimentary rocks or hard surfaces near the coastlines. This process is undertaken with the help of several other processes like sedimentation, compaction, cementation and solidification of the skeletons of coral polyps.

Reefs, which are usually made up of many colonies, are much bigger still.

The largest coral reef is the Great Barrier Reef, which spans 1,600 miles (2,600 km) off the east coast of Australia. It is so large that it can be seen from space.

3.5.2 Type of Coral?

The more common corals include hydrocorals, octocorals (polyps with eight tentacles), and scleractinian corals (polyps with six, or multiples of six, tentacles).

1. Hydrocorals.

The hydrocorals include the fire corals (genus Millepora). Millepora is common on shallow, tropical–subtropical reefs in the Caribbean and the Pacific. Hydrocorals have a life cycle of alternating sexual and asexual generations known as metagenesis. The hydroid asexual generation attaches itself to the reef and produces a medusa offspring by budding. The medusa generation sends eggs and sperm into the water, and the product of this union, a free-swimming larva, settles on the bottom and grows into a new hydroid coral. The upward growth for Millepora is about 1 centimeter (2.5 inches) annually.

2. Octocorals.

Octocorals include sea fans, plumes, mats, and rods. They are flexible and sway to and fro in the waves. The octocoral skeleton is a matrix of limestone structures called spicules and an organic connective material. Spicules provide strength like bones, and the connective material holds the spicules together.

3. Scleractinian Corals.

The scleractinian corals have many growth forms: branching, hemispheres, columns, sheets, mushrooms, and tubes. Because of the strength and persistence of their limestone skeletons, these corals are the principal reef architects.

Reproduction in the scleractinian corals is either by broadcasting eggs and sperm into the water or by internal fertilization and brooding of larva.

Branching corals have relatively rapid growth (15 centimeters, or 6 inches, per year).

The builder corals grow 1.2 to 2.5 centimeters (0.5 to 1 inch) per year.

Branching corals are more fragile, often breaking during storms and generating fragments that in turn can grow into new coral colonies. Boulder corals generally do not fragment.

3.5.3 Type of Coral reef

• **Fringing reefs :** reefs that grow close to the shore and extend out into the sea like a submerged platform. Eg- Ningaloo Reef(Australia)

• **Barrier reef :** reefs separated from the land by wide expanses of water and follow the coastline. Eg- Great Barrier reef of Australia

• **Atolls:** a roughly circular ring of reefs surrounding a lagoon, a low lying island. They are common in the Indian and South pacific oceans.eg- Atolls of Lakshadweep

• **Patch reefs :** They are small, isolated reefs that grow up from the open bottom of the island platform or continental shelf. They usually occur between fringing reefs and barrier reefs. They vary greatly in size, and they rarely reach the surface of the water.

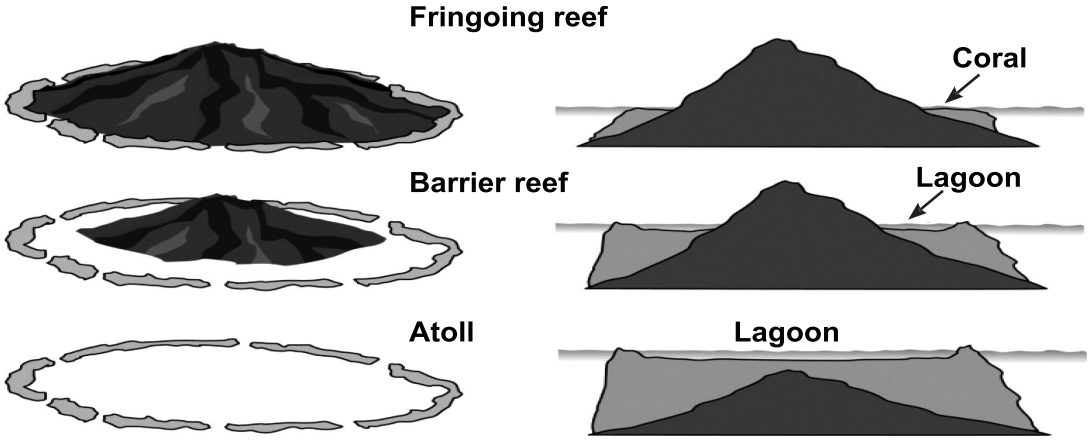


Figure-11

3.5.4 What are the ideal environmental conditions for corals to grow?

1. Shallow water

Coral reefs need to grow in shallow parts of the water. The surface of the reef shouldn't be more than 80m from the water surface. The Zooxanthellae need adequate sunlight for their photosynthesis processes.

2. Semi-hard or hard surface

The semi-hard or hard surface is a precondition for compaction, cementation and solidification of the coral polyps skeletons.

3. Clear water

The beautiful coral polyps perish in areas filled with sediment-filled waters. Moreover, they cease to exist in opaque waters. This is because the presence of sediments and opaque water limits the passage of sunlight to the algae that sustains their life.

4. Warm water

Coral reefs are directly connected with the warm oceanic waters. The temperature of the water must be around 20 degrees. Hence, coral reefs generally prevail on the eastern coasts of continents. However, this is not true in the case of India as the eastern waters are filled with high amounts of sediment matter.

5. Saline-filled waters

The slight salt in ocean waters is extremely important for the development of coral polyps. The polyps extract calcium from the waters to protect their skeletons. Hence, mild salinity is a necessity for coral reefs to flourish.

6. Rich supply of nutrients

Coral reefs flourish in sea waters because ocean waves support the constant supply of rich nutrients. Coral polyps multiply faster when supplied with nutrients.

3.5.5 Why is the survival of corals and coral reefs important to human and marine life?

Corals are important to marine life because of the following reasons :

1. The health of the marine ecosystem is dependent on corals.

2. They support a wide range of ecosystems and hence, are called the rainforests of the ocean.

3. Corals provide a place to live for a huge variety of fish.

4. Corals are a primary source of food in the marine ecosystem.

Coral reefs also have a somewhat similar significance which are :

1. Coastal protection

Coral reefs act as a barrier and protect the coastal areas from strong ocean currents and waves.

They provide protection from ocean storms and cyclones. With the increasing amount of cyclones in India due to climate change, these natural barriers have become excessively important.

2. Food source

Fish that live in and around coral reefs are a healthy source of protein for billions of people, mainly living on coastlines. Some fishing industries are entirely dependent on the coral reefs and the wildlife that it attracts.

3. Medicinal properties

Coral reefs are said to be the medicine chests of the sea. Some fish that the corals attract, leave behind some chemical compounds that are similar to the ones used in human hospitals.

4. Meteorology

A new study by the Indian Institute of Meteorology has stated that corals along the north-western coast provided insights on the patterns of the onset and withdrawal of Indian monsoons.

5. Tourism

Most of the gross national product of countries with coral reef industries comes from the tourism sector due to these beautiful corals. A study had estimated that the value of coral reefs was $ 10 billion and the direct economic benefits were approximately $ 360 million per year.

3.5.6 What are the threats that push corals to the brink of extinction?

Coral reefs are facing a large number of threats, directly or indirectly, by human actions.

Scientists believe that all coral reefs will face threats by 2050, 75% of them facing high-risk threats. Some of these threats are :

1. Global warming

Due to global warming, the waters are getting more acidic and posing threats to the coral ecosystem. Moreover, the glaciers across the world are melting due to which sea levels are rising. Rising sea levels lead to the coral reefs drowning and not getting enough sunlight which leads to their slow growth.

2. Coral Bleaching

Coral bleaching takes place when the oceans get warmer. Since corals have a narrow temperature tolerance, they get stressed and release a symbiotic algae in response. When they run out of the algae, they run out of their life source and hence, cease to exist.

3. Marine pollution

Marine pollution in the form of plastic pollution and other activities has led to the corals being suffocated. Coral reefs need air and space to breathe. With the rising levels of sea pollution, we might lose them sooner than we thought.

4. Stronger storms and ocean acidification

The upsurge of stronger storms has led to oceanic waves that break and damage the coral reefs. They might even break colonies and make them unsafe for living. As the sea absorbs more and more CO2, the pH levels continue to increase. High pH levels lead to weaker coral skeletons, their vulnerability to diseases and destruction by storms.

5. Ozone depletion

Coral polyps have in-built UV rays protection. However, now that the radiation is increasing, the corals in shallow waters can get damaged and destroyed.

3.6 Conclusion

Polymorphism is the phenomenon of occurrence of the same species of the organism in more than one form with different functions. Polymorphism is a Greek word, polys meaning many and morphe meaning form.This occurrence of polymorphism guarantees well-organized division of labor between several individuals. In coelenterates different individuals get united in the form of a colony and hence polymorphism is a very important feature of this Cnodarian phylum. Class hydrozoa is the best example of polymorphism.

Corals are related to sea anemones, and they all share the same simple structure, the polyp. Corals differ from sea anemones in their production of a mineral skeleton.

3.7 Summary

Polymorphism means many forms of an animal whichhh actually exist due to the division of labour.

The maximum degree of polymorphism is found in Cnidaria which helps these animals to survive in the unstaable marine environment.

Corals are related to sea anemones, and they all share the same simple structure, the polyp.

There are several types of corals like true stony corals, which compose most tropical reefs, each polyp sits in a cup made of calcium carbonate.

Stony corals are the most important reef builders, but **organpipe corals**, **precious red corals**, and **blue corals** also have stony skeletons.

There are also corals that use more flexible materials or tiny stiff rods to build their skeletons the seafans and sea rods, the rubbery soft corals, and the black corals.

3.8 Glossary

Corals- These are invertebrate animals belonging to a large group of colourful and fascinating animals called Cnidaria

3.9 Further reading

Hyman,L.H. (1946) The Invertebrates, Protozoa through ctenophora,McGraw Hill, London

3.10 Model questions

Describe the mechanism of coral reef formation ?
How many types of reefs are fromed ?
Mention the important environmental condition needed for reef formation.

Unit-4 ❑ Osmo-regulatory system in Protozoa and Evolution of excretory system in Helminth, Annelida and Arthropoda.

Structure

4.1 Objective

Osmoregulation is the process by which all cells establish their water and salt balance keeping the cell's cytosol slightly hypertonic or isotonic to its external environment. In this unit students will learn how protozoans are able to regulate tthheir water and salt balance in different conditions.

4.2 Introduction

Contractile vacuole performs the function of osmoregulation by removing excess of water content from the body. In addition to its water regulatory function, the contractile vacuole is also believed to be excretory in function.

Protozoa living in fresh water are subjected to a hypotonic environment. Water flows across their plasma membrane since their cytosol is always hypertonic to the environment. Many wall-less protozoa have an organelle, the **contractile vacuole complex (CVC),** that collects and expels excess water maintaining the osmoregulation in protozoa.

However marine and parasitic protozoa do not have any contractile vacuole.

4.3 Mechanism of Osmoregulation by contractile vacuole in Protozoa

The contractile vacuoles are usually large, colourless, pulsatile fluid-filled organelles found in majority of protozoans.

These vacuoles are nearly always found in freshwater Flagellata, Sarcodina and Ciliata.

The contractile vacuoles are also found in some marine ciliates but these are not at all found in parasitic protozoans.

The contractile vacuoles are found in their simplest form in Sarcodina like Amoeba.

In this case, these are usually spherical vesicles or sometimes irregular and bounded by a limiting membrane.

These vacuoles are found surrounded by a circlet of mitochondria which provide energy for their pulsating activity.

In Flagellate like Euglena, the contractile vacuole is somewhat complicated and surrounded by a large number of accessory contractile vacuoles.

In Ciliata like Paramecium, the contractile vacuoles are much complicated and found surrounded by 5 to 12 radiating canals or feeding canals which collect water from the various parts of the body.

The number of radiating canals varies in different ciliates. The radiating canals discharge their contents in the main contractile vacuole, thus, serving as feeders.

The number of contractile vacuoles varies in the different groups of Protozoa but its number remains constant, in the same species.

However, it is single in Amoeba, single in Euglena, two in Paramecium but these are many in Radiolaria and Heliozoa.

Contractile vacuole is an empty space filled with fluid. Electron microscopic studies have revealed that its limiting membrane is lipoprotein in nature, like that of the plasma membrane.

The mode of working of contractile vacuole includes two steps, the diastole and the systole.

The diastole is the phase of enlargement of the contractile vacuole to its maximum size and systole is the phase of its contraction to expel its contents.

A contractile vacuole is usually formed by the fusion of a large number of very small droplets in the area where contractile vacuole is to be formed (Amoeba) or around the mitochondria contractile vacuole (Euglena).

The systole occurs by the sudden burst of the contractile vacuole in Sarcodina but in Flagellata like Euglena, it empties in reservoir and so is the case with other forms. As referred, the energy required for the working of contractile vacuole is furnished by the mitochondria surrounding the vacuole.

4.3.1 Theories regarding the exact mechanism of working of contractile vacuole

1. Osmotic theory :

This theory explains that the water from the surrounding cytoplasm enters into the contractile vacuole by osmosis.

2. Filtration theory :

This theory explains that the water from the cytoplasm is forced into the contractile vacuole through its membrane due Fig- to internal hydrostatic pressure. Kitching has, however, contradicted this theory.

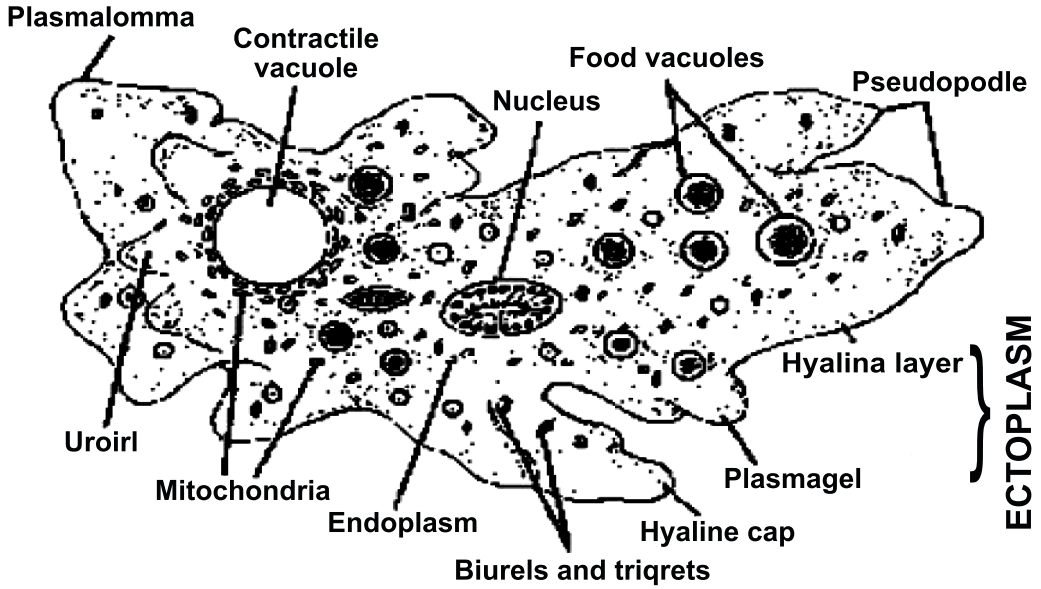
3. Secretion theory :

This theory states that the water is actively secreted into the vacuole during diastole through the vacuole wall. This theory, too, is not widely accepted.

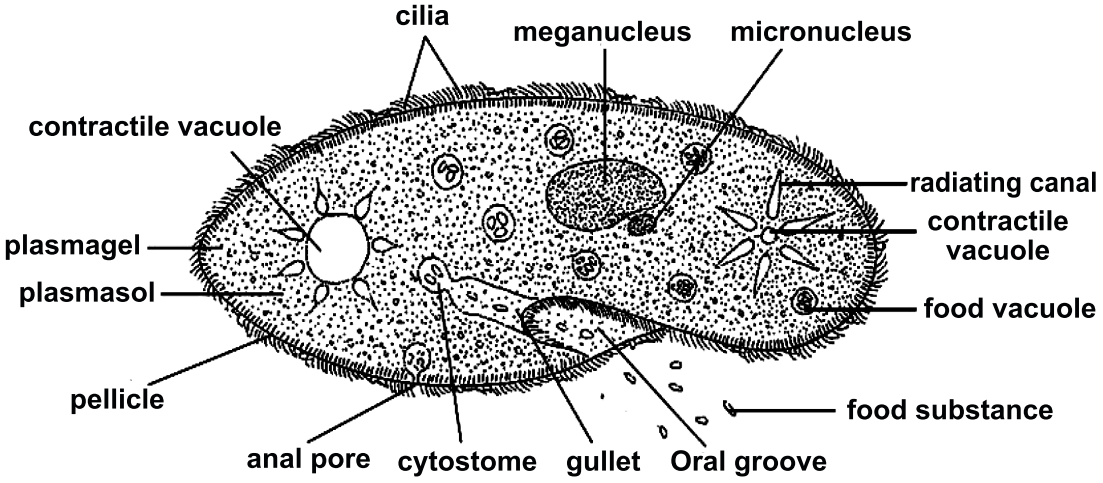
4.3.2 Structure of contractile vacuole

When examining a protozoan under a microscope, the Contractile Vacuole appears to be a clear, roomy, spherical, membrane-bounded, water-filled cell organelle within the cell. If you keep an eye on the contractile vacuole, you will notice repetitive phases of collecting water (expansion) and releasing water (contraction) every few seconds, depending on the species and the osmolarity of the environment.

In comparison to other protozoans, Paramecium has a highly sophisticated and advanced contractile vacuole. On the contractile vacuole, you will also find different tubules, canals, and accessory vacuoles, all of which work together to maintain osmoregulation. Depending on the species, the cell may have one, two, or many contractile vacuoles.



Figer-12 : **Contractile vacuole in Amoeba**



Figer-13 : **Contractile vacuole in Paramoecium**

4.4 Evolution of excretory system in Helminth, Annelida and Arthropoda.

4.4.1 Excretory system in Flat worm or Platyhelmintes

The excretory system removes waste products and excess water from tissues of flatworms.

Flatworms have a surprisingly elaborate system to rid the body of wastes.

This network runs the length of the animal on each side and opens to the outside through small pores in the posterior region of the body. Connected to the tubes are tiny cells that move wastes and water from the tissues into the tubes. These cells contain flagella that beat back and forth, creating a current of fluid that constantly moves toward the excretory pores.

Under a microscope the flagellar movement looks like a flickering fire, and the structure is called a **flame bulb**.

Osmoregulation in flatworms has not been demonstrated conclusively, but is thought to take place in the protonephridia.

There are two types of protonephridia described from flatworms,

1. A single-cell type (composed of a blindly ending tube of cytoplasm) and

2. A two-cell type (composed of a terminal cell that interdigitates with a proximal tubule cell).

Numerous structures associated with the protonephridium have been used to study phylogenetic relationships among the flatworms. Following are the structures fond in different flat worms :

The Catenulida are the only flatworms that have an unpaired protonephridial system and a unique terminal cell type.

The Macrostomida and the Proseriata have a two-cell protonephridium with processes from the terminal cell external to those of the proximal tubule cell.

The Prolecithophora, Lecithoepitheliata, Typhloplanoida, Kalyptorhyncha, Dalyellioida, Temnocephala, and Tricladida have a single-cell protonephridium.

The Neodermata also have a two-cell protonephridium, but the processes from the terminal cell are internal to those of the proximal tubule cell.

Based on protonephridial characteristics, the Neodermata appear to be more closely related to the Macrostomida and the Proseriata than to the Rhabdocoela and the Lecithoepitheliata.

4.4.2 Excretory system in Round worm or Nematohelminthes

Nematodes excrete wastes in the form of ammonium, which diffuses through the body wall.

The excretory system is not well developed in nematodes. The excretory pore is located in midventral line close to the nerve ring.

The excretory system in nematodes are two types :

A. Glandular type :-

The glandular type consist of a single specialized cell known as renette cell (a specialized excretory cell of nematode). It has posteriorly located enlarged gland known as excretory gland o ventral gland. This gland is connected to the excretory pore by a duct that terminates in a pouch like structure known as ampulla.

This type found in members of the class Adenophorea.

B. Tubular / canalicular type :-

It consists of four cuticularised canals. Two anterior and two posterior. A pouch like structure in the middle which connects both the lateral canals known as excretory pore. This type found in members of the class Secrenentea.

The excretory system lacks flame cells and protonephrids.

A few Nematodes lack any excretion system.

Osmoregulation, ionic regulation and, perhaps, the excretion of other wastes, are generally associated with particular specialized structures:

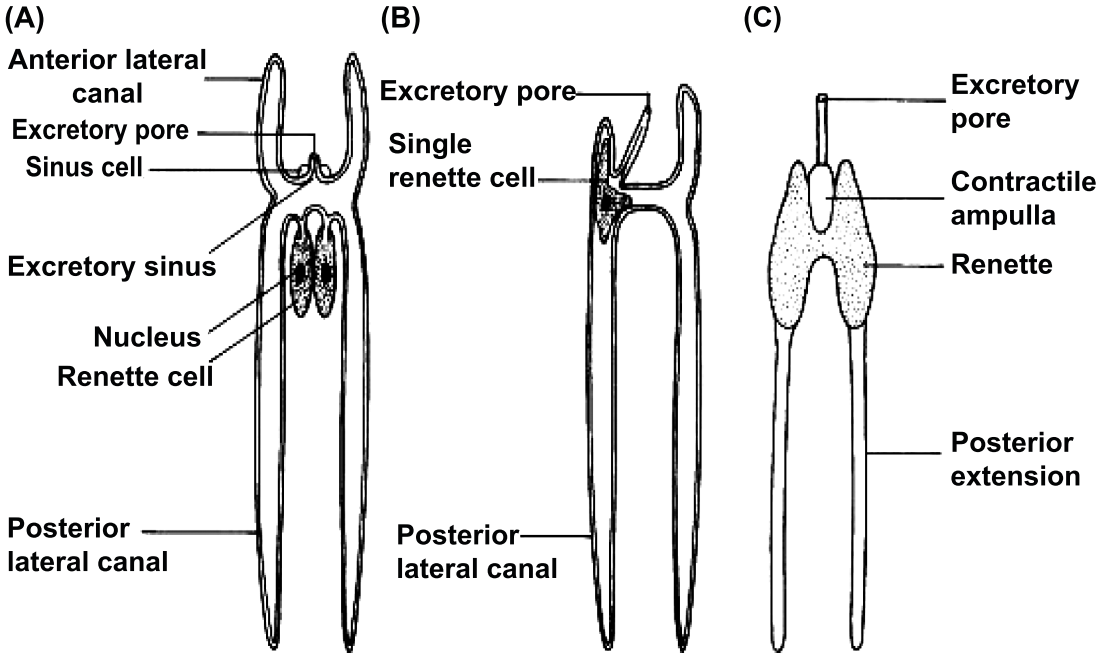
1. An excretory glandular cell or cells (ventral gland),

2. Excretory canal system (aquifer ducts), or both.

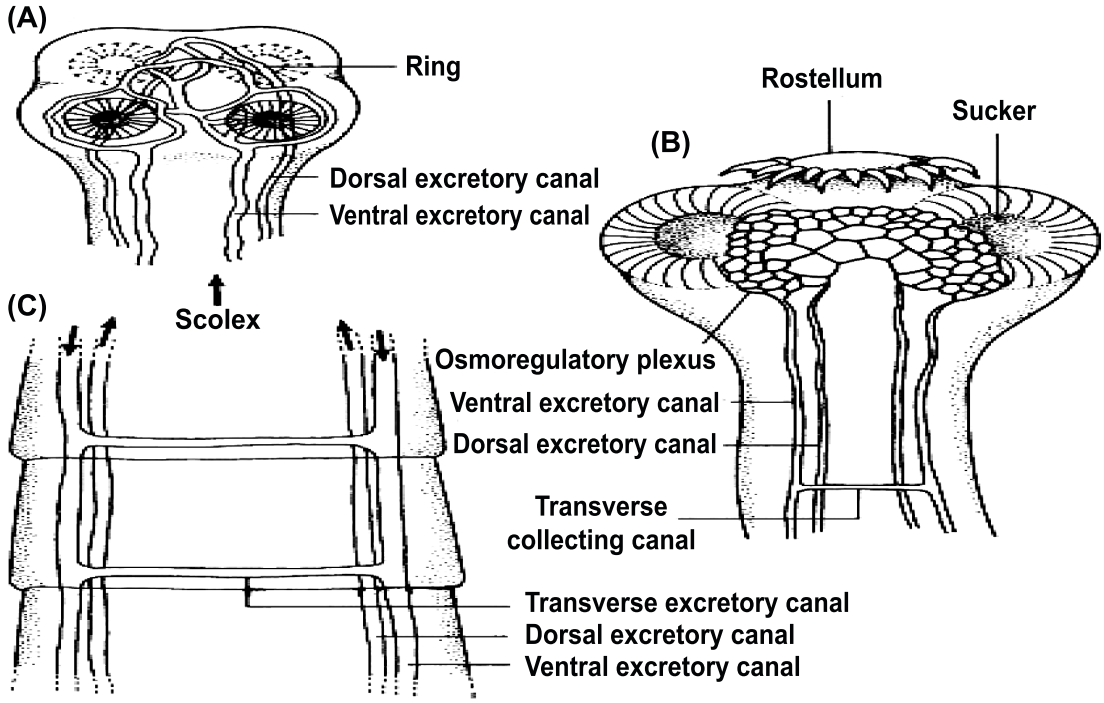
These systems appear only in Nematodes and within the group constitute the most developed organs. In both cases it deals with unicellular formations. When both the canal system and the glands are present, they share the same pore outwards.

The excretory glandular cell is large, is located at the level of the union of the pharynx with the middle intestine, protrudes into the pseudocele and has a neck-shaped duct that empties halfway into a pore. Its excretory role is uncertain, other functions have been suggested, such as secretion of gelatinous matrix around the eggs, secretion of a cover of glycoproteins on the cuticle and production of exoenzymes to initiate the digestion of host tissues.

The excretory organ of the ventral gland type is especially found in free-living forms, so marine nematodes usually have a simple sacciform excretory cell with its neck open towards the excretory pore.



Figer-14 : **Excretory system or Osmoregulatory system in Nematodes**



Figer-15 : **Excretory system or Osmoregulatory system in Flat worm**

4.4.3 Excretory or Osmo regulatory System in Annelida

In the more primitive annelids, the nephridia and coelomoducts are separate.

In many Polychaeta coelomoducts are grafted over nephridia forming a nephromixium.

The nephromixium naturally functions both as a genital duct and an excretory organ.

In Glycera and Phyllodoce etc., the coelomoduct is fused with the duct of the protonephridium forming protonephromixium.

When the nephridium is a metanephridium, the funnel of the coelomoduct may be grafted to the nephrostome itself forming metanephromixium as in Hesione.

In some the nephrostome of the metanephridium may be replaced by the grafted coelomostome to form myxonephridium as in Syllis.

In other Polychaete the nephrostome is completely replaced and the double nature of myxonephridium can only be understood by study of its development.

The grafting of the coelomostome to the nephrostome may occur only in those segments in some polychaeta in which gonad develop.

In Arenicola all the nephridium is represented as myxonephridium.

A ciliated organ and protonephridia are found in each segment in Nephthys.

The ciliated funnel loses their primary function of conveying germ cells and are probably phagocytic.

All oligochaetes possess nephridia as well as coelomoducts. The two segmental organs are distinct and separate.

The tubule forming the metanephridia are often long, very much coiled having. distinct structural peculiarities in different regions. The tubules open to outside by a sphinctered nephridiopore.

The primitive condition of nephridial distribution is holonephric and meganephric, a single pair of large nephridium is found in each segment as in *Lumbricus* and *Megascolex.*

In *Pheretima* three types of variously modified numerous small meronephridia or micronephridia are found in different segments.

Three types of metanephridia present in *P. posthuma* are

1. Pharyngeal nephridia

2. Septal nephridia

3. Integumentary nephridia

The nephridia in leeches are simpler in structure.

In Hirudinea 17 pairs of nephridia are found in the segment 06 to22 one in each segment.

The first five segments lack nephridia.

11 pairs of nephridia located in segments 12 to 22 are associated with the testis sac and are called testicular nephridia.

The remaining 6 pair present are not associated with testicular sac hence called pre testicular nephridia.

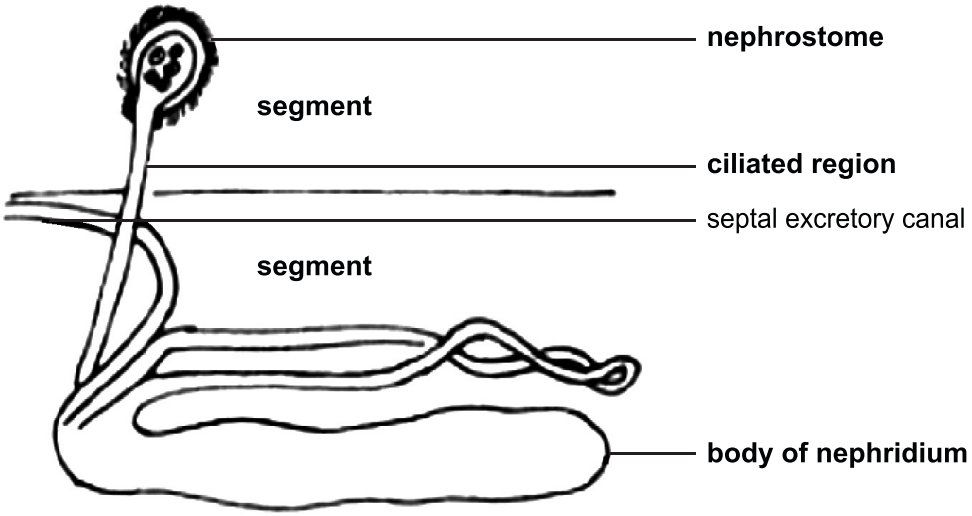


Figure-16 : **A nephridium of Earthworm**

4.4.4 Excretory organs in Arthropods

The are several types of excretory organs found in Arthropods which are :

Nephridia
Coxal Glands
Green Gland
Shell Glands
Malpighian Tubules
Hepatopancreas
Fat Body
Exoskeleton
Intestinal Caeca
Midgut Epithelium
Pericardial Cells
Nephrocytes
Oenocytes.

Nephridia :

These are present in the *Peripatus* and are situated on the lateral side of the segmented body cavity.

Numbers of these paired organs correspond to the number of the segments of the trunk.

Each nephridium consists of a terminal vesicle which opens to the exterior through one end and remains connected to a coiled loop with the other.

This loop is known as nephridial canal and it opens inside the body cavity. Its internal lining is ciliated.

Coxal Glands :

These glands are present only in Arachnida and their structures and positions vary.

Each coxal gland consists of convoluted tubules, called labyrinth and a sac called labyrinth sac.

It opens externally by a short tube.

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 found in Malacostraca (excepting Isopods) and larval forms of all Crustaceans, especially in Entomostracan larvae. It is present in the proximal segment of the second antenna or adjoining regions of the head. Each gland has three parts—end sac, labyrinth and bladder. The labyrinth is the proper excretory gland.

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.

5. Malpighian 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.

In Insecta these develop from the undifferentiated region between the midgut and hindgut and the number varies from 2 to 150.

Malpighian tubules occur almost in all insects except in Collembola, some of the Thysanura and the Aphids.

The Malpighian tubules often occur in two's or multiples of two.

The Malpighian tubules are of 4 main types which are :

(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 and sometimes found the crystals when the insects are found in arid condition, e.g., Orthoptera, Dermoptera and Coleoptera.

(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 the insects when they live in the drier environments 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 are found in the Lepidoptera and this type is a combination of second and third types. Two to four pairs of tubules are found in Myriapods and Arachnids and in the later the tubules are endodermal in origin.

6. Hepatopancreas :

In Limulus, absorptive cells are present in the hepatopancreas.

These cells shed large amount of calcium phosphate as excretory product into the intestine through which it is eliminated along with faeces.

7. Fat Body :

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.

8. Exoskeleton :

In Crustaceans and Insects, the cells of the hypodermis secrete nitrogenous substances which remain diposited within the exoskeleton.

These are eliminated at the time of ecdysis.

9. Intestinal Caeca :

In Squilla, the rectum bears a pair of intestinal caeca having a comb-like internal wall. These are believed to be excretory in function.

10. Midgut Epithelium :

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

11. Pericardial Cells :

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

12. 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.

13. Oenocytes :

In Insects and Myriapods, certain cells are found in groups around the abdominal spiracles.

These cells originate from 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.

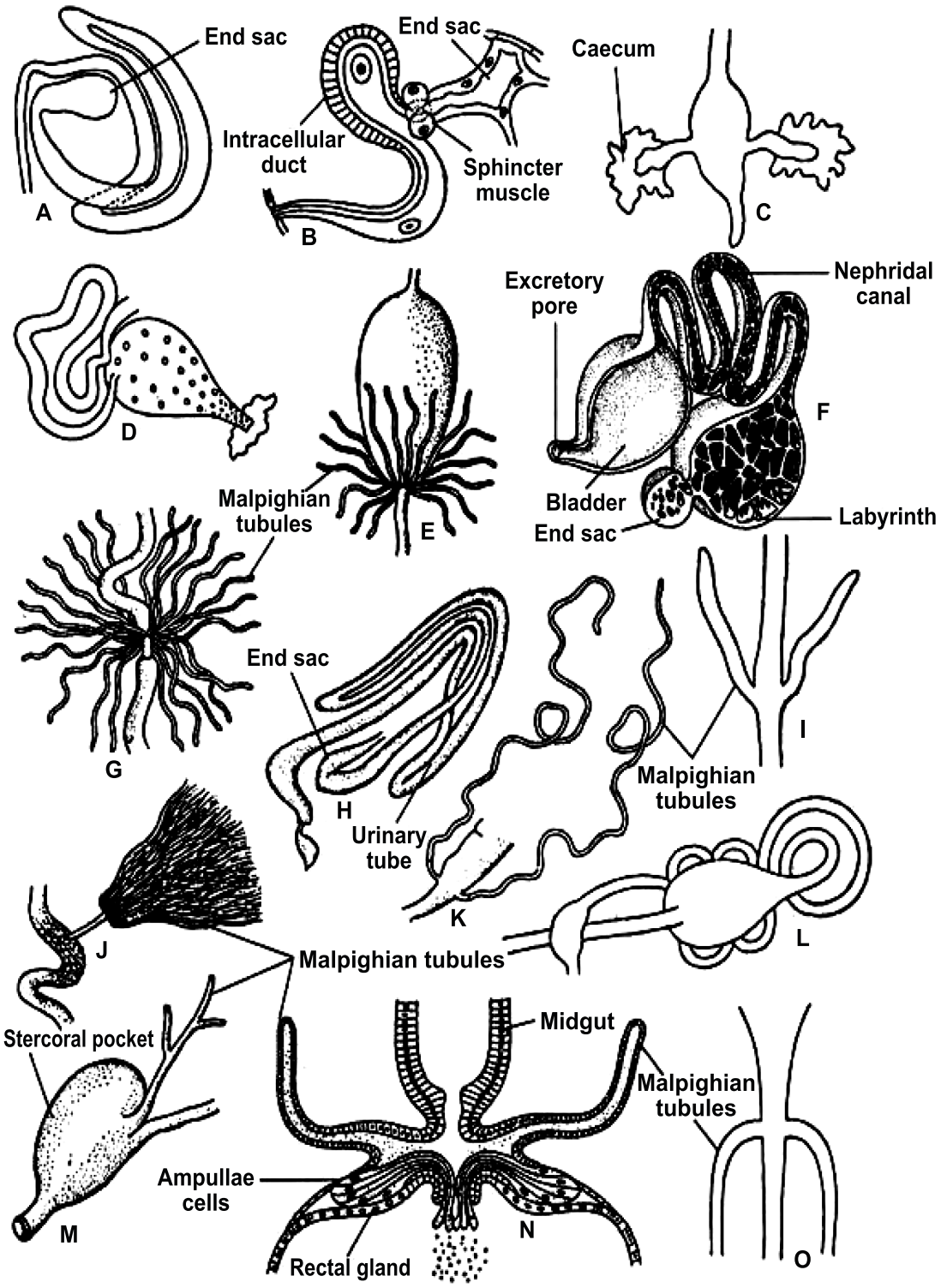


Figure-17 : Excretory organs of some Arthropods

A- Maxillary gland, **B-**Antennal gland**, C-** Intestinal caeca**, D-** Nehridium of Peripatus**, E-** Malpighian tubules**, F-** Green gland**, G-** Another type of Malpighian tubule **H-** Shell gland**, I** – Arachnid Malpighian tubule, **J-**Malpighian tubules of cricket **, K-** Malpighian tubules of Myriapod **, L-** Coxal gland , **M-** Malpighian tubule of Spider **N-** Junction of Malpighian tubule with intestine , **O-** Crustacean Malpighian tubule

4.6 Conclusion

Excretion is the process of removing waste products and toxic substances from the body. Osmo regulation refers to the process of maintaining constant osmotic pressure within the body fluids by keeping the water balance. Excretion allows an organism to rid itself of waste molecules that could be toxic if allowed to accumulate. It also allows the organism to keep the amount of water and dissolved solutes in balance.

4.7 Summary

Every organism should adopt well to its environment to perform its day to day functions without any problem or hurdles. Some needs to regulate their temperature while other needs to regulate their ionic balance.

Here we discuss about regulation of ions and water content in invertebrates which is known as osmoregualtion.

There are two major types of osmoregulators – Osmoconformers (most marine invertebrates) & Osmoregulators (most common in animal kingdom)

4.8 Glossary

Diffusion – it is a random movement of molecules along the concentration gradient from the region of high concentration to region of lower concentration.

Osmosis – in osmosis selective diffusion of solvent is driven by internal energy of solvent molecules. We can also say that osmosis is specialised case of diffusion that involve passive transport of solvent from its region of higher concentration to its region of lower concentration through a semipermeable membrane.

Osmotic pressure – it is define as pressure required to completely stop the entry of solvent of osmotically active solution.

Isotonic solution– when concentration of ion of cell is equals to concentration in external environment or in solution.

Hypotonic solution – when concentration of ion in cell is more than to concentration in external environment or in solution.

4.9 Further reading

Barrington, E.J.W(2012)-Invertebrate Structure and Function, East West Press Pvt. Ltd New Delhi.

4.10 Model Questions

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Unit-5 ❑ Locomotory organs in Invertebrates – Parapodia, Setae and Tube feet

Structure

5.1 Objectives

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5.2 Introduction

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5.3 Parapodia

Parapodia are primarily the organs of locomotion used both in creeping and in swimming. Since they are highly vascularised, they also serve the function of respiration.

Most species of polychaete annelids have paired, fleshy parapodia which are segmentally arranged along the body axis.

Parapodia vary greatly in size and form, reflecting a variety of functions, such as gas exchange, anchorage, protection and locomotion.

Parapodia in polychaetes can be uniramous (consisting of one lobe or ramus) but are usually biramous (two lobes or rami). In the latter case, the dorsal lobes are called notopodia and the ventral lobes neuropodia.

Both neuropodia and notopodia may possess a bundle of chaetae (neurochaetae and notochaetae respectively), which are highly specific and greatly diversified.

A single stout internal chaeta, called an acicula, may be present in each lobe, which are used to support well-developed parapodia.

Notopodia and neuropodia can also bear cirri which are tentacle-like projections of the parapodia.

In some groups, such as the scale worms (e.g. Polynoidae), the dorsal cirrus is modified into a scale (or elytra)

Polychaetes have several means of locomotion. When crawling slowly, they use the parapodia much like legs to propel themselves over their substrate

Thus, the parapodia have a dual function, the upper part being a respiratory organ, and the lower part a propulsive one. Muscles on either side of the body can contract out of phase, producing a rapid wiggling motion.

5.4 Setae

Setae are the main locomotor structures in oligochaetes, but as already seen, they are also piesent 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, while the swimming forms have characteristically long, forked or plumose setae.

5.5 The water vascular system in Ecinoidermata helps in loocomotion

The water vascular system (WVS) , one of the most distinctive characteristic of Echinodermata is a system of canals and appendages of the body wall that functions as a means of locomotion . Also known as the ambulacral system , it is derived entirely from the coelom and the canals are linked by ciliated epithelium and filled with watery fluid along with certain corpuscles .

The essential parts of the Water Vascular System are :-

The Madreporite

It is a hard rounded and calcareous plate lying on the aboral surface . It is situated in theinter radial position . The surface of the madreporite is provided with a number

of radiating grooves or furrows . The bottom of these furrows are perforated by minute pores , so that the whole plate looks like a sieve . Each pore leads into a pore – canal and all the pore canals merge into collecting canals . The collecting canals converge into a small bag – like ampulla beneath the madreporite . The ampulla opens into a stone canal.

Stone Canal

It is an S – shaped canal . The walls are strengthened by a series of calcareous rings and hence the name . Internally the stone canal is lined with cilia , the movement of which draws the sea water from outside into the canal . One end of the tube opens to the outside through the madreporite . The other ends opens into a ring canal . The lumen of the stone canal is occupied by a ridge with spirally coiled lamellae.

Ring Canal

It is a white pentagonal ring - vessel lying around the mouth.

Radial Canals

From its outer surface the ring cana gives off five radial canals , one entering each arm.

The radial canal runs upto the tip of the arm an ends in the terminal tentacles.

Tiedmann's bodies

The ring canal gives off inter radially from its inner surface 10 small yellowish rounded glandular bodies called Tiedmann's bodies. In Asterias only 9 Tiedmann's bodies occur, the position of the 10 th being occupied by the ston canal. They produce phagocytes.

Polian Vesticles

The ring canal bears on it's outer side five pear – shaped structures called polia vesicle. They are inter – radially arranged . These are thin walled bladders with long narrow necks. The polian vesicles serve as store houses for the fluid in the water vascular system.

Lateral Canals

Each radial canal gives off many paired lateral canals on both the sides, which lead to a tube foot or podium. Each canal is provided with a valve to prevent backward flow of fluid into the radial canal.

Tube feet

The tube – foot is a hollow elastic thin walked closed cylinder . It consists of an

upper sac – like ampulla , a middle tubular podium and a terminal disc – like sucker.

Muscle fibres are present in the walls of the ampulla and the podium . The tube feet are capable of greater extension an when extended they come out through the ambulacral grooves.

Locomotion :

1. Starfish exhibits creeping movement with the help of tube feet at a speed of 15 cm/min

2. The water vascular system sets up a hydraulic pressure mechanism which brings about the locomotion.

3. In the direction of movement , one or two arms are slightly raised from the substratum.

4. The ampulla of tube feet contract. The valves in the lateral canals close. The water flows into the podium. The hydraulic pressure within tub feet increases.

5. The tube feet elongate in the direction of movement .

6. The tube feet extend forward and adhere firmly to the substratum by the suckers .

7. After attachment , the tube feet assume a vertical posture by pulling the body forward .

8. The podia now contract . This causes the flow of water from the podia into the ampulla.

9. This results in the shortening of tube feet.

10. The suckers are released and the tube feet are raised and moved forward to repeat the process.

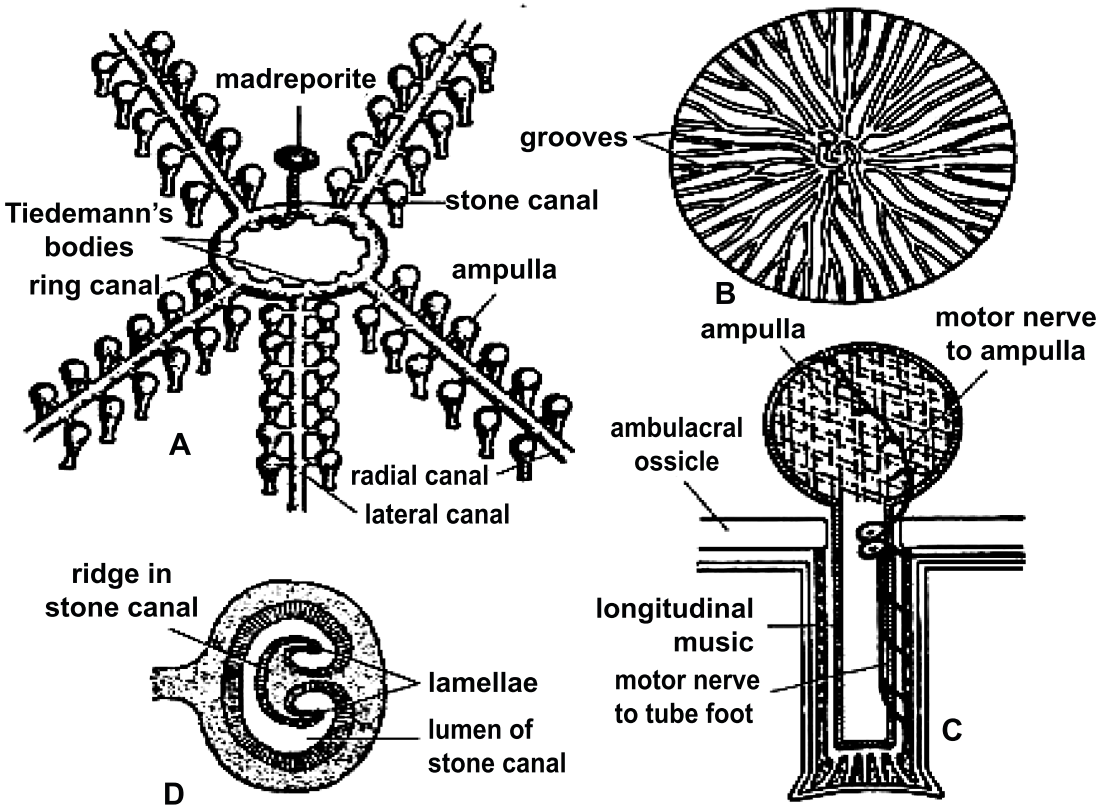

Figure : 18 : **A. Watervascular system in Echinoderm : B. Madreporite C. Tube foot D. Stone canal**

5.6 Conclusion

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5.7 Summary

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5.8 Glossary

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5.9 Further reading

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5.10 Model questions

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Unit - 6 ❑ Invertebrate Nervous system and Cephalization in Mollusca, Torsion and detorsion

Structure

6.1 Objective

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6.2 Introduction

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6.3 Invertebrate Nervous system and Cephalization in Mollusca

Invertebrate nervous systems are extremely diversified spanning from diffuse nerve nets (e.g., cnidarians) to tetra-neury (molluscs), ventral cords (e.g., annelids,

arthropods), nerve net-like in hemichordates, and do not resemble those of higher chordates that are organized around a dorsal "hollow tube".The more primitive Porifers (sponges) do not have a nervous system.

> In **Cnidaria,** there is a disordered network of neurons. And if a nerve pulse is triggered in one of them, it is transmitted to all cells that communicate with it through synapses, and from these to others, resulting in poorly elaborated responses - such as "pulsating" movements in living water when it's swimming. It is the most primitive type of nervous system, called Diffuse Nervous System.

In **Flatworm Worms** neurons associate together to form nerve threads attached to some structures - the nerve ganglia in the head. These ganglia already represent precarious nerve centers in coordinating body activities. In each ganglion there is a higher concentration of neurons.

The ganglionic nervous system begins to perfect in the annelids. In them, there is a larger conglomeration of neurons in the head, forming the cerebroid ganglia, which play a primitive brain role in commanding the other ganglia.

From the cerebroid ganglia arise the periesophageal ganglia, which relate to a double ventral ganglionic nerve chain. Along this chain there are a pair of ganglia for each body segment.

These ganglia also have marked autonomy over the specific activities of the surrounding body area.

In **Annelids** not withstanding the presence of cerebroid ganglia, the pairs of ganglia along the ventral nerve chain have a great deal of autonomy, so a worm, even after being cut in half, continues to move the two pieces apart.

The cerebroid ganglia are even more developed in arthropods, especially insects.

In bilateral symmetry invertebrates (Platelminths, Nematelmints, Annelids, Molluscs and Arthropods) the nervous system is in the ventral region of the body and is organized as one or more longitudinal nerve cords presenting two or more nerve ganglia, whether functioning as command centers along its length.

In the possessors of many nerve ganglia, those in the anterior region-cerebroid ganglia are more developed and function as a rudimentary brain that controls the other ganglia.

This type of nervous organization is called the **ganglionic nervous system.**

In **Mollusca** the nervous system is centralized and ganglionic, with three parts of nerve ganglia from which nerves go to different parts of the body. Sensory, visual, tactile, chemoreceptor and balance structures are present.

The cephalopods have a large cerebroid ganglion that resembles the brain of vertebrates.

In **gastropods** the nervous system consists of a set of ganglia and cords that are distributed throughout the body and innervate the different organs. The set of sensory organs comprises eyes, tentacles, asphradium and statocysts.The eyes, in the most primitive forms, are located at the ends of the tentacles and consist of simple depressions containing pigment and photoreceptor cells.

The parallel evolution of vertebrates and invertebrates has resulted in both many homologies and differences in their brain structures and functions.

The cephalopod nervous system is the most complex of any invertebrate nervous system.

The most advanced class among the invertebrates is the Cephalopoda, which possess the largest invertebrate nervous system.

Amongst the cephalopods, the octopus shows the highest cognitive abilities and a unique 'embodiment' comprising a flexible body and maneuverable arms with virtually infinite degrees of freedom.

The octopus has a relatively small central brain which integrates a huge amount of visual and tactile information from the large optic lobes and the peripheral nervous system (PNS) of the arms.

The cephalopods are a diverse class of highly derived mollusca. Although the morphological plan of the cephalopod nervous system derives from that of other molluscs, it shows much more centralization.

Cephalopods have the largest of all invertebrate nervous systems, with a brain weight-body weight ratio exceeding that of most fish and reptiles.

The cephalopod nervous system comprises a Central nervous system (CNS) and a Perihheral nervous system (PNS). The large PNS includes the nervous system of the body and of the arms. The CNS consists of the brain and the two optic lobes.

The brain is divided into a around 30–40 lobes interconnected by commissures and tracts.

The **octopus** central brain contains <"50 million neurons.

It integrates processed information from the huge visual system (<"120 million neurons) and controls the large, complex and highly autonomous PNS of the arms (<"300 million neurons).

The brain shows a high cognitive capacity and its vertical lobe is dedicated to learning and memory.

In the octopus, as far other cephalopod species, the 'brain' is assembled through a series of ganglia of molluscan origin to form lobes that are fused together into masses (for the common octopus).

6.4 Torsion and Detorsion in Gasttropoda

6.4.A Torsion

Torsion (twisting) is the rotation of visceral organs in anticlockwise direction through an angle of 180° on the rest of the body during larval development. The phenomenon takes place in the free-swimming (veliger) larva of gastropods and converts the symmetrical larva into an asymmetrical adult.

As the larva develops shell its visceral mass starts twisting in anticlockwise direction to rearrange the visceral organs so that they are accommodated inside the coils of the shell and openings of organs are shifted to the anterior side where the shell opening lies.

During torsion visceral and pallial organs change their position by twisting through 180°.

Posterior mantle cavity is brought to the front position.

Gills and kidney move from left to right side and in front which helps in breathing.

In nervous system the two pleurovisceral connectives cross themselves into a figure of 8, one passing above the intestine and the other below it.

Alimentary canal twists in the visceral mass and opens by anus on the side of the head on the anterior side.

After torsion the foot can be withdrawn after the head.

During torsion head and foot remain fixed and rotation takes place in the visceral mass only behind the neck so that the visceral organs of the right side come to occupy the left side and vice versa.

Before torsion the visceral mass points forward and the mantle cavity is posterior in position.

This position is called exogastric.

After torsion the position becomes endogastric in which visceral mass points backwards and intestine lies in the whorls of the shell and anus opens on the anterior side.

Ninety percent of the torsion is affected by the right retractor muscle which is quite prominent in the larva while the left retractor muscle is rudimentary.

Rest of the 10% of torsion is caused by the differential growth of the visceral mass.

Torsion takes place quickly and is completed from 15-30 minutes.

Anti clockwise rotation of the visceral mass causes dextral (right handed) coiling of the shell, which happens in majority of the cases.

However, rarely clockwise rotation of visceral mass also takes place, which causes sinistral (left handed) coiling of the shell.

The entire process of torsion generally takes only a few minutes.

During the completion of metamorphosis there is a lateral torsion subsequent to primitive ventral plexus with the result that the original coil of the visceral sac and the shell which was originally dorsal or exogastric becomes ventral or endogastric.

So the lateral torsion leads to the attainment of condition of gastropods following certain changes in original organisation.

6.4.A.1 Effect of Torsion and Shutting of Pallial Complex :

1. Displacement of mantle cavity :

The mantle cavity was originally posterior in position but after torsion the mantle cavity opens just behind the head and its associated parts shifted forward.

2. Changes in relative position :

Before torsion the anus and ctenidia are pointed backwards and auricles are situated behind the ventricle. After torsion the anus and ctenidia come forward and the auricles come to lie in front of ventricle.

3. Twisting of alimentary canal :

The alimentary canal which was primarily straight is twisted in the form of a loop and approximation of mouth and anus takes place.

4. Origin of chiastoneury :

Crossing of the pleuro-visceral connectives is due to the fact that the pallial complex must have changed its position from the posterior to the anterior part of the body arid become twisted in the form of 8. The right connective with its parietal ganglion passes over the intestine called the supraintestinal and the left connective passes below the intestine called the infraintestinal.

5. Endogastric coil :

The coil of visceral sac which was primarily dorsal or exogastric becomes ventral or endogastric after torsion. The coiling of the shell is not associated with the torsion and was a separate evolutionary event and the shell remained a symmetrical spiral.

6. Loss of symmetry :

It is due to displacement of anus towards right side of the mantle cavity and loss or reduction of paired parts of the primitively left or topographically right side.

6.4.A.2 Stages of Torsion

In majority of the gastropods torsion occurs in two stages :

Stage-I :

The contraction of the larval retractor muscles account for 90° of the rotation of the visceral hump. This process usually lasts for only a few hours. At the end of Stage-I, the mantle cavity (which was initially situated ventrally and posteriorly) comes on the right side with the foot projecting on the left side.

Stage-II :

The rest of the torsion is the result of differential growth and is usually longer in duration. Actual mechanism of torsion in gastropods is not proper y known and it is difficult to give a generalised account of torsion in gastropods.

6.4.A.3 Significaane of Torsion

As gastropod shell has only one opening, it has to serve as entrance as well as exit for all visceral organs. Both mouth and anus must open on the anterior side. Mantle cavity also must open on the anterior side for easy respiration. Respiratory current opposes locomotion after torsion whichincreases availability of water inside the branchial chamber. Visceral mass has to undergo rearrangement so that openings of kidneys, gonads and anus should migrate to the front side which is the only opening of the shell. The small chemoreceptor osphradium also migrates to the front side so that it could chemically analyse water current entering the mantle cavity. The bulky buccal mass migrates to the anterior side that provides stability during locomotion. Torsion allows foot to be retracted after the head for better protection of head.

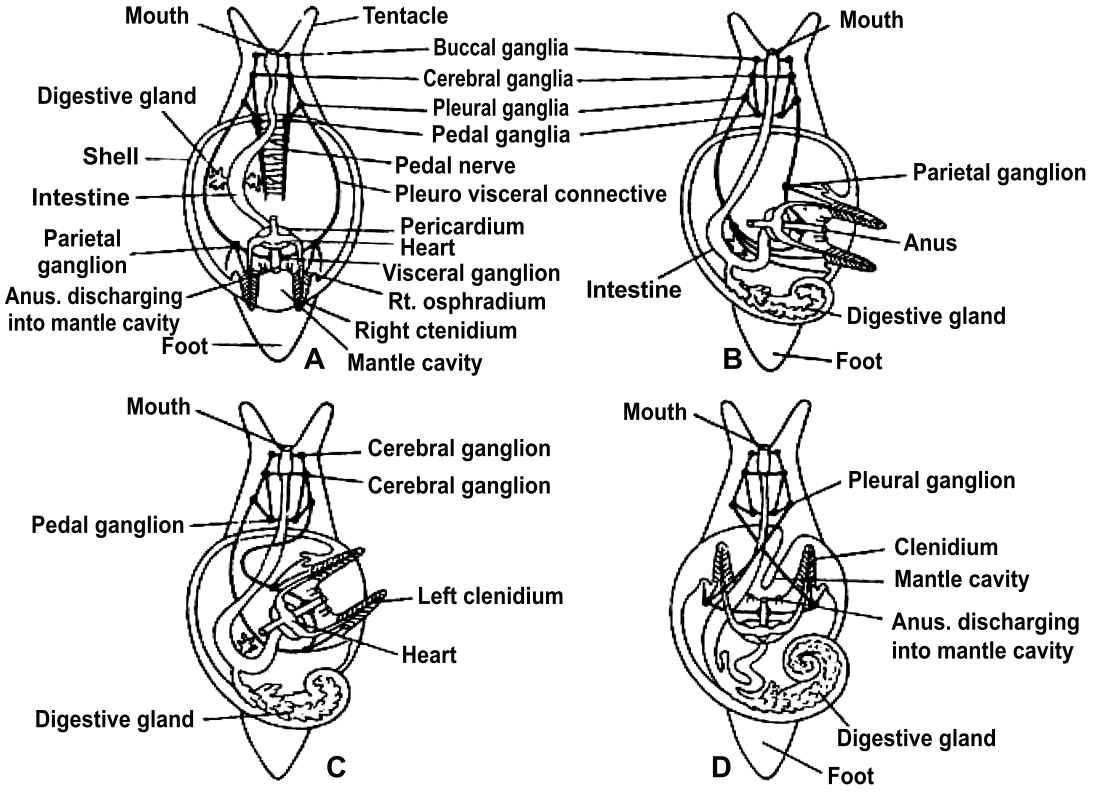

Figure 21 : **Diagrammatic representation of Torsion in Gastropod**

6.4.A.4 Theories regarding the torsion in gastropods

Several contrasting views are extant on this issue. They are :

(a) Garstang's view :

Garstang (1928) advocated that torsion is an adaptive feature and useful to the larvae (veliger larva) for protection of soft parts against enemies but of little direct use to the adult.

He suggested that before torsion the untwisted larva swimming the sea was subjected as an easy prey to its predators because the mantle cavity was at the posterior position and there is no place into which delicate head and velum can be withdrawn at the time of danger so it is disadvantageous to the larval life.

But after torsion the mantle cavity is brought around the anterior end of the larva which provides the space for head and velum and the larva gives the greater protection of the head and associated structures. At danger the larva is able to withdraw its head and velum into the mantle cavity. Then the beating of cilia stops and the larva falls to the sea bottom. In this way they avoid the predators.

This view is widely supported by Yonge (1947), Barnes (1980), Ruppert and Barnes (1994) and Anderson (1998). But the recent experiment by Pennigton and Chia (1985) does not support Garstang's view.

(b) C.M. Yonge's theory (1947) :

1. Primitive Gastropods were not twisted and the gills were attached posteriorly inside the mantle cavity. The cilia of the gills draw the respiratory current from behind the mantle which is in opposite direction of the current produced by the locomotion of the animal and the weak current of the sea itself, thus producing disadvantage in respiration and locomotion.

2. If the animal once twists all the currents would follow in the same diretion, thus aid the flushing of mantle cavity with freshwater and thus torsion becomes advantageous for ventilation of mantle cavity.

3. The twist brings the anus anterior, so there is some chance of interaction between the discharged faecal matter and respiratory current.

(c) Morton's view:

Morton (1958) emphasises the importance of anterior location of mantle cavity both in larval and adult molluscs. The anteriorly placed mantle cavity housing the head with sense organs, respiratory structures, etc. in adult add positive advantage to test the water and also to come in intimate contact for gaseous exchange with the oncoming water respectively.

(d) Ghiselin's view (1966) :

According to him, the primitive gastropods developed a conical shell on the dorsal surface for protection instead of shield-like shell. To maintain the balance of body the shell of the gastropods prolonged anteriorly.

But for the crawling purpose it was disadvantageous bearing such anteriorly prolonged shell.

The shell containing anterior- prolonged side rotated into the posterior through 180° during torsion. So it has become advantageous in the adult stage.

Stasek (1972) and Purchon (1977) have also supported that torsion is advantageous during adult stage.

6.4.B. Detorsion

Detorsion is reversal of torsion which takes place when during evolution shell is lost or a type of shell evolves that has openings on the opposite sides. In such situations twisting of visceral mass is not necessary.

Hence, detorsion takes place during the larval stage and the animal again becomes bilaterally symmetrical.

Nervous system becomes symmetrical and not twisted in the shape of 8.

Pallial complex travels backwards.

Ctenidium travels backwards or to the lateral side. Auricle moves behind the ventricle.

Visceral loop and intestine become straightened.

Detorsion takes place in Pulmonata, such as Acteon and Bulla in which anus and ctenidium are directed laterally.

In Aplysia (Opisthobranchia), detorsion takes place owing to the loss of shell.

The gills are directed laterally but lie posterior to the heart and the body becomes symmetrical.

In Pterotracheacoronata (floating sea slug) the shell, mantle and visceral sac are lost and hence the animal becomes symmetrical, worm-like with a long proboscis for feeding.

Nudibranchs (Eolis and Doris) also undergo detorsion due to the loss of shell.

Doris has symmetrical rhinophores and anal gills on the posterior side.

The sea slugs, Eolis and Iolidia are symmetrical animals because they have undergone detorsion due to the absence of shell.

They move with the help of a ventral foot and breathe with respiratory cerata that are present all over the body.

6.6 Conclusion

The molluscan nervous system shows an extreme diversity. It ranges from systems almost as simple as those of flatworms, e.g., in amphineurans (such as Chiton) and monoplacophorans (such as Neopilina) , to systems in cephalopods (such as octopuses, cuttlefishes, and squids) which are as complex as those of lower vertebrates. Despite their complexity, however, the cephalopod nervous systems still show a molluscan design ("Bauplan").

6.7 Summary

Of the different nervous system present in different molluscan animals the nervous system of Cephalopoda showed the highest development but still these animal's nervous systems still show a molluscan design ("Bauplan").

6.8 Glossary

Bauplan- The basic design of anything or in zoology it meansthe generalized structural body plan that characterizes a group of organisms and especially a major taxon (such as a phylum)

6.9 Further reading

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6.10 Model questions

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Unit-7 ❑ Larval forms of invertebrates including protochordates and their evolutionary relationships.

Structure

7.1 Objectives

This unit will help the learners to understand the different larval forms occurs in the life history of different invertebrate animals as well as their structural peculiarities.

7.2 Introduction

larva is a distinct juvenile form many animals undergo before metamorphosis into their next life stage. Animals with indirect development such as insects, or

cnidarians typically have a larval phase of their life cycle. The appearance of any larva is generally very different from the adult form (*e.g.* caterpillars and butterflies) including different unique structures and organs that do not occur in the adult form. Their diet may also be considerably different.

7.3 Larval forms in Invertebrates

7.3.1 Phylum-Porifera

Sponge larvae are relatively uniform in their morphology. They are always ciliated, but there can be regions of longer cilia or areas that lack cilia completely. Most sponge larvae spend only a brief time in the plankton, usually less than three days, before exhibiting settlement behavior. As settlement approaches, the larvae enter a short creeping stage (2-3 hours) that may be interrupted by additional periods of swimming before settlement and metamorphosis finally occur. The larvae of some Demospongiae species have no swimming period at all; they sink to the substrate after expulsion, where they creep until settlement. Some species do not release any larvae; instead, propagules are incubated within the endosome of the parent.

There are nine types of sponge larvae found which are :

(a) Calciblastula;

(b) Pseudoblastula;

(c) Amphiblastula; -The amphiblastula larvae are hollow blastulae with one hemisphere composed of small flagellated cells and the other composed of large, nonflagellated macromeres

(d) Disphaerula;

(e) Hoplitomella;

(f) Parenchymella (example of Poecilosclerida); These larvae are similar in appearance to the cnidarian planulae

(g) Parenchymella of Haplosclerida;

(h) Trichimella;

(i) Cinctoblastula.

7.3.2 Phylum-Cnidaria

Sexual reproduction in cnidarians involves indirect development and a ciliated, free-swimming pelagic larva, called planula. Planula is the fundamental larva of Cnidaria.

They are cigar-shaped but slightly broader at the “front” end, which is the aboral, vegetal-pole end and eventually attaches to a substrate if the species has a polyp stage. A **planula** is the free-swimming, flattened, ciliated, bilaterally symmetric larval form of various cnidarian species and also in some species of Ctenophores. Some groups of Nemerteans also produce larvae that are very similar to the planula, which are called planuliform larva.The planulae of the subphylum Medusozoa have no mouth, and no digestive tract, and are unable to feed themselves, while those of Anthozoa can feed.

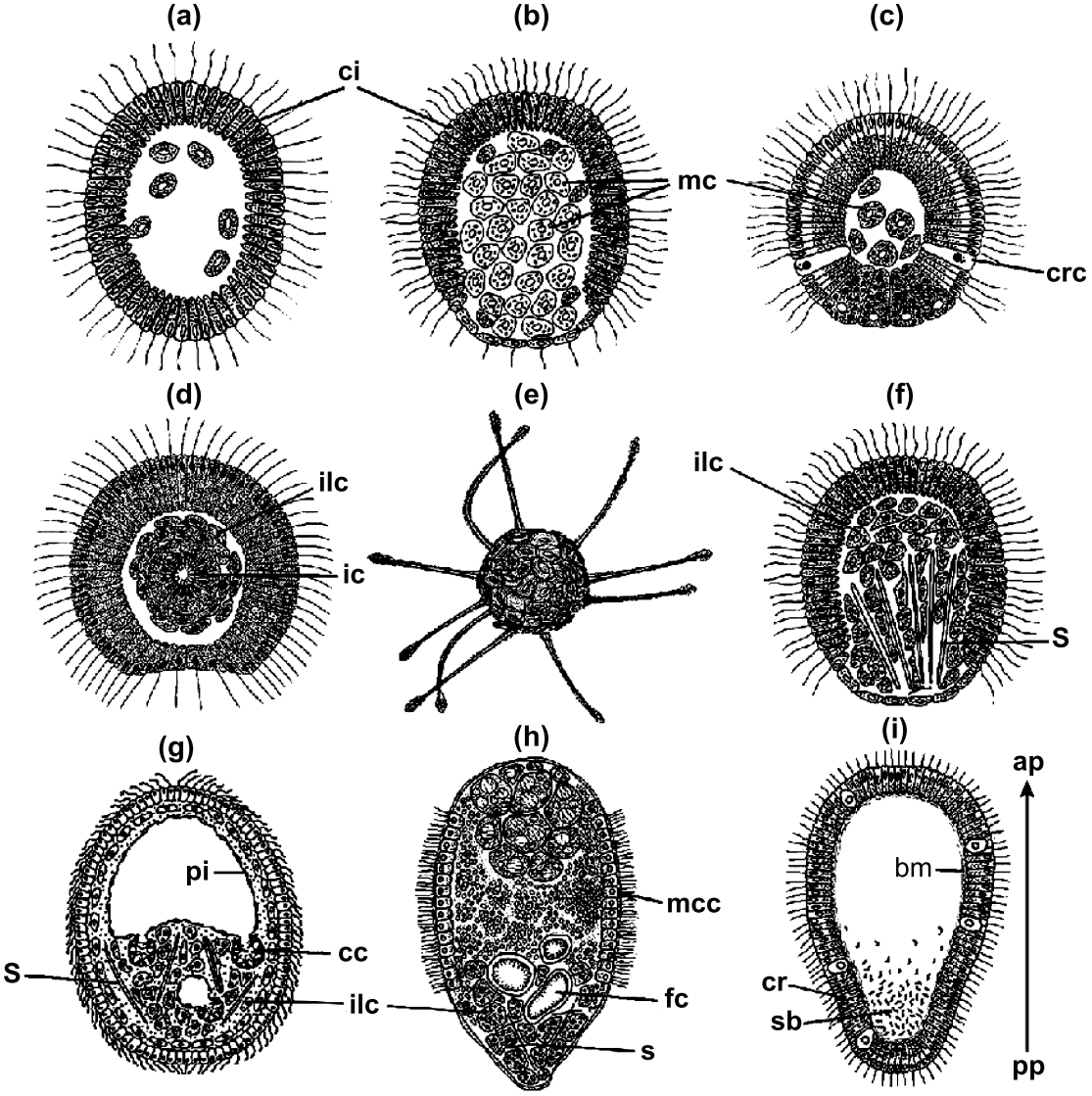

Figure 22 : **Larval forms of Porifera**

7.3.3 Phylum-Ctenophora

The characteristic larva of Ctenophora is Cydippid which is ovoid or spherical with a pair of retractable tentacles.They are free swimming larvae, which swim with the help of cilia.

But according to some authors ctenophore development of the fertilized eggs is direct; there is no distinctive larval form. Juveniles of all groups are generally planktonic, and most species resemble miniature adult cydippids, gradually developing their adult body forms as they grow.

7.3.4 Phylum-Platyhelminthes

Platyhelminthes is divided in to three classes :-

1. Tubullaria
2. Trematoda
3. Cestoda

Larval forms of class Trematoda

There are five larval forms of class trematoda which are :

Miracidium larva

The first larval stage develops in 9 to 15 days under optimum temperature of 22 – 25 degree C, until it is ready to hatch . this is known as the miracidium larva . When the larvated egg capsule comes in contact with water , the lid or operculum is dissolved and the miracidium is hatched by the capsules . it is a free swimming larva living in ponds . Which is conical in shape . the anterior end is broad and the posterior end is narrow. At the anterior end inside the body , there is a sac like gland called apical gland . it opens at the apical papilla by a duct. Two sac like glands are located on the sides of the apical glands. They are called penetration gland. A large brain is present . The interior of the larva is filled with groups of specialized cells called as germ cells.

Sporocyst larva

Sporocyst develops from miracidium . It is the 2nd larva of liver fluke. It lives in digestive gland of snail. The epidermal cells along with the cilia are shed primitive gut, cephalic glands , brain, and eye spots are degenerated and larva becomes like an elongated sac. About 0.07 mm long covered with a thin cuticle. The sub-epithelial cells , muscles and mesenchyme remain as in the previous stage. The protonephridium of each side divides in to two flame cells but they are open to outside by a common excretory duct. Besides, the sporocyst may be called as germ balls. The sporocyst may be called as a living cyst moving about in the tissue of the host absorbing nourishment from it.

Redia larva

Redia larva develops from the germ cells of sporocyst. It lives in the digestive glands of snail and cylindrical in shape. The body is covered by cuticle.

The anterior end has a mouth ,behind the mouth there is a muscular ring called as collar or opening called birth pore is located. Near the posterior end a pair of projection is found . .They are called as lappets. They are used for locomotion.

The mouth leads into a pharynx which ends in a sack like intestine.

To protonephridia are located inside the body and each protonephridia formed of many flame cells. The cavity of redia larva is filled with germ cells . The germ cells of daughter redia develop into the next larva called as cercaria.

Cercaria larva

Each redia produces about 20 cercaria . They lives in the digestive gland of snail. Its body is tadpole like rounded or oval with a long simple tale. Its length about 0.25 mm to 0.35mm. Its body surface is covered with cuticle. Digestive system consist in this larva . Numerous flame cells are located inside the body .

The cercaria lives for 3 days and it is transformed into another larva called as metacercatria.

Metacercaria larva

The cercaria looses its tail and the cystogenous gland secretes a cyst around larva. The encysted cercaria is called metacercaria. It is found attached to the grasses or near to water . Shape is round , germ cells are present . In this larva tail and cystogenous gland have degenerated and a thick hard cyst wall is present . Flame cells have increased and the germ balls are present.

The metacercariae are in fact the juvenile flukes. They develop further only when swallowed by sheep. Metacercariae survive only for a few weeks

Larval forms of class cestoda

Onchosphere (hexacanth larva)

It is the larva developed from the capsule . It remains in capsule it is spherical in shape. It is covered by two cover rings namely an outer shell and an inner embryonic membrane. The interior is filled with a mass of cells. The embryo has 6 pairs of hooks hence it is also called as hexacanth larva(hexa-6,canth-hook). The oncho sphere remains inside the gravid proglottid. It is passed out along with faeces further development takes place only inside the pig. When a pig eats the faeces, the onchosphere inters the intestine of the pig . Where the embryonic membrane dissolves. The larva penetrates the intestine wall with the help of hooks then reaches the muscles it looses the hooks and develops into the next larva called as cysticercus or bladder worm.

Cysticercus larva or bladder worm

Cysticercus developes from the onchosphere . It has following salient features :-

It lives in the muscles of the pig. It is formed of a fluid filled vesicle called bladder. The bladder is covered by two coverings namely an outer cuticle and an inner dermal layer. The flesh of pig containing the cysticercus is called measly pork. Further development of cysticercus occurs inside the man.

Larval forms of class Tubullaria

In most species of Tubullaria "miniature adults" emerge when the eggs hatch, but a few large species produce plankton-like larvae.

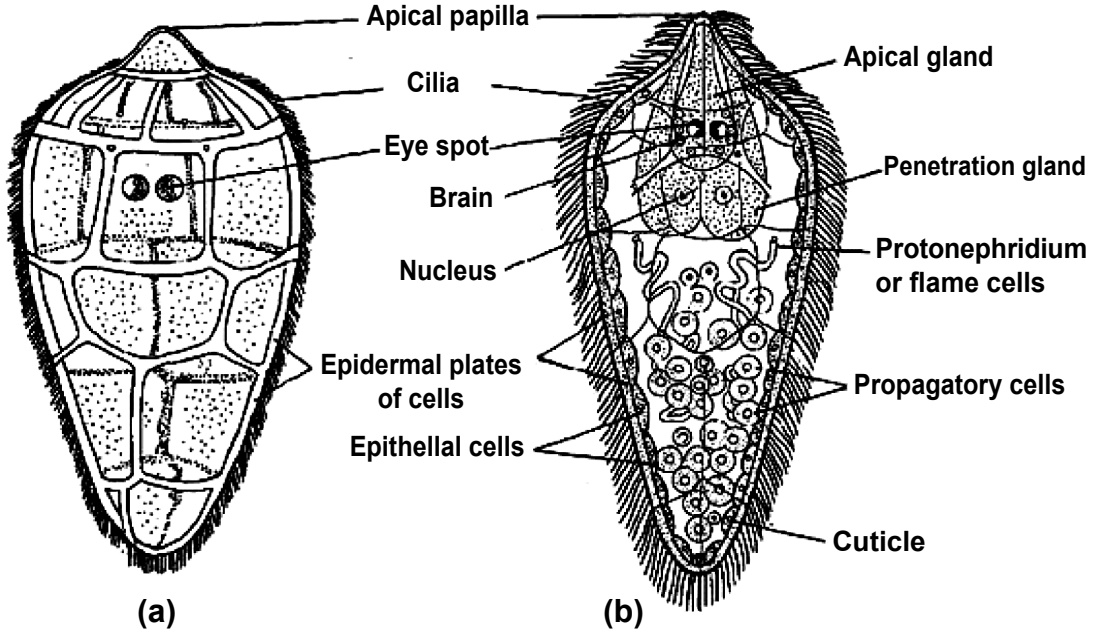

Figure-23 : **Miracidium larva**

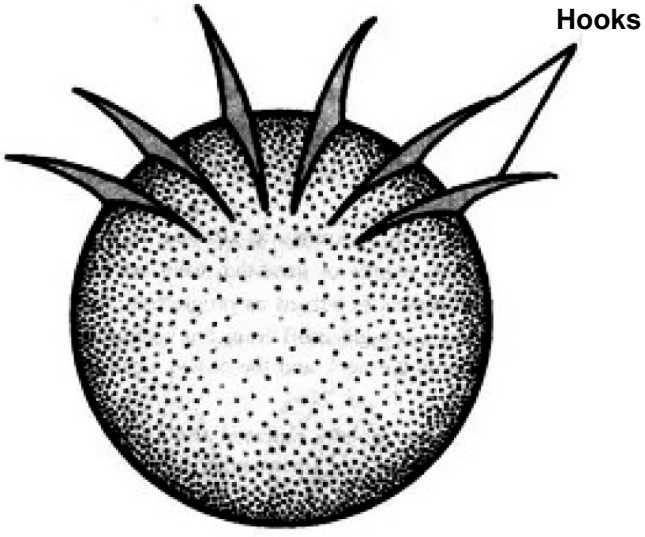

Figure-24 : **Hexacanth larva**

7.3.5 Phylum-Nematohelminthes

All nematodes go through four larval stages. At the end of each larval stage, a new cuticle is synthesized and the old one is molted off. In the stem species of Rhabditida , a clade comprising C. elegans and its relatives as well as most parasitic nematode species, a specialized survival and dispersal stage evolved, the dauer larva. This alternative third larval stage does not feed or age and can withstand adverse conditions much better than other stages. The dauer larva is the evolutionary precursor of the infective juveniles in all parasitic Rhabditida. Dauer larvae generally remain motionless, but can react to touch or vibrations. The dauer state is given other names in the various types of nematodes such as 'diapause' or 'hypobiosis' larval stage. The dauer stage is also considered to be equivalent to the infective stage of parasitic nematode larvae.

7.3.6 Phylum-Annelida

Larval forms of Annelida is **trochophore**, small, translucent, free-swimming larva characteristic of marine annelids . Trochophores are spherical or pear-shaped and are girdled by a ring of cilia (minute hair like structures), the prototroch, that enables them to swim. The prototroach , the enables them to swim and it is a sensory plate an apical tuft of cilia and an ocellus(simple eye). Below the prototroach are the mouth , stomach , anus and other structure including the solenocyte. The function of which seems to be maintained proper internal salt water balance.

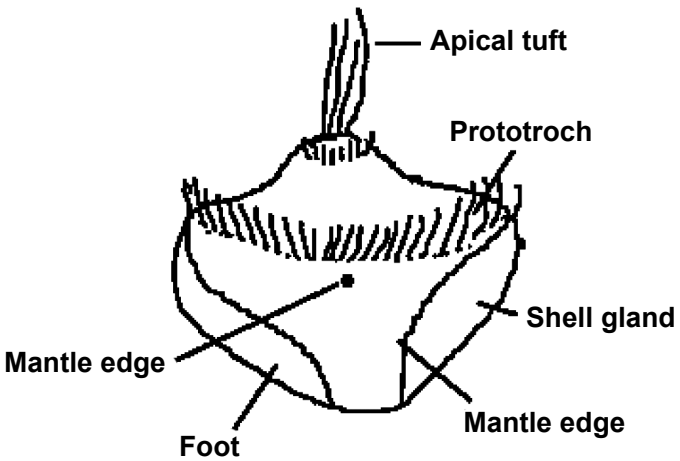

Figure 25 : **Trochophore larva**

7.3.7 Phylum-Arthropoda

Phylum Arthhropoda is divided into Hexapoda or Insecta, Myriapoda ,Crustacea . Arachnida or Chelicerata and in the most cases there are larval forms. The primary larval forms of Arthropods are :

1. Nauplius larva
2. Metanauplius larva
3. Protozoaea larva
4. Zoaea larva
5. Alium larva
6. Megalopa larva
7. Mysis larva
8. Schizopoda larva
9. Phyllosoma larva
10. Maggot larva
11. Grub larva or Scarabaeiform larva
12. Wriggler larva
13. Campodeiform larva
14. Elateriform larva
15. Vermiform larva
16. Polypod or Eruciform larva
17. Eucephalous larva — Hairy caterpillar
18. Hemicephalous larva
19. Acephalous larva
20. Caterpillar larva → Slug caterpillar

Semilooper

7. 3. 8 Phylum-Echinodermata

Echinoderms are deuterostomes and hence cleavage is radial, holoblastic and indeterminate.The larvae hatch in water and feed and grow through successive larval. The larvae hatch in water and feed and grow through successive larval stages to become adults. Following are the primary types of larva found in echinoderm animal.

1. DIPLEURULA

Itt is the fundamental larva of all echinoderms. Microscopic , free-swimming and bilaterally symmetrical. It has a gut and two ciliary bands, namely a perioral band and adoral band. It has a gut and two ciliary bands, namely a perioral band and adoral band. Generally feeds on diatoms.

2. BIPINNARIA

It is the second larva of starfish and Microscopic, free-swimming , bilaterally symmetrical, bilaterally symmetrical. The cilia are concentrated into bands arranged in a particular pattern called the arms. It has 2 unpaired (ventro-median arm, dorso-median arm) and 5 paired arms (Pre oral arms, post oral arms, antero-dorsal arms, postero-dorsal arms, postero-lateral arms).

3. BRACHIOLARIA

It is the third larva of starfish and formed after 6-7 weeks of life and growth of bipinnaria. Pre-oral region has three arms called brachiolar arms. Arms are provided with suckers.

4. OPHIOPLUTEUS

It is the larva of Ophiuroidea and arms are supported by calcareous rods.

It has 4 pairs of arms which are Pre-oral , Post-oral, Postero-dorsal and Postero-lateral.

5. ECHINOPLUTEUS

It is the larva of Echinoidea. Arms are supported by calcareous rods and provided with 1 unpaired (Median posterior arm) and 6 paired arms (Preoral, post oral, anterolateral, anterodorsal, posterolateral, posterodorsal).

6. AURICULARIA

It is the larva of Holothuroidea and has single ciliated band. Arms without calcareous rods that are not distinct.

7. DOLIOLARIA

It is the larva of Crinoidea. Free-swimming, bilaterally symmetrical, barrel-shaped symmetrical. It has 4 or 5 ciliary bands. Anterior end bears apical plate, apical tuft and adhesive pit.

8. PENTACRINOID

It is the second larva of Crinoidea and has stalk attached to the substratum with a disc. Free end bears crown with mouth and tentacles.

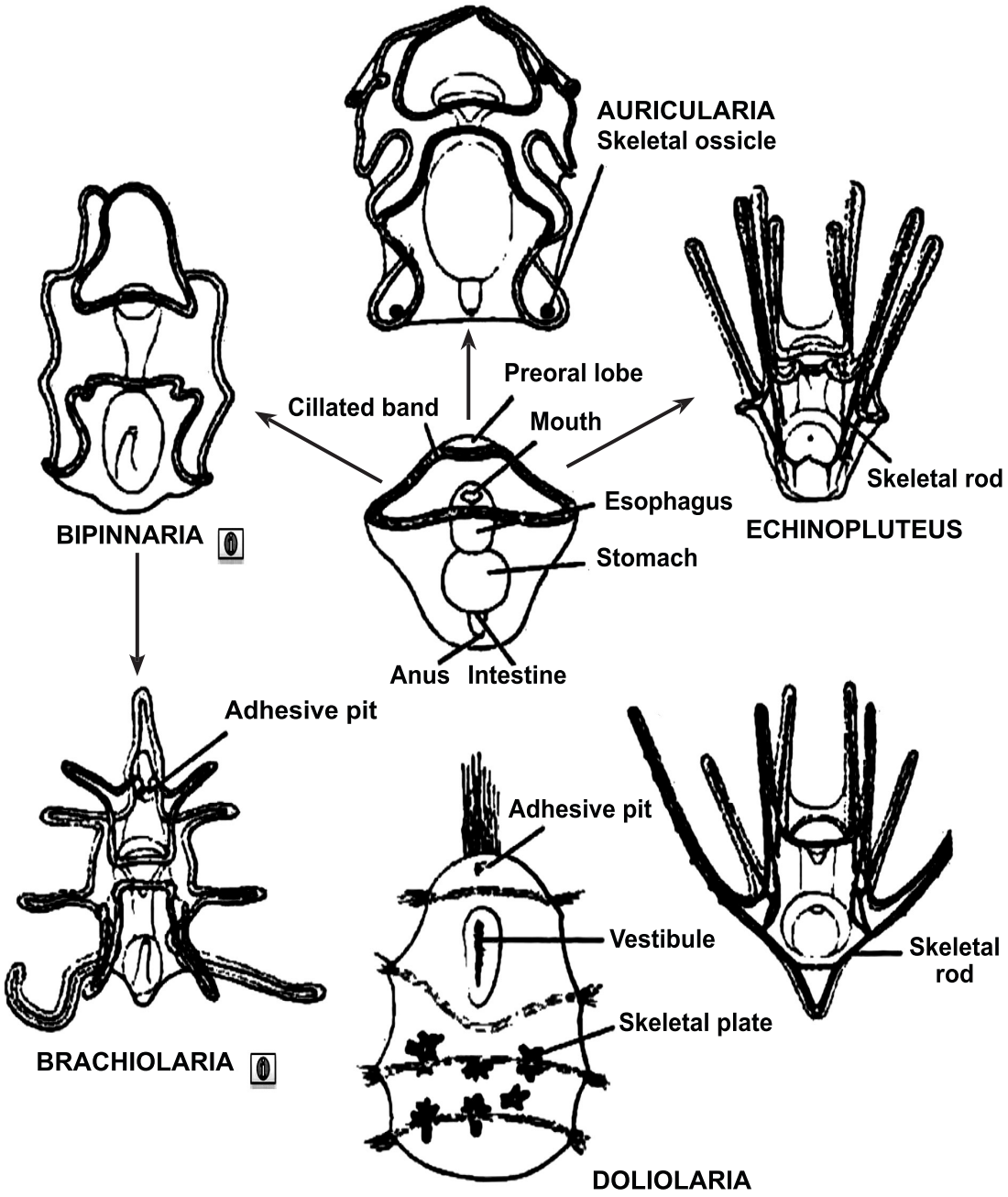

Figure 26 : **Larval forms of Echinodermata**

7. 3. 9 Phylum-Mollusca

The earliest molluscan larva was no doubt a trochophore like that of an annelid. It was a top-shaped creature with a tuft of cilia above and a ciliated band around the middle. This is the only closest resemblence of Mollusca to the Annelida. However now the animals belong to phylum mollusca has following types of larva :

1. Veliger Larva

In this larval stage the prototroch is present at anterior side as a pair of ciliated lobes, an arrangement that considerably increases the support given to the larva and makes for a more vigorous and controlled locomotion. This development is explained by the advanced stage of differentation reached by the velliger. It has something like the form of a mollusca i.e. have a shell, a mantle cavity, a beginnings of the foot and sometime bearing an operculum.

Figure-27 : **Veliger Larva of Aolis**

2. **Glochidium Larva**

Glochidium means the "Point of an arrow". It is a minute larva, 0.1 to 0.4 mm wide, it is found in the development of pelecypoda or Bivalvia. Shell consists of two triangnlar and porous valves, united closely and free ventrally. The ventral free end of each valve is produced into a conspicuous hook (curved) bearing spines. The shell encloses the body with the right and left mental lobes. The mantle lobes are very small and their margins bear on each side, three or four groups of peculiar brush like sensory bristles. The valves close together by the action of a single massive adductor muscle extending transversely between the two valves. The foot is not yet developed but glandular pouch which secretes a long sticky thread called larval byssus.

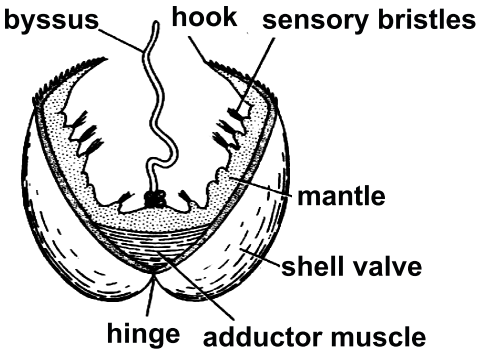

Figure-28 : **Glochidium larva (Source : Invertebrate by Kotpal)**

3. Planktotrophic larvae with long larval life

This larvae have larval life of two or three months e.g. Lamillibranchs, Prosobranchs. They are capable of wide distribution.They are usually found in tropical, subtropical and a few in high Arctic seas.

4. Planktotrophic larvae with short swimming life

This larvae have larval fife of not more than a week. They are less dependent on food, they are surprisingly adaptable to unfavourable conditions, and serve mainly for dispersal.

5. Yolk larvae

This larvae take no food in plankton. They are lecithotrophic, as they hatch from very yolky eggs and develop into large, "yolky larvae".

7. 3. 10 Lrva of Protochordata

The larval forms of Protochordata are significant in phylogenetic studies of Chordata as they exhibit all the essential characters possessed by chordates. Notochord is solid, unjointed stiff but flexible rod like structure situated on the dorsal side of these animals.

Following are the larval forms of Protochordata :

1. Tornaria larva of Balanoglossus (Hemichordates)

It is very similar in appearance to the bipinnaria larva of (Star fishes) Echinoderm. It is an oval shaped transparent larva. The diameter of the body is about 3mm. It has an apical plate which is a thickened region provided by a tuft of cilia and a pair of eyespots. The larva has complete alimentary canal. The cilliary band stretches throughout the anterior and posterior region and also the post oral region.

2. Ascidian tadpole larva of Urochordata.

The ascidian tadpole larva has a short oval body and long tail. The entire body is covered by a thin test secreted by ectoderm. The tail is fringed with a caudal fin formed by the test. At the anterior end of the trunk are three adhesive papillae made of ectodermal cells. The nervous system consists of an enlarged anterior part called sense vesicle or brain, which is hollow.The brain is continued into a nerve cord, which is also hollow. The nerve cord continued into the tail and lies mid- dorsally.The sense vesicle contains pigmented 1statocyst and 2 ocelli as sense organs. Notochord runs to the end of the tail. The alimentary canal is complete. The pharynx has anendostyle and also some stigmata. The atrial cavity is formed around the pharynx and opens to the exterior through the dorsal atrial aperture. The heart and pericardium have been formed.

3. Tunicate larva of Lancet (Cephalochordates) :

Lancet or Amphioxus is a small fish like animals of about 3.5 to 6.0 cm in length. The body is slender, somewhat translucent, laterally compressed and pointed at both ends. The pointed anterior end projects in front as a snout or rostrum. The oral hood enclosed in a cup shaped buccal cavity or vestibule. The dorsal and ventral fin is supported by a series of fin- rays. Nerve cord hollow and dorsal. Excretory system protonephric.

7. 3. 11 Evolutionary relationship of invertebrate larval forms wit protochordate larval froms.

Several theories have been advanced to explain the origin of chordates either directly from some invertebrate group or through the intervention ot some protochordate.

The greatest group of metazoan phyla, the Bilateria, is divided into two major divisions — Protostomia and Deuterostomia. The basis of division is the basic difference in embryonic and larval developments. The divisions probably represent two main lines of evolution within the Animal Kingdom.

Common features of all Deuterostomia, suggests strong evidence of a closer evolutionary relationship between the three principal deuterostome phyla— Echinodermata, Hemichordata and Chordata.

The striking larval resemblance led Johannes Muller and Bateson to suggest a common ancestry for the echinoderms and the hemichordates.

Garstrong (1894) imagined that if ciliated bands together with underlying nervous tissue of auricularia larva of echinodermates, concentrates to form ridges leaving a groove between them and if lips of the groove fuses subsequently, it will give rise tube. It will resamble with the nervous system of chordates.

Cambrian and ordovician fossil records of Carpoid echinoderms lead some zoologist to assume that Carapoid echinoderms might have evolved from tornaria like creatures which have begun to settle down to lead sedentary life.

The water vascular system might have developed out of ciliated grooves of these creatures. Besides this, it was also claimed that in the lower silurian period, one carapoid echinoderm had the calyx perforated by a series of 16 small apertures. These apertures can be compared with the gill-slits of Branchiostoma.

There is a strong suggestive evidence that the early evolutionary stage of Deuterostomia group was sessile or sedentary.

On the other hand, the ascidian larvae are tadpole-like, elongated, bilaterally symmetrical and free-swimming creatures with pharyngeal gill-slits, notochord, dorsal hollow nerve tube, and a muscular postanal tail. They represent only slightly modified living caricature of the ancestral chordate that gave rise to the vertebrate line of evolution. However, the ascidian theory of chordate origin does not seem to be perfect.

The cephalochordates, particularly the lancelets (Branchiostoma lanceolatum) are an interesting group of animals. They possess the three basic , chordate features in diagrammatic form.

According to Colbert, the living Amphioxus (Branchiostoma) answers the logical structure of a model prevertebrate.

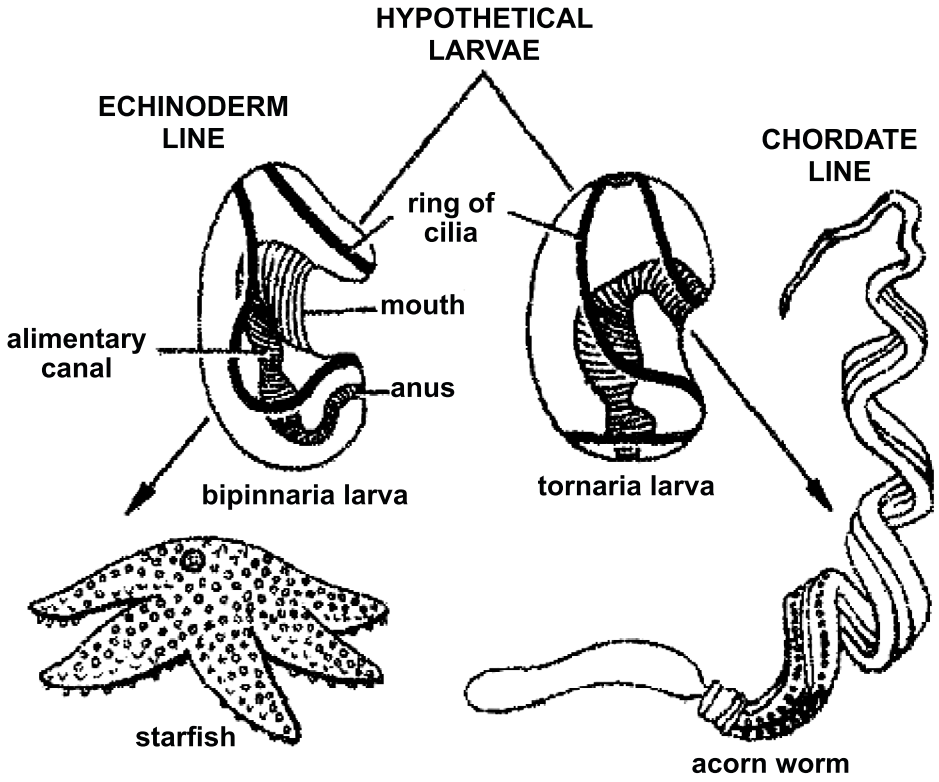

Figure-29 : **Similarity of larval forms of echinoderms and hemichordates**

The most plausible hypothesis by E.J.W. Harrington (1965) is based on the deuterostome line of chordate evolution.

The common echinoderm—chordate ancestor was in all probability a small, sessile or semisessile, lophophorate or arm feeding creature. It fed by ciliary method by trapping food particles in a set of waving tentacles.

From this ancestral stalk were derived early stalked echinoderms and pogonophores.

The remarkable similarities between the echinoderm (bipinnaria) and hemichordate (tornaria) larvae is taken as good evidence for common ancestry.

Garstang suggested that probably free-swimming auricularian larvae of some ancestral echinoderms evolved into chordates through paedogencsis, i.e., prolongation of larval life without undergoing metamorphosis and reproducing sexually.

Similarly the trochophore larva also shows striking similarities among oter larval forms. It is significant in all archi annelids and now class polychaeta or phylum mollusca.

Mollusca- Veliger : Presence of ciliated bands., well distinct alimentary canal. Presence of rudimentary eye.

Arthropoda- Nauplius : Presence of eye and oval or ovoid body.

Echinodermata- Bipinaria : 5 pairs of ciliated bands, preoral and postoral ciliated bands, presence of gut and mouth.

Auricularia : ciliated bands, mouth anus well developed.

Hemichordata- Tornaria : translucent oval ciliated body, complete alimentary canal.

It is presumed that the trochophore represents a transitional stage in the line of emergence of the bilateral groups (e.g., Rotifers) from the radial groups (Ctenophores). Similarities between the trochophore and the echinoderm larva (Bipinnaria and Pluteus) and Tornaria larva of Balanoglossus added more weight to this contention.

Many zoologist are of the opinion that the Trochophore larva serves as a bridge between radial and bilateral symmetry. They have opined that the bilateral symmetry has evolved from the radial one.

The typical trochophora larva, found in many annelids, molluscs and entoprocts, and the larvae of some platyhelminths (Müller's and Götte's larvae) and nemerteans (pilidium larvae), share important characters with the typical trochophores.

Indirect development is typically observed among marine invertebrates, where sexual reproduction leads to motile embryos and larvae with functions and ecologies that are quite different from their respective juvenile and adult forms.

In other groups (e.g., echinoderms, nemerteans), larvae may represent distinct body plans with little or no resemblance to the adult. In either case, production of a ciliated, swimming larva is in high contrast to direct development, which does not produce a recognizable larval stage. There is very little debate about whether numerous records of eeding (planktotrophic) and nonfeeding (lecithotrophic) larval types from extant and extinct clades across the Metazoa point to an ancient origin of indirect pelagobenthic life history patterns.

7.7 Conclusion

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7.8 Summary

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7.9 Glossary

?????

7.10 Further reading

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7.11 Model Questions

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Unit-8 ❑ Affinity of Limulus and Ectoprocta (Bryozoa).

Structure

8.1 Objective

The main objective of this unit is to analyse the question "why Limulus is considered as living fossils ?" and in which group it should belong. Similarly this unit also tells us what are the archetypal characters ? This unit also elaborates the affinities of Ectoprocta and their systematic position.Similarly this unit also elaborates why the phylum Bryozoa, or Polyzoa, or Ectoprocta are the greatest and most common of the three lophophore phyla?

8.2 Introduction

The horse-shoe crabs—misnomerly called king crabs—are marine arthropods, which were abundant in Ordovician and Silurian periods. They have undergone little changes from the Silurian time and are represented by only five species today.

8.3 Affinity of Limulus

The five existing species of horse-shoe crabs are placed in three genera—*Limulus, Tachypleus* and *Carcinoscorpias.* The largest measuring 60 cm including the telson is Limulus polyphemus.

Xiphosurans, colloquially known as horseshoe crabs, are a clade of aquatic chelicerates represented by four extant species with an evolutionary history stretching back 470 million years to the Ordovician. Horseshoe crabs are considered archetypal 'living fossils' due to their low diversity and apparent morphological conservatism . However, their fossil record reveals that horseshoe crabs have in the past exhibited a relatively high species diversity and a greater variation in both morphology and ecology than their modern representatives. Although three of the four modern horseshoe crab species are distributed mainly along the coast of Indonesia and the Bay of Bengal, with one species extending into the South and East China Seas, the American horseshoe crab Limulus polyphemus is found on the Atlantic coast of North America and the Gulf of Mexico, hinting at a more complex biogeographic history that is borne out by the global distribution of the horseshoe crab fossil record .

Limulus has certain features common with several groups of both extinct and living non-chordates but quite a number of differences have also been recorded.

8. 3. 1 Affinities with Extinct Forms with Trilobite :

Similarities :

1. Cephalothorax with lateral eyes.
2. Appendages biramous.
3. Presence of lateral pleural spines.
4. Presence of trilobite stage in the life history of Limulus.
5. Certain fossils — Synxiphosura are very close to trilobites.

In spite of above similarities, Limulus differs from trilobites in having a telson, in the structure of genital operculum, abdominal appendages, and in the absence of antennae. Cephalothorax of trilobites is distinctly flattened.

With Eurypterida (fossil Merostomata) :

Similarities :

1. Three similar body segments—prosoma, mesosoma and metasoma.
2. Similar cephalothoracic appendages and telson.
3. Structures of median and lateral eyes similar.

Although Limulus bears above mentioned similarities with Eurypterida, the dissimilarities are no less striking and rule cut the possibility of any close relationship. In fact, the Eurypterida exhibit a much closer relation with the modern Chelicerata (scorpions).

With Hemiaspidae (fossil Crustacea) :

1. Construction of carapace and telson similar.

2. Lateral compound eyes present in both.

3. Trilobite larva of Limulus resembles some Hemiaspidae after first moult. Many workers believe that the affinities are merely superficial.

8. 3. 2 Affinities with living forms :

With crustacean :

Similarities :

1. Aquatic habits and similarity in appearance.

2. Appendages (specially abdominal) biramous.

3. Simple median and less complicated lateral eyes.

4. Presence of endosternite.

Dissimilarities :

1. Book-gills have no parallel structure in Crustacea.

2. Antennae absent in Limulus.

3. Absence of Nauplius larval stage in Limulus.

With Arachnida :

Similarities

1. Presence of a broad carapace.

2. Number and arrangement of cephalothoracic appendages.

3. Caudal spine of Limulus resembles the post-abdominal part of scorpion.

4. Structure of genital operculum.

5. Presence of median eyes.

6. Presence of endostennite.

7. Pharynx suctorial and symmetrical digestive glands.

8. Presence of coxal glands.

Dissimilarities :

1. Respiratory structures—book-gills and book-lungs are different.

2. Malpighian tubules absent in Limulus.

Attempts have been made to establish affinities of this archaic creature with other forms including chordates. Gaskell (1908) tried to establish its affinities with ammocoete larva of Petromyzon, largely based on the structure of dermal skeleton, median and lateral eyes, gills and endosternum.

But these similarities are only superficial. Patten (1912) attempted to establish affinity with ostracoderms (fossil armoured agnathans), but this gained a little support.

It appears that Limulus has much closer relationship with Arachnid and extinct Eurypterida than to any other arthropods.

Formerly it was placed under the class Arachnida but Manton (1970) and others have assigned a separate class Merostomata for it along with eurypterids, and hold that Arthropoda is polyphyletic.

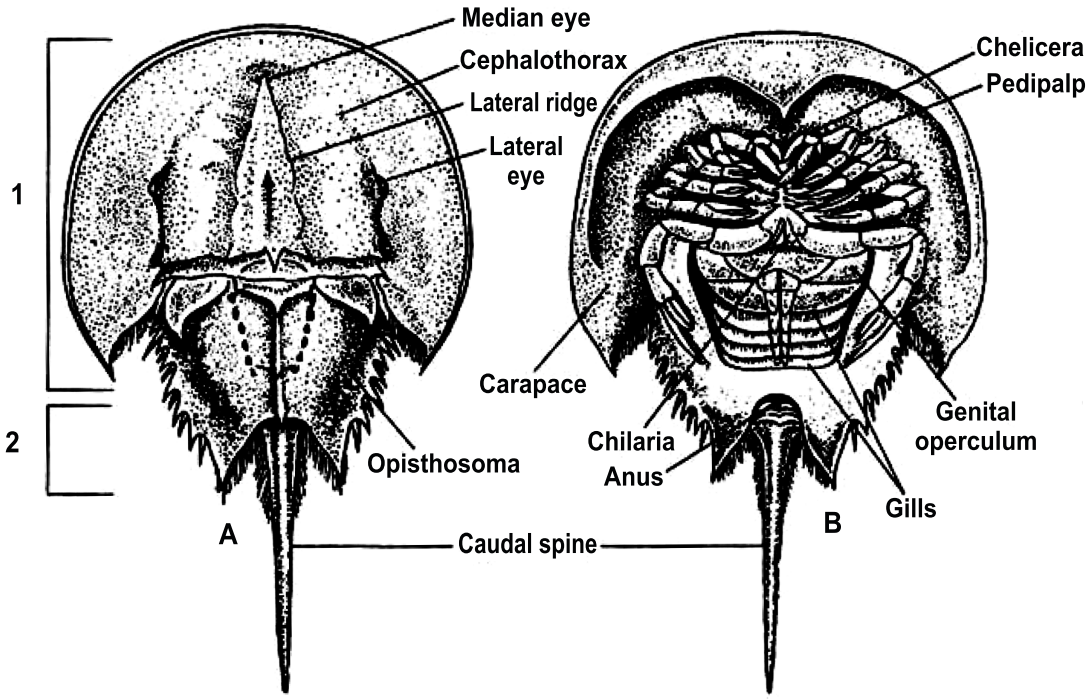

Figure 30 : ***Limulus sp*** **(A) Dorsal view (B) Ventral view**

8.4 Affinities of Ectoprocta (Bryozoa).

The Ectoprocta are minute, sessile, colonial, unsegmented coelomate animals.

They are provided by the circular or cresentic lophophore, a u-shaped alimentary canal with anus opening near the mouth but outside of lophophore.

Usually posses free swimming larva but without nephridia or circulatory system.

Geographically they are very ancient group preserve since the Cambrian period.

Their calcareous covering occurs in Palaeozoic and Mesozoic formation.

The form of the colony is variable in some extent even within the same species.

8. 4. 1 Affinities with entroprocta

Formerly ectoproctas and entoproctas were linked together as a class under the phylum Bryozoa. Due to the following similarities-

1. Presences of crown of ciliated tentacles

2. Presences of looped digestive tract

3. The cyphonautes larva of ectoprocta bears a marked superficial resemblance to larva of entoprocta.

But such features are common in all sessile animals. The tentacular circlet act as good catching device.

Differences

There are sharp difference between entoprocta and ectoprocta that are following

1. Entoproctas are without true coelom

2. In ectoprocta the tentacular crown embraces only mouth not anus.

3. Nephiridia are absent in ectoproctas while present in entoprocta.

4. Gonoduct are also absent in ectoprocta while present in entoprocta.

Thus pseudocoelomate entoprocta are much lower in organisation than coelomate ectoprocta.

8. 4. 2 Affinities with other Iophoporate phyla

They are found to be closely related with Phoronida and Brachiopoda. Following are the close resemblance :

1. Presence of horse shoe shape tentacular lophophore.

2. Lack of cephalisation

3. Reduced dorsal body surface

4. Coelomate animals

5. Presence of looped digestive tract

6. Presence of sub-epidermal nervous plexus.

7. Chitinous secretion is common

8. The free swimming and ciliated larvae.

Apart from their above similarities there are enough differences which compel us to separate and classify them independently. These difference are mainly occur in their anatomy and development.

8.4.3 Affinities with Phoronida

Similarities :

(1) Both are provided with horse-shoe shaped lophophore.

(2) Presence of epistome.

(3) U-shaped alimentary canal.

(4) Similar disposition of the coelom and the presence of a septum separatingthe mesocoel and metacoel.

(5) The nerve centre is located in the mesocoel and is supraenteric.

Differences

(1)The origin of coelom is different.

(2) The region between the mouth and anus is dorsal in position in Phoronida and ventral in Ectoprocta.

(3) The circulatory system and nephridia are absent in Ectoprocta, while in Phoronida both the systems are present.

8.4.4 Affinities with Brachiopoda

(1) Both have similar body organization.

(2) Bivalved shell of cyphonautes larva of Ectoprocta can be compared to the shell of Brachiopoda.

(3) Presence of coelomic septum between the mesocoel.

(4) Alimentary canal is U-shaped. Besides the above similarities, there are many structural differences between these two groups.

Differences

(1) The brachiopod shell cannot be compared to the exoskeleton of Ectoprocta.

(2) In Brachiopoda the shell is dorso-ventrally placed, while in ectoproct larva the shell is laterally placed.

(3) The chitinous setae present in Brachiopoda are absent in Ectoprocta.

(4) The nervous system is mainly supraenteric in Ectoprocta, while in Brachiopoda it is subecnteric.

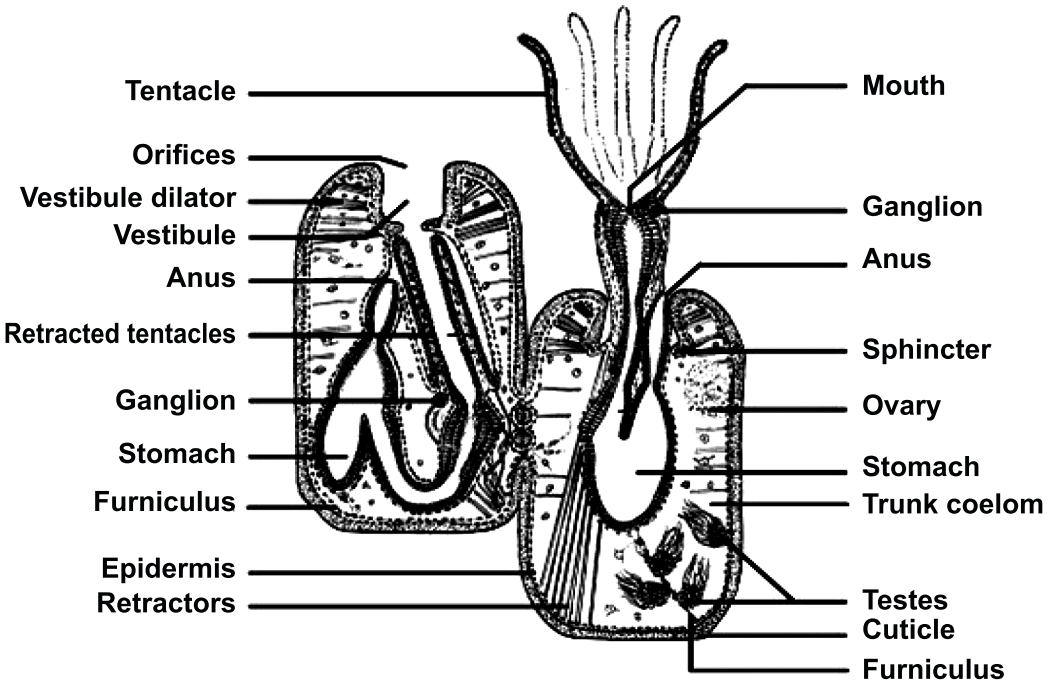

Figure 31 : **Structure of Ectoprocta**

8.7 Conclusion

With all information of anatomy and development available for ectoproctas it seems advisable to state that it is an independent phylum with closer affinity to other lophophorate phylum.The Phylactolaemates must be regarded as most primitive ectoproctas because of the presence of fundamental cylindrical shape of zooids , lack of polymorphism and their simple horseshoe shaped lophophore.

Similarly it appears that *Limulus* has much closer relationship with Arachnid and extinct Eurypterida than to any other arthropods. Formerly it was placed under the class Arachnida but Manton (1970) and others have assigned a separate class Merostomata for *Limulus.*

8.8 Summary

Horse-shoe crabs are inhabitants of shallow seas but some members occasionally occur in fresh water, as well as brackish estuarine waters. They burrow and forage for molluscs and worms in sand and mud with a head-on shoveling action of the carapace.

Similarly from the relationship of Ectoprocta with other animals it is convenient to place the ectoprocts under a separate phylum, Ectoprocta having phylogenetic relationship with the other two lophophorate coelomates—Phoronida and Brachiopoda.

8.9 Glossary

Cephalisation-The mechanism of brain formation in animals

Shell-External covering of multicellular animals made up of calcium carbonate.

8.10 Further reading

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8.11 Model questions

Deascribe the affinities of Ectoprocta ?

Unit-9 ❑ Physiology of Osmoregulation and Ventilation in fish.

Structure

9.1 Objective

This unit helps to learn the students that how fishes employ osmoregulation to combat diffusion and osmosis and maintain the internal salt and water balance that is required for their efficiency and survival, regardless of the salinity of their external environment.

This unit also tells the story of the osmoregulatory mechanism in fishes as well as their ventilation process and gill functions.

9.2 Introduction

Osmoregulation is a kind of homeostasis during which water volume and electrolyte content are both maintained.It is the active monitoring of the osmotic pressure of

an organism's bodily secretions, as measured by osmoreceptors. In this processs organisms must maintain the correct balance of solutes and water in their body fluids in both aquatic and terrestrial contexts. In comparison to its aquatic environment, the body fluid of freshwater fish is frequently hyperosmotic. But in case of marine fishes in comparison to their surroundings, they have blood that contains more water and as a result, there is a propensity to lose water and absorb the salt. Osmoregulation is vital for animals because it maintain a consistent, appropriate osmotic pressure within their bodies or cells.

The salinity/osmolarity of aquatic habitats can be quite variable. Fish have evolved mechanisms for maintaining fluid and electrolyte homeostasis across a wide range of salinities. Marine teleosts, freshwater teleosts, and marine elasmobranchs all utilize different physiologic strategies for osmoregulation. Kidneys do play a role in osmoregulation, but overall, extrarenal mechanisms are equally if not more important sites for maintaining osmotic homeostasis. Extrarenal sites include the gill tissue, the alimentary tract, the rectal gland (elasmobranchs), and the urinary bladder.

In fishes the kidneys play an important role in osmoregulation, but major portion of the osmoregulatory functions are carried out by other organs such as the gills, the integument and even the intestine. Osmoregulation may be defined as "the ability to maintain a suitable internal environment in the face of osmotic stress".

9.3 Osmoregulators and Osmoconfirmers

Osmoregulators are those animals who can maintain the internal osmolarity different from the medium in which they live. The fishes, except the hagfish which migrates between fresh and saline waters, the changing osmotic stress due to environmental changes is overcome with the help of endocrine mechanism.

Osmoconfirmers are those animals who are unable to control osmotic state of their body fluids but confirms to the osmolarity of the ambient medium. Majority of fishes either live in freshwater or in salt water (a few live in brackish water).

9.4 Mechanism of Osmoregulation

According to habitat, fishes can be distinguished as (i) Marine, and (ii) Fresh water.

The marine fishes fall into two distinct groups :-

(a) Those whose osmotic concentration is the same as or slightly above sea water, e.g., hagfish, elasmobranchs, Latimeria etc. This group has no major problem of water balance, because its inside and outside concentrations are equal, there is no osmotic water flow,

(b) Those whose osmotic concentrations are about one third of that of sea water, e.g., lampreys, teleosts, etc. These are hyposmotic animals. They live in constant danger of losing water to the osmotically more concentrated medium.

The fresh water fishes, on the other hand, have internal concentrations greater than that of their external medium. Thus, they are hyperosmotic to the medium. Therefore, the osmotic problems and the means to solve them differ drastically among fishes of different habitats.Fish have developed remarkable mechanisms for coping with life in water. The salinity/osmolarity of aquatic habitats can be quite variable.Fish have evolved mechanisms for maintaining fluid and electrolyte homeostasis across a wide range of salinities. Marine teleosts, freshwater teleosts, and marine elasmobranchs all utilize different physiologic strategies for osmoregulation.

Kidneys do play a role in osmoregulation, but overall, extrarenal mechanisms are equally if not more important sites for maintaining osmotic homeostasis.

Extrarenal sites include the gill tissue, the alimentary tract, the rectal gland (elasmobranchs), and the urinary bladder.

9.4.1 Mecanism of Osmoregulation in Cyclostomes (Lampreys and Hagfishes):

Lampreys, which are anadromous, i.e., live both in sea and in fresh water. The Lampreys, weather fresh-water or marine, have osmotic concentrations about one-quarter to one-third the concentration of sea-water. Their main problem is similar to that of teleost fish.

Hag- fishes are strictly marine and stenohaline. The hagfishes are the only true vertebrates whose body fluids have salt concentrations similar to that of sea-water. In fact, the normal Na^+ concentration in hagfish blood exceeds that in their surroundings . Therefore, they have pronounced ionic regulation as an isosmotic animal.

9.4.2 Osmoregulation in Marine Elasmobranchs:

The common examples of marine elasmobranchs are sharks and rays.

The salt concentration in their body fluid is roughly one- third the level of the sea-water , but they still maintain osmotic equilibrium.

This is achieved by adding to the body fluids large amount of organic compounds primarily urea.

Addition of different organic compounds in the body fluid/blood makes the osmotic concentration equal or slightly above the sea-water .

In elasmobranchs urea is a normal component of all body fluids; this is abnormal for other vertebrates.

In marine elasmobranchs, the tissue cannot function normally in the absence of such a high urea concentration.

Urea is the end product of protein metabolism in vertebrates. Generally it is excreted through kidney, but the shark kidney actively reabsorbs this.

The use of urea for maintaining osmotic equilibrium helps these animals to keep salt concentration much lower than those of sea-water.

Although the eldsmobranchs have solved the osmotic problem of life in the sea by being isosmotic, they are still capable of extensive ionic regulation.

Part of the sodium excretion is undertaken in the kidney.

Major excretion of Na^+ is performed by a special rectal gland. This is a small gland that opens via a duct into the posterior part of the intestine, the rectum. The gland secretes a fluid with high sodium and chloride concentrations, which is higher than the sea-water concentration.

The elasmobranch blood is usually slightly more concentrated than sea-water.

This higher concentration inside causes a slight osmotic inflow of water via the gills.

In this way, the elasmobranchs slowly gain water osmotically, and this water is used for the formation of urine and for the secretion of rectal gland.

The excess osmotic concentration is due to the presence of urea.

But retaintion of urea solves the otherwise difficult osmotic problem of maintaining a low salt concentration while living in sea.

9.4.3 Osmoregulation in Freshwater Elasmobranchs:

Among freshwater elasmobranchs, Carcharhinus leucas of Lake Nicaragua, four species of elasmobranchs of Perak River in Malaysia and Amazon sting ray Potamotrygon, are remarkable.

Their blood concentrations are lower than those of strictly marine forms. The urea concentration is reduced to less than one third of the value of marine sharks.

The problem of osmotic regulation is reduced due to the low level of solutes in the blood.

The osmotic inflow of water is diminished because lower salt concentration is easier to maintain.

The reduced osmotic inflow of water gives less water to be eliminated by the kidney.

The urine always contains some solutes; therefore, a low urine flow reduces the urinary salt losses.

9.4.4 Osmoregulation in marine Teleosts:

Teleost fishes are living both in marine and freshwater.

Both types of fishes maintain their osmotic concentration at about the quarter to one-third the level in sea-water.

Marine fishes are hyposmotic with the environment.

Their main problem is losing body water to the more concentrated sea-water.

The body water comes out through their body surfaces, in particular the large gill surfaces.

The gill surface is more permeable to water than general body surface.

These fishes compensate their inevitable water loss by drinking sea-water.

Drinking of sea-water may restore the water content of the body, but impose another problem.

Along with the sea-water, large amount of salts are also ingested and absorbed through the intestine. So salt concentration of the body increases.

Excess salt must be excreted but teleost kidney cannot serve this purpose, because it cannot produce a urine that is more concentrated than the blood.

Therefore it is done by the gills.

So gills have dual function—one, participation in osmoregulation and second, gas exchange.

The secretion of salt through gill is an active process, i.e., energy mediated. Because, it takes place from a lower concentration in the blood to a higher concentration in the surrounding medium.

However, the kidney plays a major role in the excretion of divalent ions, magnesium and sulfate.

These ions are not eliminated by the gills.

9.4.5 Osmoregulation in fresh-water Teleosts:

The osmotic concentration of the blood of fresh water teleosts in much higher than the surrounding water (~300 mOsm/litre).

Therefore, their major problem is the osmotic water inflow .

Water mainly enters through the highly permeable gills. In freshwater teleosts skin is less important in transporting water inside the body, because it is less permeable.

The large volume of water is excreted as urine, which is very dilute and may be produced in quantities up to one-third of the body weight per day.

The urine contains 2 to 10 mmol/litre of solutes.

So large urine volume also causes a substantial loss of solutes .

This loss is replaced by the gills, which is also slightly permeable to ions.

Some solutes are taken in with the food, but the main intake is by active transport in the gills.

It is evident from the studies that skin plays only a minor, if any, role in active absorption.

9.5 Ventilation in fish

It is apparent that fish have a wider range in their basic types of ventilation than is found in the other vertebrate groups.

They vary from mechanisms in which there is a continuous unidirectional flow of water across the gills to tidal mechanisms involving either water or air as the respiratory

medium; most recently, a mechanism has been discovered in which air is replaced by water before air is once more admitted to the supra-branchial chamber of some air-breathing teleosts.

The essential features of the double-pumping mechanism are most clearly seen in the teleost fishes, where pressure and suction pump mechanisms are developed to a greater or lesser degree.

In general, bottom-living forms have a more dominant suction pump associated with greater development of the branchiostegal apparatus and a less complex gill sieve.

Similar conditions are found in other less active fishes, including forms such as the trigger fishes, in which the branchiostegal apparatus has been secondarily enclosed.

More actively-swimming fish have a greater development of the buccal pressure pump, culminating in pelagic forms such as the tunas and mackere, which swim almost continuously.

Fish breathing mechanism are of following types :-

9.5.1 Buccal pumping or active ventilation or double pump system :

Buccal pumping (active ventilation) occurs when a fish pumps water through its mouth and over its gills.

In majority of teleosts, 2 respiratory pumps, buccal and opercular function in co-ordination with each other, to propel water through the gills which occurs in two phases:-

Phase I

Expansion of buccal and opercular cavities while opercula are closed

Phase II

Mouth closes, opercula open, forcing water across gills

Fishes that swim slowly, hold in place against the current, rest in place on the sea bottom breathe this way this a lot.

Skates, rays and nurse sharks, angel sharks and carpet sharks normally breathe this way.

9.5.2 Ram ventilation :

Ram ventilation is a simpler process in which a fish swims forward with its mouth open, taking in water that passes over the gills.

The drawback to ram ventilation is that the fish has to swim continuously to be able to continue breathing.

A lot of sharks breathe this way, as do some large bony fish swimmers like tunas and billfishes.

Many fishes, including sharks like the sand tiger shark, can switch between buccal pumping and ram ventilation as the situation and their swimming speed dictates.

9.5.3 Obligate ram ventilation :

Some sharks and bony fishes, on the other hand, can't accomplish buccal pumping at all and have to swim continuously to maintain the water/blood gas exchange.

This is obligate ram ventilation.

The bony fishes include the aforementioned tunas and billfishes.

Obligate ram-ventilating sharks include great whites, makos, salmon sharks and whale sharks.

There is an often-stated "fact" that "sharks have to swim continuously to survive."

But in reality, most do not.

Only some two dozen of the 400 or so known shark species are in the obligate ram ventilation category.

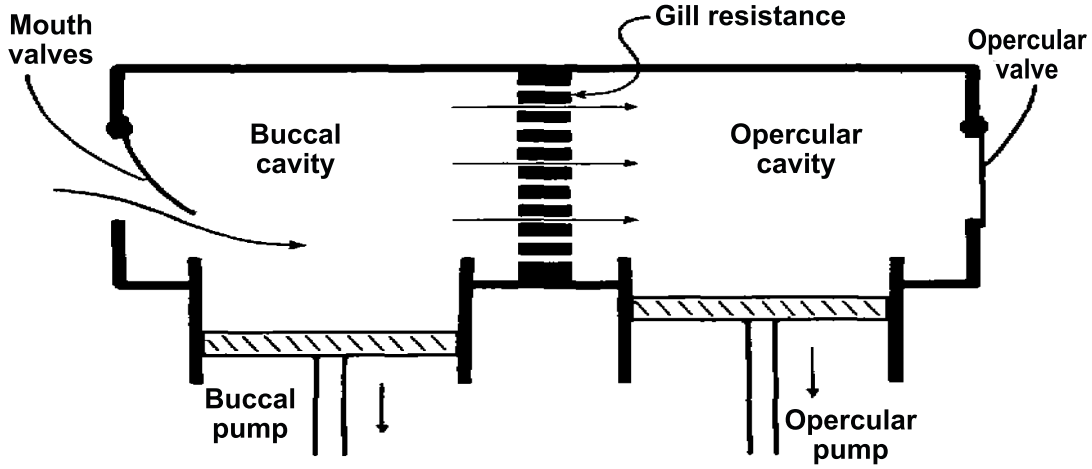

Figure 32 : **Ventilation in fish**

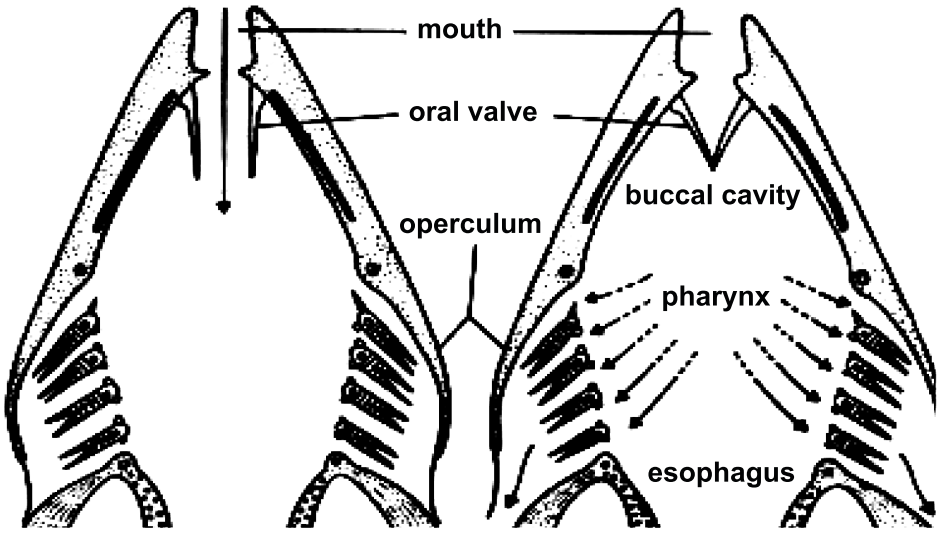

Figure 33 : **Respiratory pump in fish**

9.6 Conclusion

In addition to respiration, in fish , the respiratory system has other functions such as osmo- regulation, excretion of nitrogenous waste (ammonium), acid-base regulation and detoxification. The basic structures for gas exchange in the water are the gills, which are located on either side of the pharynx. Fish take water into their mouth, passing the gills just behind its head on each side. Dissolved oxygen is absorbed from—and carbon dioxide released to—the water, which is then dispelled. The gills are fairly large, with thousands of small blood vessels, which maximizes the amount of oxygen extracted. The ionic composition of the body fluids of freshwater species is hypertonic (more concentrated) to the surrounding water, so these species tend to accumulate water from the environment. Osmoregulation in freshwater species involves excretion of water and active uptake and retention of salts.

9.7 Summary

Due to the osmotic pressure of the body fluids of fish is considerably higher than that of freshwater, there will be a continuous influx of water across the surface epithelium and a corresponding loss of ions into the water.

The influx of water is balanced by a copious discharge of urine, from which as much sodium and chloride as possible has been re-absorbed in the kidneys.

Fish obtain the oxygen that they require for their metabolic processes from the gas dissolved in water.

Because of this low concentration of dissolved oxygen in water, the fish has to have an extensive and efficient respiratory mechanism.

9.8 Glossary

Homeostasis = maintaining steady state equilibrium in the internal environment of an organisms

Osmotic concentration – Total concentration of all solutes in an aqueous solution

Stenohaline - tolerate a narrow range of salinities in external environment

Euryhaline - tolerate a wide range of salinities in external environment

Osmosis- movement of water molecules from a solution with a high concentration of water molecules to a solution with a lower concentration of water molecules,

9.9 Further reading

Handbook of Fish Biology and Fisheries Volume 1 Fish Biology Edited by Paul J.B.

Hart Department of Biology University of Leicester and John D. Reynolds School of.

Biological Sciences University of East Anglia, Wiley Online Library.

A Textbook of Fish Biology and Fisheries by S.S. Khanna and H.R. Singh Published by

Narendera Publishing House.

Srivastava : A Textbook of Fishery Science and Indian Fisheries (1985, Kitab Mahal)

Ayappan, S.(2011) : Hand book of fisheries & Aquaculture, ICAR Publication.

9.10 Model Questions

How does osmoregulation occur in freshwater organisms?

Describe the environments in which freshwater and saltwater fish live.

Describe two ways in which each type of fish attempts to compensate for the problems it faces.

How does osmoregulation occur in marine water organisms?

Unit-10❑ Metamorhosis of Amphibia – Neoteny and Paedomorphosis.

Structure

10.1 Objective

This unit will help the learners to know about the mechanism of transformation of larval form into the adult form i.e. how tadpole larva is transformed into toad or frog. Not only that this unit also elaborates the different conditions needed for metamorphosis and if this transformation will not occur then whhat will happen. Similarly this unit also discuss about the molecular perspective of amphibian metamorphosis.

10.2 Introduction

Metamorphosis in amphibians is the transformation of the larva to a miniature adult replicate, and usually from an aquatic to a terrestrial or semi-terrestrial lifestyle. Metamorphosis marks the beginning of the end of larval life. During metamorphosis, developmental processes are reactivated by specific hormones, and the entire organism changes to prepare itself for its new mode of existence.

10.3 Stages of Amphibian Metamorphosis

Etkin (1968) aadvocated that Amphibian Metamorphosis can be divided into three stages :

1. Premetamorphic stage : The stage is characterized by the considerable growth and development of larval structures but metamorphosis does not occur.

2. Prometamorphosis : The stage is characterised by the continuous growth specially the development of limbs and initiation of metamorphic changes.

3. Metamorphic climax : The stage is characterised by the radical changes in the features of the larva, and climax is considered by the loss of most larval features.

10.4 Morphological changes associated with metamorphosis

In amphibians, metamorphosis is generally associated with the changes that prepare an aquatic organism for a primarily terrestrial existence.

In urodeles (salamanders), these changes include the resorption of the tail fin, the destruction of the external gills, and a change in skin structure.

In anurans (frogs and toads), the metamorphic changes are more dramatic, and almost every organ is subject to modification.

Regressive changes include the loss of the tadpole’s horny teeth and internal gills, as well as the destruction of the tail.

At the same time, constructive processes such as limb development and dermoid gland morphogenesis are also evident.

The means of locomotion changes as the paddle tail recedes while the hind limbs and forelimbs develop.

The tadpole's cartilaginous skull is replaced by the predominantly bony skull of the frog.

The horny teeth used for tearing pond plants disappear as the mouth and jaw take a new shape, and the tongue muscle develops.

Meanwhile, the large intestine characteristic of herbivores shortens to suit the more carnivorous

diet of the adult frog.

The gills regress, and the gill arches degenerated.

The lungs enlarge, and muscles and cartilage develop for pumping air in and out of the lungs.

The sensory apparatus changes, too, as the lateral line system of the tadpole degenerates, and the eye and ear undergo further differentiation.

The middle ear develops, as does the tympanic membrane characteristic of frog and toad outer ears.

In the eye, both nictitating membranes and eyelids emerge.

The eyes of the tadpole are laterally placed, so there is relatively little binocular field of vision.

The eyes migrate dorsally and rostrally during metamorphosis.

10.5 Anatomical Changes in Frogs and Salamanders accompanying Metamorphosis

Frogs	**Salamanders**
Buccal region	
Major remodeling	Slight remodeling
Oral disc with papillae and keratinous tooth rows and jaw sheaths disappears	
Jaws elongate, enlarging mouth, and teeth develop	
	Teeth change from bicuspid to monocuspid
Buccal musculature reorganized	
Tongue muscles develop	Tongue muscles develop

Pharyngeal region

Remodeling with shortening of the pharynx

Gills and pharyngeal slits disappear | Gills and pharyngeal slits disappear

Rearrangement of aortic arches | Rearrangement of aortic arches

Modification of hyoid and segments of the branchial skeleton for tongue support | Modification of hyoid and segments of the branchial skeleton for tongue support

Viscera

Lung development completed | Lung development completed

Stomach develops slightly | Digestive tube modified

Reduction of intestine and change of digestive epithelium

Reduction of pancreas

Pronephros kidney disappears | Pronephros kidney disappears

Skin

Number of epidermal cell layers increases | Number of epidermal cell layers increases

Pigmentation and pattern change | Pigmentation and pattern change

Skeleton

Ossification moderate to strong | Ossification slight to moderate

Major remodeling of cranial skeleton | Little change in cranial skeleton

Loss of tail; development of urostyle

Sense organs

Protrusion of eyes with development of eyelids	Protrusion of eyes with development of eyelids
Remodeling of eye and growth of eye muscles	
Development of stapes in middle ear	

10.6 Summary of metamorphic changes in Anurans

System	Larval stage	Adult stage
Locomotory	Aquatic; tail fins	Terrestrial; tailless tetrapod
Respiratory	Gills, skin, lungs; larval hemoglobins	Skin, lungs; adult hemoglobins
Circulatory	Aortic arches; aorta; anterior, posterior, and common jugular veins Carotid arch; systemic arch; cardinal veins	Carotid arch; systemic arch; cardinal veins
Nutritional	Herbivorous: long spiral gut; intestinal symbionts; small mouth, horny jaws, labial teeth	Carnivorous : Short gut; proteases; large mouth with long tongue
Nervous	Lack of nictitating membrane; porphyropsin, lateral line system, Mauthner's neurons	Development of ocular muscles, nictitating membrane, rhodopsin; loss of lateral line system, degeneration of Mauthner's neurons; tympanic membrane
Excretory	Largely ammonia, some urea (ammonotelic)	Lergely urea; high activity of enzymes of ornithine-urea cycle (ureotelic)
Integumental	Thin, bilayered epidermis with thin dermis; no mucous glands or granular glands	Stratified squamous epidermis with adult keratins; well-developed dermis contains mucous glands and granular glands secreting antimicrobial peptides

10.7 Biochemical changes associated with Metamorphosis

In addition to the obvious morphological changes, important biochemical transformations occur during metamorphosis.

In tadpoles (as in freshwater fishes), the major retinal photopigment is porphyropsin.

During metamorphosis, the pigment changes to rhodopsin, the characteristic photopigment of terrestrial and marine vertebrates.

Tadpole hemoglobin is changed into an adult hemoglobin that binds oxygen more slowly and releases it more rapidly than does tadpole hemoglobin.

The liver enzymes change also, reflecting the change in habitat. Tadpoles, like most freshwater fishes, are ammonotelic; that is, they excrete ammonia.

Many adult frogs (such as the genus Rana, but not the more aquatic Xenopus) are ureotelic, excreting urea, like most terrestrial vertebrates, which requires less water than excreting ammonia.

During metamorphosis, the liver begins to synthesize the urea cycle enzymes necessary to create urea from carbon dioxide and ammonia.

10.8 Physiological changes associated with Metamorphosis

At the beginning of metamorphosis, the pancreas starts to secret insulin and glucagon hormones.

This is related to the increased role of the liver.

During the larval stage, the end product of nitrogen metabolism is ammonia.

But after metamorphosis, the toads and frogs excrete most of their nitrogen in the form of urea.

This is a shift from ammonotelism to ureotelism with the change of environment from aquatic medium to land.

10.9 Coordination of developmental changes during Metamorphosis

One of the major problems of metamorphosis is the coordination of developmental events. For instance, the tail should not degenerate until some other means of locomotion—the limbs has developed, and the gills should not regress until the animal can utilize its newly developed lung muscles.

The means of coordinating metamorphic events appears to be a difference among tissues and organs in their responsiveness to different amounts of hormone. This model is called the **threshold concept.**

As the concentration of thyroid hormones gradually builds up, different events occur at different concentrations of the hormones.

If tadpoles are deprived of their thyroids and are placed in a dilute solution of thyroid hormones, the only morphological effects are the shortening of the intestines and accelerated hind limb growth.

However, at higher concentrations of thyroid hormones, tail regression is seen before the hind limbs are formed.

These experiments suggest that as thyroid hormone levels gradually rise, the hind limbs develop first and then the tail regresses.

Similarly, when T3 is given to tadpoles, it induces the earliest-forming bones at the lowest dosages and the last bones at higher dosages, mimicking the natural situation.

Thus, the timing of metamorphosis appears to be regulated by the sensitivity of different tissues to thyroid hormones.

10.10 Hormonal Control of Metamorphosis :

Two hormones such as Triiodothyronine (T3) and Tetraiodothyronine (T4) or thyroxine are necessary for biochemical and morphological changes during anuran metamorphosis.

These thyroid hormones are produced by the induction of anterior pituitary lobe or pars distalis when it reaches certain degree of differentiation.

Then it is capable to synthesize a hormone, thyrotropin (Thyroid Stimulating Hormone, TSH) which acts on the thyroid, stimulating the production and secretion of triiodothyronine (T3) and thyroxine.

In pre-metamorphic stage the prolactin level is high but levels of thyroid stimulating hormone (TSH) and thyroid hormone (T3, T4) are low.

The hypothalamus – pituitary link is poorly developed. In pro-metamorphosis, the hypothalamus and pituitary link develops.

The prolactin level is low but the levels of thyroid stimulating hormone (TSH) and thyroid hormones (T3, T4) are high.

In metamorphic climax, the prolactin level increases suddenly, then maintain steady low level.

The TSH is high until end of climax and the thyroid hormone (T4) level becomes low.

10.10.1 Molecular responses of thyroid hormones during metamorphosis :

Thyroid hormones appear to work largely at the level of transcription, activating the transcription of some genes and repressing the transcription of.

The transcription of the genes for albumin, carbamoyl phosphate synthase, adult globin, adult skin keratin, and the *Xenopus* homologue of sonic hedgehog is activated by thyroid hormones.

The earliest response to T3 is the transcriptional activation of the thyroid hormone receptor (TR) genes.

There are two major types of T3 receptors, TRα and Tβ.

The thyroid hormone receptors may bind to their specific sites on the chromatin even before thyroid hormones are present, and they are thought to repress gene transcription.

10.11 Neoteny :

Neoteny is defined as the failure or delay of larva to metamorphose while becoming sexually mature. It is character of some amphibians. The best example is the axolotl larva of *Ambystoma* which has the following characters :

It is aquatic.

It has gills.

It develops gonads.

It lays eggs and attains large size.

Ambystoma on the other hand, is terrestrial and without gills.

It was considered the axtolotl as a separate genera in the beginning, with the administration of thyroxine, axtlotl lost its gills and develops lungs.

It metamorphosed into the adult. Metamorphosis of axolotl can be induced by reducing the water level.

Proteus. and Necturus are permanently neotenous forms. They retained the larval features and reproduce sexually like a mature animal.

10.11.1 Types of neoteny :

According to Kollman there are three types of neoteny :

1. Partial neoteny: Tadpoles of *Hyla arborea, Rana escülenta* during winter will show simple retardation of metamorphosis beyond the normal period.

2. Total neoteny: It will retain its gills and becomes sexually mature throughout the life.

Necturus, Siren and Proteus

3. Intermediate Neoteny: Intermediate stages between partial and total neoteny are also recorded where the larvae become sexually functional and may metamorphose into adults with the advent of favourable conditions.

10.11.2 Factors affecting Neoteny :

There are three types of factors which are generally affecting the neoteny which are :

1. Environmental factors affect metamorphosis in several ways.

Abundance of food, cold temperature or insufficient iodine (a component of thyroxin hormone that induces amphibian metamorphosis) may cause failure of metamorphosis and retention of larval features.

2. Following extrinsic factors are also affecting the neotenic process:-

Abundance of food and other favourable requisites in the aquatic life is the cause of retention of larval features (Gadow, 1903).

Deepwater and coldness inhibit the secretion of thyroxin (Shufeldt).

Saline nature of water is responsible for neoteny (Weismann).

Low temperature is responsible for the arrest of metamorphosis (Huxley, 1929).

3. Intrinsic factors : Metamorphosis is primarily influenced by the following intrinsic factors :

(a) varying threshold levels of thyroxin and its analogues and

(b) by the degree of responsiveness of the larval tissues to the hormones.

10.11.3 Significance of Neoteny :

According to Weismann (1875) neoteny to be a case of retarded evolution or **atavism,** that is, reversion to ancestral condition. However, this is now regarded to be of secondary specialization, a physiological adaptation of advantage.

10.12 Paedomorphosis or paedogenesis

The phenomenon of attainment of sexual maturity leading to reproduction in an arrested larval stage (pre-adult stage) is called Paedogenesis (Gk. pais; child; morphe form). The term first used by Von Baer (1866).

The paedomorphosis (Gk. pais, child; morphe, form) is the retention of ancestral juvenile characters in the late developmental stages of descendants.

The affected individuals are called paedomorphic.

But Kardong, 2002 refers to paedomorphosis as an individual which is larval in anatomy but it becomes sexually mature and neoteny is a special case of paedomorphosis where sexual maturity occurs but somatic development slows, allowing juvenile features to persist.

De Beer (1951) favours to use the broader term Heterochrony which is any evolutionary changes in the relative rates of development of characters during ontogeny.

McFarland et al., (1985) use the term paedogenesis, neoteny and pro-genesis for the attainment of sexual maturity in an arrested larval animal.

10.12.1 Types of Paedomorphosis :

There are two types of paedomorphosis found in urodeles.

1. Obligatory Paedomorphosis :

Some species of urodeles or larval stages always remain mature permanent larval stages.

They do not metamorphose at any time.

The developing tissues fail to respond to the thyroid hormone (T4), when in other forms the tissues respond to the thyroid hormone and metamorphose into adult.

In obligatory paedomorphosis, the genes for transformation during metamorphosis have become suppressed.

Some populations of *Cryptobranchusalleganiensis*, after complete metamorphosis, retain a single gill-slit that reflects the ancestral larval feature. So it may be considered a paedomorphic species.

2. Facultative Paedomorphosis :

The axolotl larva of some urodeles, e.g., some species of *Ambystoma* of north western part of U.S.A. and *Triturus* exhibit paedomorphosis. The larvae become sexually mature and breed but they can metamorphose and change into adults when the available conditions are changed. They are not the permanent larvae like Necturus or Proteus.

10.13 Conclusion

Metamorphosis may be defined as “a rapid differentiation of adult characters after a relatively prolonged period of slow or arrested differentiation in a larva”. According to Duellman and Trueb (1986) metamorphosis can be defined as “a radical transformation from larval life to the adult stage involving structural, physiological, biochemical and behavioural changes”.The young tadpole larva resembles a fish. It leads an independent and self-supporting life.

This fish like tadpole larva completely metamorphoses into toad, is exclusively a progressive process.

10.14 ?????

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10.15 Summary

In most species of animals, embryonic development leads to a larval stage with characteristics very different from those of the adult organism. During metamorphosis, developmental processes are reactivated by specific hormones (Thyroxine), and the entire organism changes to prepare itself for its new mode of existence. These changes are not solely ones of form. In amphibian tadpoles, metamorphosis causes the developmental maturation of liver enzymes, hemoglobin, and eye pigments, as well as the remodeling of the nervous, digestive, and reproductive systems. Thus, metamorphosis is often a time of dramatic developmental change affecting the entire organism.

10.16 Glossary

Metamorphosis-The total chage of characteristics in respect to morphology,physiology and biochemistry of any animal or larval stages of an animal.

10.17 Further reading

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Tata, J.R., (2006). Amphibian metamorphosis as a model for the developmental actions of thyroid hormone. *Mol. Cell. Endocrinol*., 246: 10-20.

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10.18 Model questions

Which hormone plays the most crucial role in metamorphosis?

What is paedomorphosis?

What is neoteny and where do you find it?

Unit - 11 ❑ Special organs in snake-Jacokson's organ, Poison appearatus and biting mechanism.

Structure

11.1 Objective

This unit helps the learners to understand about the special chemosensory organ known as Organ of Jacobson present in snakes and why the forked tongue of snakes are licking always.

Similarly this unit also elaborates the structure of poison glands present in snaes and its product, the venom.

This unbit also unravelled the mecanism of biting of snakes as well as the mechanism of introduction of venom by the snakes.

11.2 Introduction

The vomeronasal organ (VNO), or Jacobson's organ, is the paired auxiliary olfactory (smell) sense organ located in the soft tissue of the nasal septum, in the nasal cavity just above the roof of the mouth (the hard palate) in snakes as well as in various tetrapods.

It is present and functional in all snakes and lizards,

11.3 Structure of Jacobson's organ or vomeronasal organ

Jacobson's organ is an organ of chemoreception and it is a part of the olfactory system of amphibians, reptiles, and mammals, although it does not occur in all tetrapod groups.

This organ was named for its discoverer, Danish anatomist Ludvig Levin Jacobson, in 1811.

Jacobson's organ is also known as the vomeronasal organ.

They are present in pairs. It is an olfactory sense organ. This means that this organ is related to smell.

It is located near the soft tissue of the nasal septum.

It is present in the nasal cavity, above the roof of the mouth.

The name vomeronasal organ is derived from the fact that this organ is present near the unpaired vomer bone.

This organ is present in all snakes and lizards.

It is also present in mammals such as dogs and cats.

This organ is present in human beings also, but it is vestigial and non-functional in nature.

The Jacobson's organ is most developed in lizards and snakes, in which its connection with the nasal cavity has been closed and is replaced by an opening into the mouth.

The nerve connecting Jacobson's organ to the brain is a branch of the olfactory nerve. In turtles the Jacobson's organ has been lost.

Jacobson's organ is a short-range chemoreceptor of nonairborne odours, as contrasted to the detection of airborne odours, smelling in the usual sense, by olfactory sensory patches in the nasal tube.

Jacobson's organ is present at the base of the nasal cavity.

This organ is split into two parts and these parts are divided by the nasal septum.

Both sides of these organs possess an elongated C-shaped structure that is called the lumen.

This is present inside a bony or cartilaginous capsule. This capsule opens into the base of the nasal cavity.

11.4 Functional Mechanism of Jacobson's organ or vomeronasal organ

Snakes have evolved a unique way of smelling odors in the world around them; they have two vomeronasal organs and can therefore smell in stereo.

When a forked tongue flicks out, it collects the scent particles onto each tip and retracts back into the snake's mouth. It then presses the ends against the vomeronasal organ; each can detect how strong a scent is. This allows snakes to see multiple smells from different directions and effortlessly follow a scent trail.

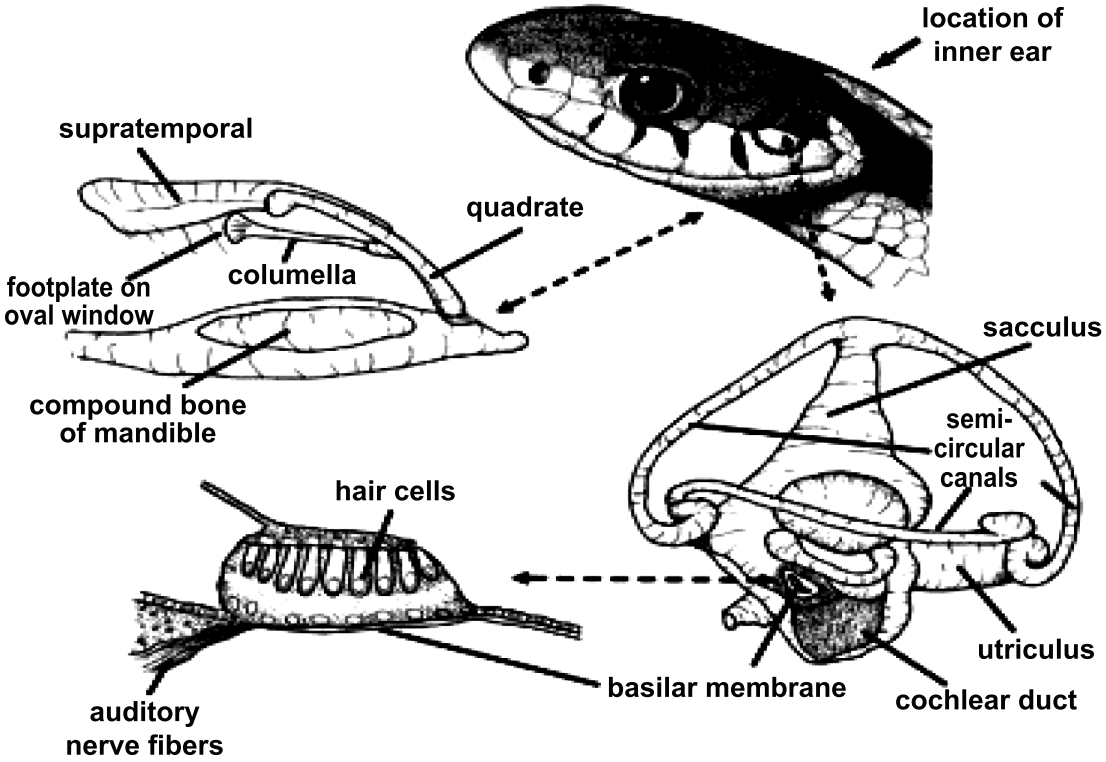

Figure-34

11.5 Anatomy of the Vomeronasal Organ or Jacobson's Organ

The vomeronasal organ is situated in the anterior and lower mucosal areas of the nasal septum . It comprises a 2–8mm pouch with a diameter of 0.2–2mm. The numerous mucous glands opening into this pouch ensure constant irrigation. At the end of the pouch there are elongated sensory cells with small mobile saccules resembling handles. Numerous blood vessels and nerve fibers are situated basal to this cell layer. The precise spread of these fibers and of the information thus transmitted to the CNS is not

known. However, stimulation of the vomeronasal organ is not perceived consciously. This organ is embedded at the base of the septum on the vomer bone. It also contains a sensory epithelium which is not directly exposed to airflow, and therefore possesses a pumping mechanism for flushing the organ with mucus. In coronal sections of the vomeronasal organ, a crescent-like lumen lined with a sensory epithelium is localized medially, whereas a nonsensory cuboidal epithelium is located more laterally.

11.6 Posion apparatus and biting mechanism of snakes.

Majority of the snakes are non poisonous and only there are four poisonous genera .

All the poisonous snakes have poison apparatus in their heads, which is not found in non–poisonous snakes.

Poison apparatus of snakes consist toxic substance which is considered as poison and venom.

The poison and venom both substances are toxic in nature but the difference are ; if the plants and animals produce toxic reaction after eating them than the plants and animals supposed to be poisonous.

When substance injected into the body of enemy or organism by those animals having poisonous apparatus it is called venomous.

11.6.1 Structure of Poisonous apparatus

Poisonous apparatus of snakes consists of following organs :

1. A pair of poison glands

The poison apparatus of snakes consists of a pair of poison glands, their ducts. In poisonous snakes the poison glands are situated one on either side of the upper jaw. The poison glands are possibly the superior labial glands or parotid glands. Each poison gland is sac-like and provided with a narrow duct at its anteriorb end. Capsule sends vascular fibrous septa that separate the glandular substances into secretory pockets. The duct passes forward along the side of the upper jaw and loops

over itself just in front of the fang and opens either at the base of the fang or at the base of the tunnel on the fang. The poison gland is held in position by ligaments. An anterior ligament attaches the anterior end of the gland to the maxilla. A posterior ligament extends between the gland and the quadrate. Fan-shaped ligaments are situated between the side walls and squamoso-quadrate junction.

2. Poison ducts

The gland is provided with a narrow duct at its anterior end. The duct passes forward along the side of the upper jaw and loops over itself just in front of the fang and opens either at the base of the fang or at the base of the tunnel on the fang.

The duct actually opens in a pocket of mucous sheath that covers the basal part of the fang. In spitting cobras (Naja nigricollis), the poison duct is modified in that it has an "L" shaped bend, just prior to exiting the fang, with the discharge orifice being located on the front of the fang.

3. Fangs

The fangs of snakes evolved to inject venom into the pray of various snakes that possess them. the term fangs refers to a grooved or tubular tooth that is used to inject venom. It is pointed and hook like teeth, which are actually modified form of maxillary teeth. They are long, curved, sharp and pointed.

Fangs are divided into three types on the basis of structure and position which are given bellow-

(a) Proteroglyphous (protero, first) :

Proteroglyphous types of fangs are small, grooved and articulated and permanently erect at the anterior end of maxillae. Such fang is found in cobras, kraits, coral snakes and sea snakes,

(b) Opisthoglyphous (opistho, behind) :

Opisthoglyphous fangs are also small, grooved but remain associated with the posterior end of maxillae.

(c) Solenoglyphous (solen, pipe + glyph, hollowed) :

Solenoglyphous fangs in vipers and rattle snakes, a large functional fang occurs on the front of each maxilla. This contains a narrow hollow poison canal with enamel, which opens at the anterior end of the fang. The fangs are movable and turned inside to lie in the roof of mouth when it is closed.

4. Muscles

The poison apparatus is associated with specialized bands of three types of muscles which are -

i. Digastrics- Attached to the squamosal of the skull at one end and articular of the lower jaw at the other end. It helps in opening jaws.

ii. Sphenopterygoid- Attached anteriorly to the spheroidal region and posteriorly to the dorsal surface of the pterygoid. It assists in pulling the pterygoid forward.

iii. Anterior and posterior temporalis- attached to the side walls of the cranium and the lower jaw. They help in closing the lower jaw.

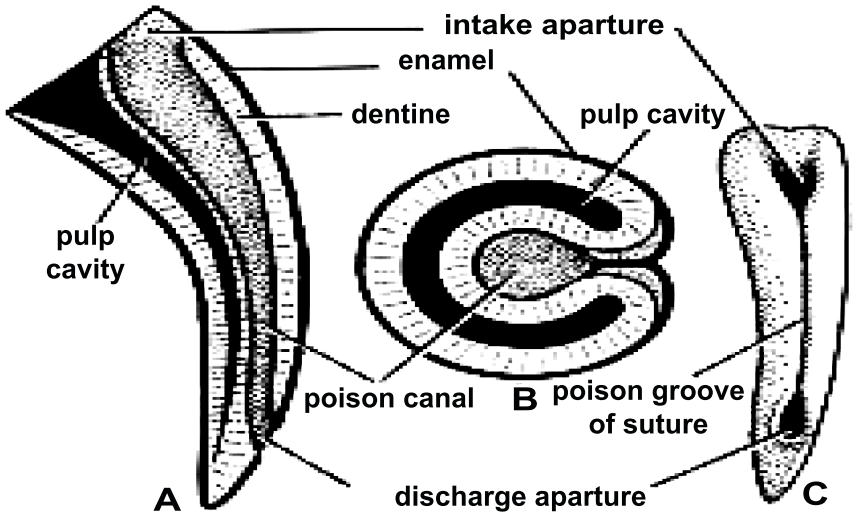

Figure 37 : **Fangs**

11.6.2 Biting mechanism of poisonous snakes

The skull and jaw bones in poisonous snakes are very much kinetic and movably articulated, thus, allowing an enormous gape and swallowing whole of large prey.

In cobras fangs are small and remain permanently erect, but in vipers the fangs are large and curved and lie against the root of mouth cavity when closed. Premaxilla, usually toothless and the bones of the upper jaw are loosely attached to rest of the skull.

Quadrate jointed to the squamosal.

There are movable joints between the frontals behind and prefrontals and nasals in front and also between several other bones of brain case, palate and jaws. These joints have loose ligaments and allow movement in several directions and so permit a huge gap.

The two halves of the lower jaw are connected together by elastic ligamentous tissue.

So they are capable of being widely separated from one another.

There are four distinct phases of the biting mecanism of poisonous snakes which are-

(i) The strike :

In this phase the snake throws itself forward with great rapidity .

Vipers strike with greater velocity than the colubrids, some of which especially the hooded species raise the head from the ground thus compensating to some extent for the limited mobility of the fangs.

(ii) Opening of the mouth and elevation of the fangs :

Most poisonous snakes commence the strike with closed jaws, but as the head approaches the victim the mandibles are depressed by a rapid contraction of the

digastrics, cervico mandibular and vertebro-mandibular muscles and simultaneously the fangs are elevated or rotated forward by the forward swing of the pterygo-palatine-transverse arch produced by the contraction of the sphenoand parieto-pterygoid muscles.

As the mouth opens the lower jaw moves down and the lower end of quadrate moves

forward. Quadrate and squamosal are very movable. The pterygoid is movably attached to the palatine. Quadrate pushes the pterygoid forward and the pterygo palatine joint bent.The contraction of sphenopterygoid muscles also helps in the movement of pterygoid forward.

(iii) Closing of the jaws and the injection of venom :

Closure of the jaws are due to the simultaneous contraction of the anterior, middle and posterior temporal muscles which strongly elevate the mandibles.

In the colubrids the venom gland is also compressed by the superior and inferior portions of the anterior temporal muscles, producing torsion on its capsule with the expulsion of venom from the gland along the duct, the papilla of which becomes approximated to the groove at the base of the fang, but in certain Australian species venom may sometimes be observed to spurt a considerable distance during a snap bite at a time when no object is actually being bitten.

In the vipers there is an entirely different anatomical arrangement of muscles acting on the venom gland; expulsion of its contents is instantaneous and independent of fixation of the lower jaw.

(iv) Retraction of the fangs and insertion of venom :

Immediately following the insertion of the fangs accompanying with the discharge of venom occurs which are due to contraction of the retractor muscles.

The muscles contract at the time of insertion of venom which occurs after the piercing of the fangs.

The contraction of the muscle causes the squeezing the poison gland into the groove or channel of the fangs.

11.7 Conclusion

Snakes are specialized group of reptiles under order Ophidia, (limbless group). There are about 3,000 species of snakes are found in the tropical and subtropical part of the world. Out of these about 300 are poisonous. All the poisonous snakes have specialized poison apparatus in their heads.The biting mechanism serve two purposes, erection of fangs and injection of venom or poison in victim's body.There are some important bones and muscles which are directly or indirectly associated with the mechanism of biting. In the skull, maxillae, quadrate, pterygoid, squamosals, ectopterygoids and palatines are movably articulated.

11.8 Summary

Snake venom is a clear, transparent, pale yellow or straw-coloured fluid having a specific gravity of 1.03-1.07. The pH of the venom varies in different species, e.g. in Russell's viper pH is 5.8 while that of cobra's venom is 6.6. There are two kinds of snake venom. One affects the nerves (the venom of the Cobra and Krait), the other affects blood (that of the Vipers). Venom is protein in nature containing many enzymes, viz. Proteinase, Hyaluronidase, L-Arginine hydrolases, Transaminase, L-Amino acid oxidase, Phospholipase-A, B and C, Phosphodiesterase, Cholinesterase, Ribonuclease, Deoxyribonuclease, Alkaline phosphatase, Acid phosphatase, Exo peptidases etc. The composition of venom varies from species to species.

11.9 Glossary

Fang- The biting teeth of snake by which poison will come out.

11.10 Further reading

B D Sharma (2002)-Indian Poisonous Snakes: An Ecological And Clinical Study, pp 336,

Cleveland Hickman, Jr., Susan Keen, David Eisenhour, Allan Larson and Helen I'Anson (2018)- Integrated Principles of Zoology, Mc Graw Hill,, London & New York

11.11 Model questions

How many types of fangs are found in poisonous snakes ?

Which gland is modified as poison gland ?

How many types of poisons are found in snakes ?

Unit-12❑ Evolution of Tetrapoda skull and its divergence.

Structure

12.1 Objective

This unit helps the learners to understand the evolutionary changes occurred in the skull bones of tetrapod or vertebrate animals. Not only that this unit also helps to learn about the functional significance of these evolutionary changes in the skull bones.

12.2 Introduction

The skull is a vertebrate novelty, the origin and elaboration of which is associated with major evolutionary transitions, including the shift to a predatory lifestyle, the colonization of land, and the ability to masticate while breathing. The vertebral theory,

which posits that the skull forms by fusion of initially discrete vertebrae, was an early and compelling idea for the origin of the skull. Of the different evolutionary hypotheses, such as the spatial packing hypothesis, assert that increases in relative brain size (en-cephalization) have caused alterations to the modern human skull.

12.3 Evolution of Tetrapoda skull and its divergence

The word "tetrapod" means "four feet" and includes all species alive today that have four feet — but this group also includes many animals that don't have four feet. That's because the group includes all the organisms (living and extinct) that descended from the last common ancestor of amphibians, reptiles, and mammals.

So, for example, the ichthyosaur, an extinct swimming reptile, is a tetrapod even though it did not use its limbs to walk on land.

So is the snake, even though it has no limbs. And birds and humans are tetrapods even though they only walk on two legs.

All these animals are tetrapods because they descend from the tetrapod ancestor described above, even if they have secondarily lost their "four feet."

Theories regarding the origin of the skull are closely tied to theories of the origin of the head.

The vertebral theory, which posits that the skull forms by fusion of initially discrete vertebrae, was an early and compelling idea for the origin of the skull.

As the structural interface between the skull and the rest of the body, the occiput has been the subject of intense study, especially in tetrapods.

The occiput in tetrapods forms most of the posterior surface of the skull. In adults, it comprises several endochondral bones that ossify within the posterior (post-otic) chondrocranium.

The occiput forms in the segmented, post-otic region of the skull, which is derived from the anteriormost, or occipital, somites.

The loss and fusion of skull bones is common to a number of evolutionary transitions.

Cranial bones that have fewer contacts are more likely to be lost across tetrapod lineages.

The presence or absence of cranial bones and the distribution of sutures have important implications for load transfer and the structural resistance of the skull.

12.3.1 Composition of the skull

There are three elements that contribute to skull formation in the vertebrates / Tetrapods :

A) The Neurocranium (Chondrocranium)

The neurocranium is the portion of the skull that protects the brain and certain sense organs. In the Elasmobranchs (sharks and rays) it is composed of cartilage

(chondrocranium), but in most other vertebrates, the cartilage is replaced by bone (endochondral or replacement bone). The neurocranium is a specialized portion of the splanchnocranium and comes from neural crest cells and mesodermal mesenchyme. The bones forming these regions are grouped as the occipitals, sphenoids and ethmoids.

B) The Splanchnocranium

The splanchnocranium consists of the gill arches and their derivatives. The gill arches serve to support the gills and offer a site for respiratory muscle attachment. The original branchial skeleton of cartilage came from neural crest cells.

C) The Dermatocranium

These bones are grouped as the facial (upper jaw, nose), vault (front of skull), orbital (around eyes), temporal (side of skull), palatal (roof of mouth) and mandibular (lower jaw) series.

12.3.2 Bones of the skull and their origins

1. Neurocranium (Chondrocranium) is from neural crest cells and mesodermal mesenchyme. It can remain catrilage or become replacement bone. We will study three groups of bones the Occipitals, the Sphenoids and the Ethmoids.

2. Splanchnocranium comes from neural crest cells and is either cartilage or replacement bone.

Arch 1 forms the jaws and is called the mandibular arch. We will particularily study the articular which becomes the malleus of the ear in mammals and the quadrate which forms the incus.

Arch 2 is the hyoid arch and we will see the hyomandibular become the collumella and then the stapes of the ear. The hyoid bone also remains as part of the hyoid bone of the larynx.

Arches 3-5 are gill arches in fishes and also involved in jaw suspension.

3. Dermal bone is from mesenchyme and ectomesenchyme of the dermis and it overlies the neurocranium and splancnocranium. Tese are the the bones on the dorsal drawing of the wolf plus the lower jaw of mammals (dentary bone) and the new bones, the palatine and bulla.

12.3.3 Modifications to the skull

Following are the major evolutionary modifications occurred in the tetrapod skull :

1. Temporal Fossae :

Fossae (cavities, pits, or holes), are modifications of the skull that allow for more powerful jaws. They provide more space in the skull for the jaw muscles to expand during contraction and they offer a more secure area for the muscles to attach.

Fish skulls have no fossa and are therefore called anapsid.

The turtle skull, like the fish skull, has no fossa and is anapsid.

In reptiles (excluding turtles), there evolved a pair of openings on either side of the skull in the temporal region, called the temporal fossa. Study the location of the supratemporal fossa, and the infratemporal fossa on the skull of the alligator. The presence of two temporal fossae is the diapsid condition and is found in some reptiles and birds.

Some fossil reptiles lost the lower (infratemporal) fossa; this is the parapsid (or euryapsid) condition, which is now extinct.

The loss of the supratemporal fossa and the presence of only the infratemporal is the synapsid condition. It occurred in some extinct reptiles, and is represented now by the mammals.

2. The palate :

Modifications for breathing air: evolution of the secondary palate.

The secondary palate separates the oral passageway from the nasal passageway. There have been three stages in the evolution of the secondary palate:

The fishes and amphibia have a complete roof to the mouth which is the primary palate.

This is the floor of the neurocranium. This was inconvenient when breathing while eating.

Reptiles show a trend in the evolution of a secondary palate.

The turtle on demonstration shows a development of the maxilla, premaxilla, which turn inward to form a shelf, and a new bone, the palatine, which provided a partial secondary palate.

The alligator is a further stage and shows a complete bony secondary palate.

Mammals (wolf, ox) have a functional complete secondary palate, though not the complete bony palate of alligator, the posterior portion being the fleshy soft palate, with the hard palate in the anterior.

3. Jaw Suspension :

Splanchnocranium contributes to jaw attachment to the skull.

The mandibular arch (1st segment) of the splanchnocranium formed the upper and lower jaws of cartilage called the palatoquadrate (upper) and Meckel's cartilage (lower).

The hyoid arch (2nd segment) surrounded the spiracle opening.

The Ostracoderms, with one fused head plate of dermal bone (extinct) and modern Agnathans (e.g. Lamprey), lack jaws .

Primitive fish, Holocephali (e.g. the Rat Fish-Chimaera) display the condition in which the palatoquadrate articulates, or is fused to, the chondrocranium with no supporting function from the hyoid arch.

This is the autostylic condition of jaw suspension.

Early sharks and bony fish (now almost all extinct, except for the extant six-gilled shark) had the palatoquadrate attached by ligaments to the chondrocranium.

In addition, the hyoid arch specialized to form the hyomandibular, which helped to stabilize the posterior end of the jaws and was attached by a second ligament.

This double type of suspension is referred to as amphistylic jaw suspension.

In modern bony fish and modern day sharks (e.g. dogfish) the hyomandibular of the hyoid arch forms a bridge attaching the jaws to the skull.

The jaws, free from the skull.

In tetrapods, the upper jaw alone suspends the lower jaw.

This condition is metautostylic.

Mammals have only one paired bone, the dentary, in the lower jaw.

The articular and quadrate bones are jaw joints in most vertebrates but are moved to the ear in mammals (Ear ossicles).

The entire upper jaw is incorporated into the baincase and jaw suspension is craniostylic.

12.3.4 Characteristic features of skull in different classes of vertebrates

1. FISH

One occipital condyle.

Opercles present only in the fish.

Some fish have bones which are lacking in others, there being a great difference between some of the families in this respect.

2. AMPHIBIANS

Two occipital condyles ;

No trace of supra- or basioccipitals.

The skull is remarkable for the extent to which the chondrocranium is retained and the consequent small number of primary bones.

The pro otic alone forms the auditory capsule in the frog, the other otic ossifications not being developed ; in the Urodela an opisthotic is added.

3. REPTILES

One occipital condyle.

The transverse is present in all reptiles, except the turtles, and in no other vertebrates. The zygomatic arch, formed by the quadrato-jugal and the jugal, is wanting in the Ophidians.

In turtles there are no teeth, and the basisphenoid is the only one of the s'phenoidal bones present.

Of the otic bones the prootic is always distinct, the epiotic is fused with the supraoccipital, while the opisthotic (free in turtles) is usually united to the exoccipital.

4. BIRDS

One occipital condyle.

The bones of the cranium fuse early so that the sutures between them are obliterated.

Teeth are lacking in modern birds.

The anterior end of the parasphenoid forms the rostrum and the posterior the basitemporal.

5. MAMMALS

Two occipital condyles.

The lower mandible articulates with the squamosal and is composed of five elements on each side, as the articular has been taken into the middle ear to form the malleus.

The quadrate has gone into the ear and become the incus.

The stapes is derived from the hyomandibular and from some membranous elements.

12.4 Conclusion

Over time, skulls changed from a primitive collection of bony plates to the highly reinforced, structural marvels most vertebrates carry around today. The skull is a vertebrate novelty, the origin and elaboration of which is associated with major evolutionary transitions, including the shift to a predatory lifestyle, the colonization of land, and the ability to masticate while breathing. Theories regarding the origin of the skull are closely tied to theories of the origin of the head. The vertebral theory, which posits that the skull forms by fusion of initially discrete vertebrae.

12.5 Summary

The vertebrate skull is anatomically complex and phylogenetically diverse; it presents unique opportunities to examine the role of developmental processes in evolutionary change. The skull is the most studied and documented part of the vertebrate skeleton, perhaps because of its relationship to the encephalon.The neurocranium is related to the parts of the skeleton of dermal or cartilaginous origin that surround the sense organs and the encephalon. The splancnocranium is the skeleton, also with the two origins mentioned above, that forms the structure of the maxilla, the mandible and the support of the mouth.

12.6 Glossary

ANAPSID SKULL - have no fenestrae in the skulls,, most primitive type of skull.

EURYAPSID SKULL- have one fenestra high on both sides of the skull.

PARAPSID SKULL—This skull also had only one pair of temporal vacuities on the upper side, guarded by two additional bones, namely, postfrontal and supratemporal.

DIAPSID SKULL- This type of skull has two temporal vacuities on either side of the skull.

SYNAPSID SKULL-only one inferior temporal vacuity on each side of the skull but it was guarded by postorbital and squamosal bones.

12.7 Further reading

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ROMER, A. S. (1956) Osteology of the Reptiles.: University of Chicago Press,. Chicago.

12.8 Model Questions

1. In which animal do you find monocondylic skull ?
2. What do you mean by anapsid skull ?
3. What part of the skull serve as the attachment of jaw ?
4. What are the cause for the evolution of secondary palate ?

Unit - 13 ❑ Bird migration–types, cues an mechanism of migration.

Structure

13.1 Objective

The main aim of this unit is to clear the idea about avian migration which is itself a natural miracle.Similarly this unit also tells us how migratory birds can navigate with pin-point accuracy as well as about the different cues which is inducing the birds to migrate.

13.2 Introduction

Not all birds stay in the same place their whole lives. Some migrate to take advantage of seasonal resources, especially food, so that they can breed successfully or simply survive. Some migrations are short, but many birds make truly epic journeys,

crossing continents, deserts and oceans. Globally, around 2,000 species of bird are regular migrants (about 20% of the world's total). Bird migration behaviour has evolved over long periods of time. A bird's body tells it exactly when to migrate. Each year, at the same time, glands in its body release hormones into its system.

13.3 Migration of Birds

The word migration has been derived from the Latin word "migrare" which means movement from one spatial unit to another. Any position occupied by an organism at a moment in time is considered as the spatial unit. According to Cahn (1935) migration can be defined as, "a periodic passing of animals from one place to another." In birds the migration means a two way journey- from a breeding and nesting nesting place (called home) to a feeding and resting place (called new place) and back journey from the new place to the home. The movement occurs during the particular period of the year and the birds usually follow the same route.

13.3.1 Types of bird migration :

Bird migration can be classified into various ways and different types which are as follows :

A. On the basis of place of migration

1. Return migration :- Migration to a previously known place which has been visited earlier is called return migration.

2. Exploratory migration :- Migration to a completely unknown space which has not been visited earlier is called exploratory migration. Although ability to return to return to the known place is retained but is not exploited.

3. Removal migration :- Migration to a comparable spatial unit which is not followed by a reversal to the original spatial unit is called removal migration.

B. On the basis of the plane of movement of the migrants

In this way migration is divided into 3 types :-

1. Horizontal migration :- Migration occurring on a path perpendicular to the gravitational force of the earth is called horizontal migration.

Depending upon the directions of path, horizontal migration is further divided into following two kinds :-

(a) Latitudinal migration :- Horizontal migration occurring from north to south or vice-versa is called latitudinal migration. Usually it occurs from north to south and it occurs from south to north in few cases only.

(b) Longitudinal migration :- It takes place in East- West direction. They starting moves from towards the Atlantic coast to avoid the continental winter.

2. Vertical migration :- Migration occurring in a plane parallel to the gravitational pull of the earth is called vertical migration.

3. Altitudinal migration :- This involves both horizontal and vertical components. Birds fly up and down over mountain and hills. Generally migration occurs at relatively low altitudes.

C. On the basis of time of migration :-

Migration is also divided into two types

1. Diurnal migration :- Many large birds fly in day. Diurnal migratory birds usually travel in flock which may be well organized. These are crows, swallows, robin, hawks, cranes, pelicans etc.

2. Nocturnal migration :- Majority of small sized birds like sparrows, warblers, thrushes etc. prefer to fly at night, under the protection cover of darkness to escape their enemies. They feed and rest during day.

D. On the basis of reasons of migration :-

Migration is categorized into 3 types

1. Climatic migration :- This type occurs in response to change in the climate of the environment. North-South migration of many ducks and geese is a good example of climatic migration.

2. Alimental migration :- It occurs due to shortage of water food. It may occur at any time in a year.

3. Gamatic migration :- It occurs in a need to certain environment for successful completion of the some parts of the reproductive process. Majority of the birds perform this type of migration.

E. On the basis of seasons during which birds migrate :-

In this way bird migration can be divided into three types which are-

1. Summer migration :- These birds arrive in spring from the south to breed and leave for the south in autumn. e.g., Swifts, Swallows, Nightingales, Cuckoos etc.

2. Winter migration :- These birds migrate Southward and South-West in winter and go back to North in spring. e.g., Field fare, Snow bunting, Red wig etc.

3. Birds of passage :- Some birds are seen for a short time twice in a year on their way to colder or warmer countries in spring and autumn e.g., Sand pipers, Spines etc.

13.3.2 Process of navigation or way finding during migration :

Migratory birds use land marks like mountains, hills, rivers, valleys etc. for identification of route. Birds may also navigates through responses to the earth's magnetic field. Birds may also be guided by position of sun in day and by moon and stars during

night. Birds also learn by experience and guide themselves during migration. Migration is the inherent nature of the birds which as a result of hereditary accumulation reaches the offspring or in other word migration is an example of inate behaviour.

13.3.3 Cues or causes of migration :

The obvious stimulus or cues of migration in birds is still unknown. However various factors may cause the bird to migrate and the factors are :-

1. Environmental stimulus for migration :- It is believed that decline in temperature and food availability might trigger off migration. With less hours of light during autumn in temperate and Northern hemisphere, the time for food gathering is lessened. It initiates autumnal migration. Similarly increasing day length causing elevated temperature in Southern hemisphere during spring acts as initiator of migration. However, it is true that the sensitivity of migratory birds to changes in the weather is species specific.

2. Physiological stimulus for migration :- Scientists are trying to assess the role of endocrine glands such as pituitary, gonad, thyroid, adrenal and pineal in migration. It has been demonstrated in a passerine migrant that thyroid hormones may play an important role in the initiation of migratory deposition. Gonadal hormones are also responsible for the deposition of fat in many migratory birds.

13.3.4 Mechanisms of Bird Migrations

Migrating birds can fly great distances, visiting many unique landscapes, and thus face many ecological problems which can be solved either through natural selection shaping innate behavioral programs or through cognitive processes.

Although some aspects of migratory behavior are genetically pre determined such as initial departure time, direction and distance, every migrating bird embarks on a journey that is unique, and therefore exploration, experience and learning necessarily play a fundamental role in overcoming the challenges of migration.

Fueling between migratory events is an important determinant of migration performance.

The rate of fuel accumulation partially determines the overall migration speed.

One might therefore expect adaptations which maximize both food intake and its conversion into fuel stores, such as fat, which contains the most energy per unit of mass compared to alternatives.

Migratory birds are required to locate and ingest food, break it down, absorb it, and create and transport fat bodies to specialized fat deposits. These processes require special adaptations, which among others include flexible organs that grow and shrink in relation to the requirements of fueling and movement.

During fueling, migratory birds have been shown to ingest and process food close to their metabolic capacity. To do so they grow a larger intestine, gizzard, and liver to boost their food processing capacity, and grow larger flight muscles to lift and transport increasing fuel loads.

Stochastic events during migration may play a large role in determining the habitats that migrating birds come to occupy during stopover.

Stopover sites become critical during migration; the decision where to land is vital for whether sufficient resources can be found and fat reserves restored.

Some migratory birds may use social information to gather information about the quality of habitats. For example, migrants may initially join flocks at stopover sites before foraging on their own, and may use resident species as an indicator of high-quality breeding habitats. Such social interactions may support information gathering.

One environmental feature, wind, has a very profound influence on the migratory movements of birds. Depending on the direction and strength of the wind, migrants may greatly benefit if the wind flows in the same general direction as the intended course or may be hindered during flight if the wind flows in an opposing direction.

Recent studies have demonstrated that migratory birds can choose when to fly to avoid adverse wind conditions and thus improve travel speeds.

The most remarkable aspect of migration is how birds can routinely return to previous breeding and overwintering sites following migration of often thousands of kilometers.

They do so using many sophisticated sensory adaptations and navigation capabilities.

Migratory birds have access to several compass mechanisms for orientation, using information from the sun (both the position and the pattern of skylight polarization), stars and Earth's magnetic field.

13.3.5 The Magnetic Compass of Birds (Kramer, 1953)

Friedrich W. Merkel and Wolfgang Wiltschko discovered that birds have a magnetic compass sense in the mid-1960s . When birds are placed in a round cage at night, they show migratory restlessness (or ***Zugunruhe*** in German,). The birds primarily jump/ flutter in their migratory direction, and when the magnetic field is turned horizontally in the absence of celestial cues, the birds turn their orientation with the magnetic field.This is the behavioral evidence required to show that a migratory bird species possesses and is able to use a magnetic compass . A magnetic compass has been found in more or less every migratory bird species properly tested for it ; therefore, it is quite safe to presume that **all migratory birds and potentially birds in general possess a magnetic compass.**

It is important to note that there are at least two different magnetic field properties that could potentially be used as input for a magnetic compass sense. A **magnetic polarity compass** (e.g., the human ship compass) uses only the horizontal component of the field lines, which points toward Magnetic North anywhere on Earth except at the magnetic poles. On the other hand, a **magnetic inclination compass** detects only the angle between the geomagnetic field lines and the Earth's surface or gravity—not the polarity of the field lines.

The smallest angle between the Earth's surface and the geomagnetic field lines indicates the direction **"toward the magnetic equator"** whereas the greatest angle indicates **"toward the magnetic pole."** Because the inclination is opposite on the Northern and Southern Hemisphere, respectively, this holds on both hemispheres. **All bird species properly tested so far have a magnetic inclination compass.**

The magnetic compass of night-migratory birds does not separate between North and South like our ship compass, but it distinguishes between "toward the magnetic equator" and "toward the magnetic pole" (the Magnetic North Pole in the Northern Hemisphere and the Magnetic South Pole in the Southern Hemisphere).

The birds' magnetic compass sense seems to have a rather narrow functional intensity window, but this window seems to be extendable to new intensities after a few hours of adaptation to a changed magnetic field intensity.

13.4 Conclusion

Birds express a range of migratory patterns, from highly predictable obligate migration, to less predictable nomadic and fugitive migrations. Migration is preceded by a period of physiological preparation, which can include increases in fat deposition as an energy reserve for migratory flight and increases in the size of the flight muscles. As the migratory journey progresses, birds may make stopovers to refuel along the way. . In order to find their way on their migratory journey, birds may make use of several biological compasses, as well as inherited migratory programs, and learned landmarks on the landscape. Birds time their migrations using cues in the environment, most notably day length, and an endogenous circannual clock.

13.5 Summary

Birds migrate to move from areas of low or decreasing resources to areas of high or increasing resources. The two primary resources being sought are food and nesting locations. Birds that nest in the Northern Hemisphere tend to migrate northward in the spring to take advantage of burgeoning insect populations, budding plants and an abundance of nesting locations. As winter approaches and the availability of insects and other food drops, the birds move south again. Escaping the cold is a motivating factor but many species, including hummingbirds, can withstand freezing temperatures as long as an adequate supply of food is available.

13.6 Glossary

Flyway- It's a flight path used in bird migration.

Passage migrant- This refers to a bird passing through a place temporarily on its migration.

Vagrant- This is a bird that is found well outside its usual range, so it it usually a very rare migrant.

Irruptive migration- Irruptive migration is a migration that is irregular between years.

13.7 Further reading

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13.8 Model questions

1. What are the major cues for bird migration?
2. What is bird magnetic compass ?
3. How bird navigate during migration?
4. What do you mean by " Zugunruhe"?
5. Define vagrant.
6. What is diurnal migration?

Unit-14 ❑ Ecolocation and Sonar systems in Bats and Whales.

Structure

14.1 Objective

Animal cognition is an important part of biology.The cognitive mechanism is different in different animals. Echolocation is one of the important cognitive mechanism used by some of the highly evolved animals like bats and some of the aquatic mammals like dolphins and whales. This unit helps the learners to understrand how the sound is produced and the mechanism by which the animals can understand the meaning of the sounds.

14.2 Introduction

Echolocation, or biosonar, is an active process, used by the species that have it for sensing the environment when vision is ineffective, for example at night or in turbid

water. It is the production of sound by animals and the subsequent determination of the position (and other features) of objects from information encoded in acoustic reflections. Echolocation has evolved to its greatest sophistication in bats and toothed whales (dolphins and their relatives).

14.3 Echolocation in Bats

Not All Bats echolocate but allmost about 70% of all bat species worldwide have this ability.

Bats can see as well as humans can, but they have evolved a sophisticated method of using sound that enables them to navigate and find food in the dark called echolocation. Bats produce echolocation by emitting high frequency sound pulses through their mouth or nose and listening to the echo. With this echo, the bat can determine the size, shape and texture of objects in its environment. Bat echolocation is so sophisticated that these animals can detect an object the width of a human hair.

Bats can be broadly characterized by their echolocation calls as shouting bats and whispering bats. Big brown bats and little brown bats are shouters and produce sounds (if we could hear them) of 110 decibels or similar to the loudness of a smoke alarm. Northern long-eared bats are whispering bats and produce sounds of 60 decibels (similar to the levels of normal human conversation). Shouters tend to forage for food in open spaces; whisperers glean insects from the foliage of trees and forage in the cluttered environments of forest interiors.

Most bat echolocation occurs beyond the range of human hearing. Humans can hear from 20 Hz to 15-20 kHz depending on age. Bat calls can range from 9 kHz to to 200 kHz. Some bat sounds humans can hear. The mega-chiropterans, that feed on fruit, flower, nectar etc., generally lack ultrasonic orientation however Microchiroptera are able to do this echolocation.

14.3.1 Anatomical Structure and their functionalities in respect to Echolocation

Micro-chiropterans generate ultrasonic sounds in the larynx. The larynx in micro-chiropterans is proportionately longer than that found in megachiropterans and the cartilages are ossified to make a rigid framework. The strong cricothyroid muscles put greater tension on the light vocal cords. The complexity and large size of this sound-producing structure directly relates to the range of ultrasonic sound that it produces. It is performed by discrete pulses of high intensity and up to 150 kHz frequency which is emitted through the nose and mouth. In the case of horseshoe bats there are special resonating chambers and the face is elaborately modified forming a nose-leaf.

The role of nose- leaf in echolocation is not well-understood. Rhinolophid and hipposiderid bats possess complex nose-leaf that serve to beam the ultrasonic sounds and help in directing the signal to a particular direction. The complex flaps and folds also serves to shield the ears from the outbound, nasally emitted signals and so increase their overall sensitivity to returning echoes.

The ears of bats are greatly specialised .

The pinnae or external ear of most echo-locating bats are large and funnel-shaped.

They are small in bats that fly fast and emit loud sounds, while they are enormous in those that hunt insects using faint pulses.

The ears of many bats contain a short to long vertical flap (tragus) that may improve the directionality or sensitivity to inbound echoes. If may also act as a deflective shield that protects the ear from the intense outbound acoustic pulses.

The pinnae are positioned in such a way so that it can be receptive to inbound echoes from 30°-40° on either side of the mouth.

The direction of an obstacle or target is enhanced by comparing the differences in the intensity and quality of echoes as they arrive at each ear.

As there are two ears, it yields stereophonic images in a manner like that of our two eyes which yield stereo-visual images.

Rhinolophus species is able to move the ears back and forth alternately when it scans its surroundings.

The middle ear comprises of the tympanic bone (ring) that supports the tympanic membrane and the middle ear ossicles.

The thickness of the tympanic membrane of micro-chiropterans ranges from 0-002 to 0-011 mm, which is relatively thinner than the eardrums of other mammals.

A correlation seems to exist between frequency sensitivity in hearing and the acoustic signals emitted during echolocation.

Bats that operate with high frequencies (50-125 kHz) generally have a smaller tympanic area than bats that operate at lower frequencies (below 50 kHz).

Similar correlation exists with the mass of the middle ear ossicles.

The middle ear has two muscles which are much developed in micro-chiroptera

1. Tensor tympani and

2, Stapedius .

Of the two, the stapedius muscle is especially important in regulating the sound entering the ears.

The cochlea and associated labyrinths are the most important regions of the ear.

In micro-chiroptera, the cochlea is relatively larger and more complex in structure .

In most micro-chiropterans, the number of turns in the cochlear duct varies between 2-5 and 3, while in *Rhinolophus* it is 3-5.

The membranous labyrinth and organ of corti are specialised anatomically and physiologically for the reception of certain frequencies.

The cochlea, due to these adaptive features, are somewhat conical in shape instead of spherical.

To reduce the potential interference from outbound pulses, the cochlea is suspended loosely in connective tissue, rather than being solidly fused to the bottom of the skull.

14.3.2 Specialised Brain for echolocation

The cerebral hemispheres of echolocating bats are small and the olfactory portions reduced, but the inferior collicula (concerned with hearing) and cerebellum are large. The eyes, moderately large and the retina containing mainly rods are used probably during twilight.

Electrical nerve impulses from the sensory cells in the organ of Corti are collected and travel along the auditory nerves to the inferior colliculi, where the sounds are analysed for its information content.

The location, large size and general exposure of the inferior colliculi on top of the midbrain has led to its hearing range extending from a frequency of less than 1 kHz to about 200 kHz.

Some cells of the colliculi in the micro chiroptera responds weakly to outbound signals, but responds strongly to the returning echo.

Similarly other cells are particularly sensitive to the time delay between the outgoing pulse and the returning echo.

14.3.3 Characteristics of echolocation Sounds

Natural sounds are complex in structure and consist of a collection of several to many frequencies.

The different frequencies in a complex sound are called harmonics or overtones.

The harmonic structure of a complex sound is not a random assortment of frequencies, but it is rather an ordered sequence of related frequencies .

Complex sounds are further complicated by the fact that each harmonic may be produced with different amplitudes or intensities, and, in some cases, harmonics may be ‘dropped out’ of the sound spectrum altogether.

Bats produce a variety of complex sounds in their acoustic orientation vocalizations, which comprises of sweeps through several frequencies with accompanying harmonics.

These sounds are produced in the larynx and may be filtered or altered by various resonating cavities or other peculiarities in the vocal tract or nasal passages.

The acoustic sounds thus emitted by the bat have a particular structure.

Micro-chiropterans produce high frequency sounds that are acoustic signals emitted by the bat for the purpose of gathering vital information about objects in its immediate vicinity.

14.3.4 Characteristics features of micro-chiropterans ultrasonic signal

The micro-chiropterans ultrasonic signal is characterised by a combination of several parameters which are -

1. Duration of signal- The orientation signal used by bats varies in duration from about 0-2 to 200 milliseconds (ms).

2. Harmonic structure of signal - Bats can incorporate from one to about 5 harmonics in their acoustic orientation signals.

3. Frequency-modulated (FM) - The frequency-modulated components comprise of sweeps that starts with a beginning frequency, passes through several to many intermediate frequencies and, ultimately, ends in some ending frequency that is usually lower than the beginning frequency.

4. Constant-frequency (CF) component - Constant-frequency signals are echo-location sounds emitted at one frequency.

5. Amplitude - The amplitude (intensity or loudness) of the acoustic orientation sounds of bats are of a wide range.

6. Variations of repertoire- Each bat may change its acoustic repertoire (vocal signalling) along one or more of the parameters discussed above.

14.3.5 Types of Micro-chiropterans acoustic imaging system :

It is of two kinds -

1. Time frequency spectrum consisting primarily of broadband, frequency-modulated (FM) signals. It consists of frequency-modulated signals with multiple harmonics.

2. Time-frequency structure that consists mainly of narrow band, constant frequency (CF) signals. It consist of multiple harmonic, short CF signals. These signals are of very short duration (0-2-2 ms) and lack any substantial FM sweep.

14.3.6 Acoustic orientation of bats :

With the help of echolocation bats can discriminate the following :-

1. Bat is capable of detecting and flying through an obstacle network of wires 0.28 mm in diameter.

2. Target range (distance) discrimination of echo locating bats varies with the size of the target.

3. Bats can differentiate target shape and texture of objects.

14.3.7 General Pattern of Echolocation :

A generalized sequence of acoustic events appears to be common to all echo locating bats and can be divided into three distinct phases –

Search phase

Approach phase and

Terminal phase

Each phase of echolocation is characterised by a marked quantitative change in the rate at which the ultrasonic sounds are emitted and the duration of each signal.

Different bats uses a different qualitative pattern of acoustic orientation.

During the search phase of echolocation, the initial detection of a target takes place.

The position of a target is first perceived when an echo, after getting reflected from the object, arrives back at the bat's ears.

The distance of the object can thus be evaluated by the time interval between a pulse emission and the return of its echo.

In some bats, the echo from a pulse arrives at the time when the next pulse emission has already taken place.

14.3.8 Echolocation and Doppler Effect (change in the frequency of a wave) :

Different bats use different methods of echolocation.

It is actually the process to determine the distance to prey by the time required for the signal to bounce back.

The echoes coming back from any insect show the Doppler Effect, which is, if a sound source is moving toward us, the sound will have a higher pitch; if it is moving away, the sound will be of lower pitch.

The horseshoe-nosed bat emits a signal at 83-4 kHz. If the echoes coming back from the insect (prey) are at 83-4 kHz, they tell the horseshoe-nosed bat that the insect is flying away from it at the same speed that the bat is travelling.

If the sound comes back lower than 83-4 kHz, the insect is moving away faster than the bat; and if the sound comes back at a higher speed then it means that the bat is closing on the insect. The bat then lowers the frequency of its signal.

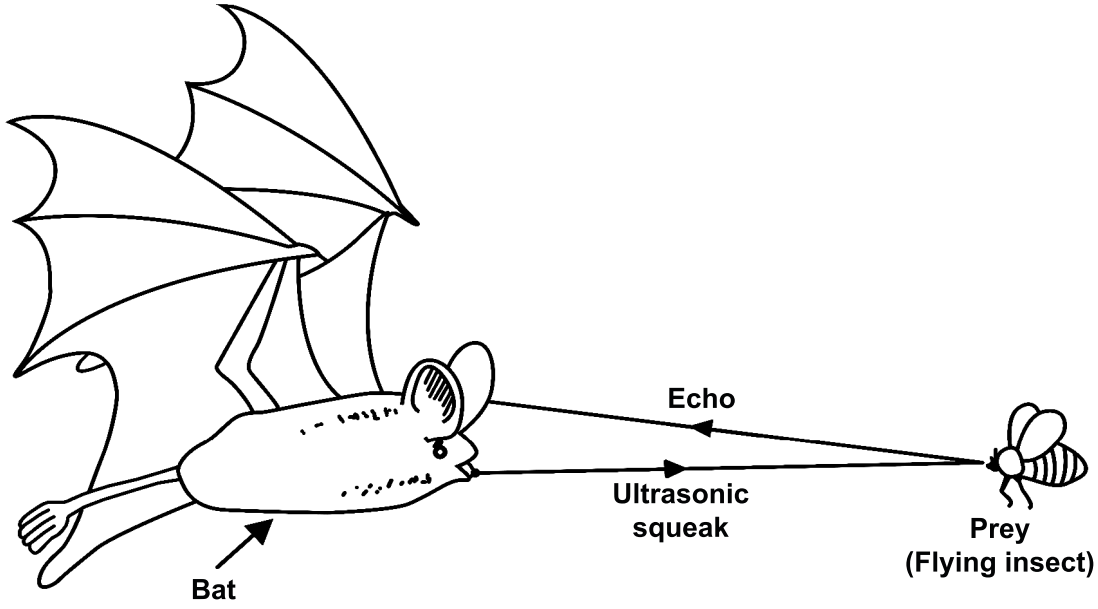

Figure 38 : **Graphical representation of ecolocation**

14.3.9 Echolocation in Whales and Dolphins :

Echolocation is very important to whales and dolphins also for hunting, navigating and communicating.

Toothed whales and baleen whales use sound quite differently.

Toothed whales and dolphins (for example killer whales and bottle-nose dolphins) use echolocation for hunting and navigating, while baleen whales (for example humpbacks and blue whales) generally produce a series of sounds which are frequently termed as 'Whale songs' that are used for cognition puposes between themselves.

Toothed whales produce a variety of sounds by moving air between air-spaces or sinuses in the head.

Sounds are reflected or echoed back from objects, and these are thought to be received by an oil filled channel in the lower jaw and conducted to the middle ear of the animal.

When swimming normally, the sounds emitted are generally low frequency; the echoes from these sounds provide information about the seafloor, the shorelines, underwater obstacles, water depth, and the presence of other animals underwater.

The evolution of acoustic fat bodies in the head, in the melon which is present in the whale forehead , extramandibular fat bodies alongside the jaw bone and intramandibular fat bodies within the jaw bone are essential for sound use during the time of echolocation.

A recent theory suggests that very high intensity focussed sounds may be used to stun or disorient prey during hunting.

14.4 Conclusion

Bats can see but they have evolved a sophisticated methods of using sound that enables them to navigate and find food in the dark. Bats produced echolocation by producing high frequency sound pulses through their mouth and nose and listening to the echos.

14.5 Summary

Echolocation is the process in which an animal obtains an assessment of its environment by emitting sounds and listening to echoes as the sound waves reflect off different objects in the environment. In a very general sense, any animal that can emit sounds may be able to hear echoes from large obstacles. Dolphins are able to detect objects more than 300 feet away, and can even tell if a target has fluid inside of it. Bats' range maxes out at about a dozen feet, but they can sense objects while flitting through a dense forest or a huge bat swarm. Using sound, both types of mammals are able to discern differences in location down to fractions of an inch. Other animals have their own versions of sonar, too, adapted to their unique features and needs.

14.6 Glossary

Echo :- It is the repetition of a sound caused by reflection of sound waves.

Sonar system :- The system present in echolocating animals which is generally used to produce sound waves to detect under water objects.

Types of sound waves :- Sound waves are characterized into three types.

Audible sound waves are those that humans can hear.

Infrasonic sound waves are those that are too low-frequency (below 20 Hz) for humans to hear.

Ultrasonic sounds waves are those that are too high-frequency (above 20,000 Hz) for humans to hear.

14.7 Further reading

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14.8 Model questions

1. What is echolocation ?
2. What is the purpose of the doppler effect in echolocation ?
3. How does an animal using echolocation to know where an object is located ?
4. What do bats use for echolocation?
5. Can bats hear each other's echolocation?

Unit-15 ❑ Affinity of Sphenodon, Archaeopteryx and Prototheria.

Structure

15.1 Objective

The primary objective of this unit is to elaborate the term living fossil , connecting link and stabilising selection in animal kingdom. This unit helps to understand the students the cause that why Sphenodon is termed as living fossil and what are their affinities with othe close relatives. Similarly this unit also helps the learners to clear their idea about the ancester of birds and how the birds are originated. Similarly this unit also helps to understand that why prototheria is considered as the most primitive mammals.

15.2 Introduction

The *Sphenodon* belongs to order Rhynchocephalia is commonly known as "tuatara" and found only in NewZealand. *Sphenodon* is the oldest surviving Lepidosaurian reptile and a Mesozoic fossil shows the continuity of the race. Sphenodon also called living fossil because its apparently close resemblance to its Mesozoic forebears and because of a long, low-diversity history.

Archaeopteryx, genus of feathered dinosaur that was once thought to be the oldest known fossil bird. *Archaeopteryx* shared many anatomic characters with coelurosaurs, a group of theropods (carnivorous dinosaurs). The significance of Archaeopteryx is so great that many people mistakenly believe this dino-bird was much larger than it actually was. In fact, Archaeopteryx measured only about 20 inches from head to tail, and the largest individuals didn't weigh much more than two pounds—about the size of a well-fed, modern-day pigeon.

Prototheria is an obsolete subclass of mammals which includes the living Monotremata and to which a variety of extinct groups, including Morganucodonta, The prototherians are the egg-laying mammals, the survivors of a phylogenetic line that must have branched early from the line leading to other living mammalian groups. All living forms are limited to the Australian Biogeographic Region (essentially New Guinea and Australia, including Tasmania)

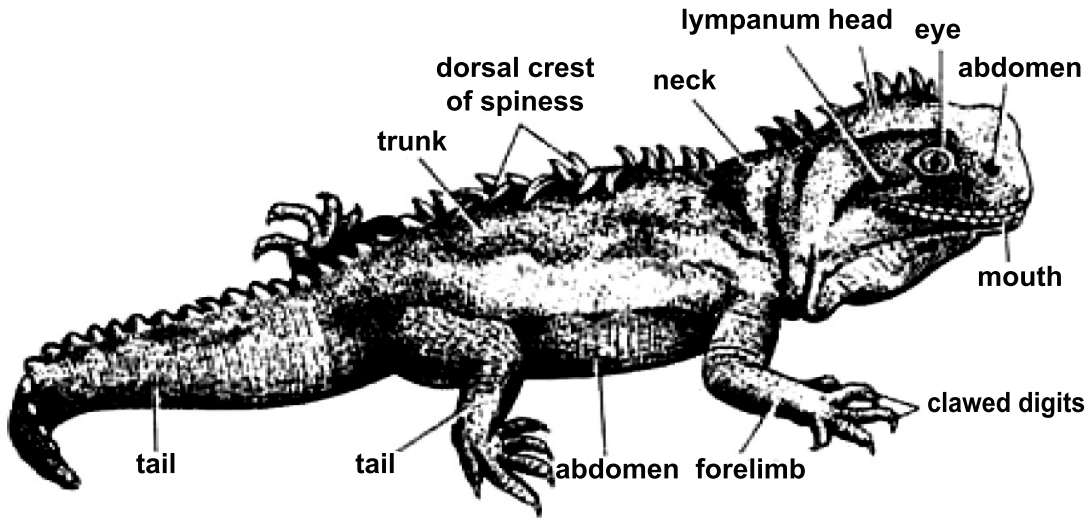

Figure 39 : **Sphenodon sp**

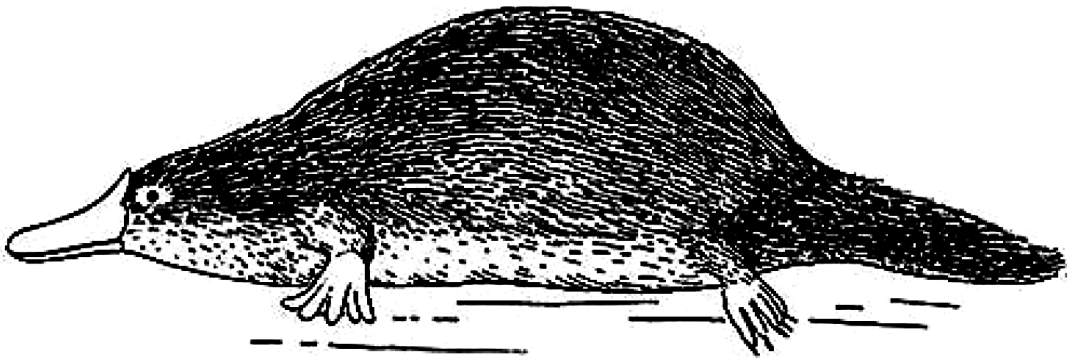

Figure 41 : **Ornithorynchus sp (Prototheria)**

15.3 Affinities of Sphenodon

Sphenodon possesses many peculiar features. It shows many structural similarities with the lizard. sphenodon is un doubtly a primitive and generalized type of reptile. They are unusual among the 10 000 species of living reptiles, being ranked at times as an order equivalent to the Crocodilia, Squamata and Testudines , but represented today by a single species, *Sphenodon punctatus.*

Now a question may raised that why *Sphenodon* be treated as living fossils ?

Sphenodon punctatus has often been identiûed as a 'living fossil' for a variety of reasons such as :

(1) the living form, superûcially, seems little different from its distant Mesozoic ancestors;

(2) the clade has had a very long duration, but with low diversity and possibly long-lived species and genera;

(3) it is the solitary sister clade to the equally ancient Squamata, comprising over 9000 species;

(4) there is a long gap in geological time between the modern form and the youngest fossil forms, in the Miocene, Paleocene and Cretaceous; and

(5) it shows supposedly 'primitive' anatomical features such as the closed lower temporal bar.

15.3.1 Anatomical peculiarities of Sphenodon :

Sphenodon has a lizard like form. Body measuring about 70cm in length.

The body is dull olive green in color with yellow spot above an whitish below.

The tail is bilaterally compressed. The tail can regenerate, if it is lost.

Except the lower side where the scales form transverse row of large square plate, the body is covered by small granular scale.

A median raw of erect spine extent from the top of the head to the tip of the tail but is interrupted at the neck region.

The eyes are large, dark and brown in color.

The cloacae aperture is a transverse slit.

The male lack copulatory organ.

The skull is typically built on the lepidopsauran plan.

The caudal vertebrae are divided by seven septum.

In rhynchocephalia, the teeth's are accordant and are fused with the subsequent bone.

The heart is typically reptilian.

The brain is simple with a very well developed parietal organ or pineal eye.

The third eye is the prominent characteristics of sphenodon.

The third eye is made up of a lens, a retina with a nerve connected to the brain, but iris is absent.

They feed mainly on insects with an occasional gecko or baby sea bird.

The life process of sphenodon is slower than on other reptiles and the eggs take more than a year to hatch.

They attain sexual maturity at the age of twenty.

15.3.2 Character analysis of *Sphenodon*:

Sphenodon shows many structural similarities with the lizard. *Sphenodon* is undoubtly a primitive and generalized type of reptile.

Affinities with dinosaurs :

Similarities

1. Skull is of diapsid type and the quadrate is fixed.
2. Presence of uncinate process and abdominal ribs.

Disimilaries

1. Ribs are single headed in sphenodon but they are double headed in dinosaurs.
2. The teeth in sphenodont are accordant while they are thecodont in dinosaurs.

Inference

All the above characteristics reveals that sphenodon very close similarities with primitive reptiles.

Affinities with crocodile :

Similarities

1. The quadrate is immovable.
2. The skull is diapsid type.
3. Abdominal ribs are present.
4. Ribs bear uncinate process.

Dissimilarities

1. The teeth are accordont in sphenodon but thecodont in crocodiles
2. Clavicle is present in sphenodon but absent in crocodile.

Affinities with Chelonia :

Similarities

1. The quadrate is immovable.
2. Urinary bladder is absent.
3. Caudal ribs are fused with vertebrae.

Dissimilarities

1. In sphenodon the vomer is paired but in chelonian, it is unpaired.

2. In sphenodon sternum is present but it is absent in chelonia.

3. The oviduct is sphenodon opens dorsally but in chelonian the opening is ventrally.

Affinities with Amphibia.

In sphenodon three(3) main arterial trunks come off from a short common trunk probably representing the conus arteriosus of the amphibians. In other reptiles such common trunk is absent.

The course of blood through arteria interossea is present in both sphenodon and amphibian.

Inference :

Because of its primitiveness sphenodon shows affinity with caudata amongst amphibians. But the reptilians' features of sphenodon are numerous and all that can be said is that sphenodon is the most primitive amongst the reptiles.

15.4 Affinities of *Archaeopteryx*

Archaeopteryx is a fossil species that is classified as a Ceolurosaurian dinosaur. Coelurosaurian dinosaurs include theropod dinosaur species that gave rise to modern birds. *Archaeopteryx* is important because it shows the transition from dinosaurs to modern bird species via the process of evolution. *Archaeopteryx* feathers are believed to have been black in color due to the presence of melanosomes, a black pigment that is sometimes found in feathers and skin.

15.4.1 Character analysis of Archaeopteryx :

Reptilian characters of *Archaeopteryx*

1. Jaws are provided with homodont teeth

2. Long lizard like tail

3. Presence of 20 free caudal vertebrae

4. Absence of pneumatic bones

5. Presence of 9-19 cervical vertebrae

6. Vertebrae are of amphicoelous type

7. Presence of cervical and abdominal ribs

8. Ribs are single headed and are without uncinate process.

9. Absence of sternum in Archaeopteryx

10. Eyes are provided with sclerotic ossicles in Archaeopteryx

11. Scales are present over the skin

12. Fore limbs are provided with free fingers with claws

13. The number of phalanges present in first,second and third fingers are 2,3 and 4 respectively

14. Presence of free carpels and metacarpels

15. Absence of carpometacarpus

16. Pelvic guirdla is always provided with elongated ilium and backwardly directed pubis.

Avian characters of Archaeopteryx

1. Presence of feathers

2. Fore limbs are modified as wings and it is the stronfest avian character

3. Tail is modified as birds

4. Tail is provided with two rows of feathers

5. Cranium is round shaped

6. Presence of beaks

7. Presence of fused skull bones

8. Limb bones and guirdle bones are bird alike

9. Sternum is always provided with keel

10. Tibia and Fibula bones are separated

11. Presence of "V" shaped fercula bone

Inference

Due to above similarities Archaeopteryx is considered as a connecting link or missing link between reptiles and birds.

15.5 Affinities of Prototheria

The prototherians are the egg-laying mammals, the survivors of a phylogenetic line that must have branched early from the line leading to other living mammalian groups. All living forms are limited to the Australian Biogeographic Region (essentially New Guinea and Australia, including Tasmania). The Platypus is the most commonest semiaquatic, semifossorial ,and carnivorous, feeding on such foods as aquatic invertebrates, frogs, and small fish. Burows are constructed in stream banks.

Prototheria resembles the reptiles and birds with some advanced characters over them establishing mammalian ancestry.

15.5.1 Character analysis of Prototheria :

Reptilian characters of Prototheria

1. Presence of cloaca
2. Presence of ectopterygoid bone in the skull
3. Vertebrae do not have any epiphysis bones
4. Presence of cervical ribs
5. All ribs are single headed
6. Presence of T shaped interclavicle bone which is medially present.
7. Presence of perforated acetabulum
8. Body temperature is not constant (pertially homeothermic)
9. Cochlia of internal ear is attached with lagina.
10. Presence of urino -genital sinus.
11. Absence of corpus callossum
12. Anterior commissure is well developed,
13. Presence of abdominal testis
14. Oviparous in habit i.e. egg laying in habit
15. Presence of meroblastic clevage.

Inference :

Due to the presence of strong reptilian features in Prototheria speaks of its primitiveness. These primitive mammals have failed to cope up with many of the evolutionary transformations which culminated in the establishment of better characteristics in higher mammals.

Avian characters of Prototheria

1. Beak of the platypus resembles that of birds.
2. Teeth in adults are absent.
3. Presence of webbed feet.
4. Oil gland is present.

Inference :

The relationship between Prototheria and birds does not stand on a solid ground. The converging characters seen in Prototheria are due more to the fact that both possess common reptilian ancestry.

Mammalian characters of Prototheria

1. Presence of hair, mammary glands, oil gland and sweat glands.
2. Double occipital condyles.
3. Presence of palate.
4. Presence of a typical mammalian diaphragm is present in the body cavity.
5. Skull is dicondylic.
6. Sternum is segmented.
7. Lobes of liver typically mammalian.
8. Presence of 4-chambered Heart .
9. Only left aortic arch present.
10. Circulatory system is typically mammalian.
11. Presence of large ear ossicles.
12. Cochlea is slightly coiled .
13. Fertilization is internal.
14. A slender caecum demarcates two intestines .
15. R.B.C. small, circular and non-nucleated .
16. Presence of 4 optic lobes (corpora quadrigemina) .
17. Presence of milk glands secreting milk.

Inference :

Though Prototheria show affinity with non-mammalian groups, but the above mentioned characters strongly speak of close and firm affinity with mammals and the prototherians are essentially belongs to mammalia. Prototheria are position at the earliest off shoot of mammalian lineage albeit their phylogenetic position has been controversial. Some believe they share a common ancestor with marsupials while other believe that monotremes are more evolutionarily related to the subclass Theria.

15.6 Conclusion

From the above discussion it can easily be concluded that *Sphenodon* bears the most primitive characters and have a discontinuous distribution although it belomgs to class reptilia and it is simply due to stabilizing selection during the course of evolution.It is found only in New Zealand. Similarly *Archaeopteryx* belongs to class reptilia and an extinct species bears some of the advance characters which are quite similar to birds

and thats why it is considered as the missing link or connecting link between reptiles and birds. The prototherians showed some primitive characters which are comparable to the birds and due to this reason It is speculated that prototherians are the evolutionary off shoots during the course of mammalian evolution.

15.7 Summary

The tuatara or *Sphenodon* is the most primitive of living reptiles. It resembles lizards in general body shape but unlike the other reptiles it has a fixed quadrate bone and lacks a copulatory organ. They have uncinate processes on the ribs, like birds, and gastralia or abdominal ribs, like crocodiles.

The egg-laying monotremes (Prototherians) diverged from the main stock in the early Jurassic period (some 200 million years ago).

15.8 Glossary

Missing link or Connecting link – These two words are synnomous i.e meaning same, those animals are considered to be the connecting links and which have been extinct.

Discontinuous distribution - Animals are not uniformly distributed on land and in water and are restricted to certain places by several factors such as climate, food, shelter, flora and fauna etc.

Stabilizing selection - Stabilizing selection is *the* opposite of disruptive selection. Instead of favoring individuals with extreme phenotypes, it favors the intermediate variants.

15.9 Further reading

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15.10 Model questions

What is unique about *Sphenodon*?

Why is *Sphenodon* called a living fossil?

What is the habit of the *Sphenodon*?

What are the affinities of *Sphenodon*?

Is Archaeopteryx the earliest known bird?

What is the scientific name for *Archaeopteryx*?

Is Archaeopteryx a living fossil?

What type of egg does a Prototheria have?

What are the unique features of Prototheria?

Do Prototheria have mammary glands?

Unit-16 ❑ Comparative anatomy of circulatory system and heart in vertebrates.

Structure

16.1 Objective

This unit helps the learners to clear their idea about evolutionary changes in the structural part of vertebrate circulatory system and the modes of the circulation. The major changes occurred in number and distribution of aortic arches as well as the structure of heart. The students will also learn the evolution of heart from two-chambered venous heart to four-chambered heart with double circulation of blood.

16.2 Introduction

The circulatory system is effectively a network of cylindrical vessels: the arteries, veins, and capillaries that emanate from a pump, the heart. The circulatory system varies from simple systems in invertebrates to more complex systems in vertebrates. In amphibians, reptiles, birds, and mammals, blood flow is directed in two circuits: one through the lungs and back to the heart, which is called pulmonary circulation, and the other throughout the rest of the body and its organs including the brain (systemic circulation).

16.3 Comparative anatomy of circulatory system

Chordates have a completely closed circulatory system, further distinguished into two systems, blood vascular and lymphatic, having part as follows:

1. Blood vascular System- It consist of heart, arteries, veins, capillaries and blood.

2. Lymphatic System- It occurs exclusively in chordates,except cyclostomes and cartilaginous fishes and consists of lymph and lymph channels.

Fish have a single circuit for blood flow and a two-chambered heart that has only a single atrium and a single ventricle . The atrium collects blood that has returned from the body, while the ventricle pumps the blood to the gills where gas exchange occurs and the blood is re-oxygenated; this is called gill circulation. The blood then continues through the rest of the body before arriving back at the atrium; this is called systemic circulation. This unidirectional flow of blood produces a gradient of oxygenated to deoxygenated blood around the fish's systemic circuit. The result is a limit in the amount of oxygen that can reach some of the organs and tissues of the body, reducing the overall metabolic capacity of fish.

In amphibians, reptiles, birds, and mammals, blood flow is directed in two circuits :

one through the lungs and back to the heart (pulmonary circulation) and the other throughout the rest of the body and its organs, including the brain (systemic circulation).

Most reptiles also have a three-chambered heart similar to the amphibian heart that directs blood to the pulmonary and systemic circuits . The ventricle is divided more effectively by a partial septum, which results in less mixing of oxygenated and deoxygenated blood. Some reptiles (alligators and crocodiles) are the most primitive animals to exhibit a four-chambered heart.

Crocodilians have a unique circulatory mechanism where the heart shunts blood from the lungs toward the stomach and other organs during long periods of submergence; for instance, while the animal waits for prey or stays underwater waiting for prey to rot.

One adaptation includes two main arteries that leave the same part of the heart: one takes blood to the lungs and the other provides an alternate route to the stomach and other parts of the body.

Two other adaptations include a hole in the heart between the two ventricles, called the foramen of Panizza, which allows blood to move from one side of the heart to the other, and specialized connective tissue that slows the blood flow to the lungs. Together, these adaptations have made crocodiles and alligators one of the most successfully-evolved animal groups on earth.

In mammals and birds, the heart is also divided into four chambers: two atria and two ventricles . The oxygenated blood is separated from the deoxygenated blood, which improves the efficiency of double circulation and is probably required for the warm-blooded lifestyle of mammals and birds. The four-chambered heart of birds and mammals evolved independently from a three-chambered heart.

16.3.1 Modifications of aortic arches in different vertebrate groups :

The aortic arches or pharyngeal arch arteries are a series of six paired vascular structures which connect ventral aorta to the dorsal aorta and arise from the aortic sac also shows major evolutionary changes among vertebrates.The basic fundamental plan of the aortic arches is similar in different vertebrates during embryonic stages.The number of aortic arches is gradually reduced as the scale of evolution of vertebrates is ascended.

1. In lampreys (Petromyzon) there are eight pairs of aortic arches and in hagfishes

(Bdellostoma) there are fifteen pairs.

2. In elasmobranch fishes there are five pairs of aortic arches. In elasmobranchs the first pair of aortic arches (mandibular) disappear. Second to sixth pair of aortic arches (II-VI) persist as branchial arteries.

3. In teleosts there are four pairs of aortic arches. First pair (mandibular) and second pair (hyoidean) are lost, only four pairs (third to sixth) persist as branchial

arteries. Four pairs afferent branchial arteries arise from the ventral aorta.

4. In amphibians, the first two aortic arches (I, II) disappear early in development. In frogs the aortic arches that persist (III, IV, and VI) expand to supply blood to the head, body, and pulmonary circuits, respectively.

5. Aortic arches III, IV, and VI persist in reptiles, but most of the changes center on enhancements and modification of the fourth arch.

6. In birds, the right systemic arch becomes predominant. The bases of the aortic arch, the right aortic arch (IV), and the adjoining section of the right dorsal aorta form the right systemic arch during embryonic development.

7. Up to six aortic arches arise in the mammalian embryo, but only three persist in the adult as the major anterior arteries: the carotid arteries, the pulmonary arch, and the systemic arch. The other notable difference in mammals is in the formation of the subclavian arteries.

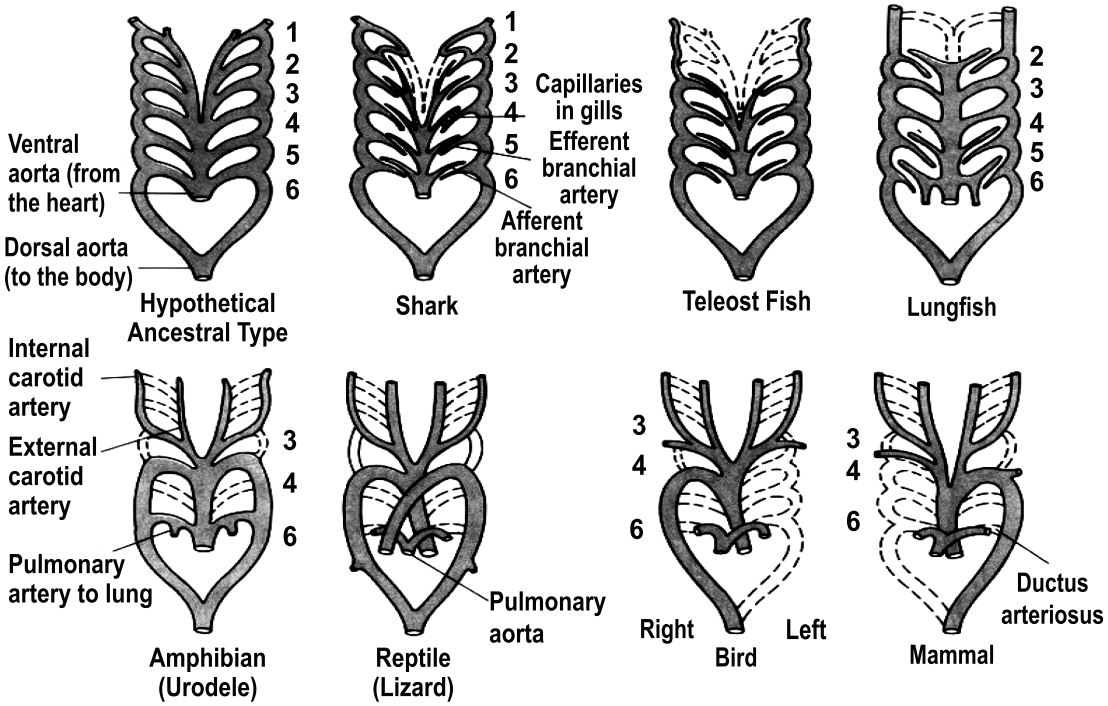

Figure 42 : **Structural modification of aortic arches in vertebrates**

The modification of aortic arches in different vertebrates in tabular form

Embryonic aortic arches	Elasmo-branches	Teleosts	Lower Amphilbians	Higher Amphilbians	Reptiles	Birds	Mammals
First pair	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear
Second pair	Persist as first branchial arteries	Disappear	Disappear	Disappear	Disappear	Disappear	Disappear
Third pair	Persist as second branchial arteries	Persist as first branchial arteries	Persist as carotid arteries	Persist as carotid arteries	Persist as carotid arteries	Same as reptiles	Same as birds
Fourth pair	Persist as third branchial arteries	Persist as second branchial arteries	Persist as left and right sys-temic arteries	Persist as right and left sys-temic arteries	Persist as right and left sys-temic arteries	Persist only as right systemic artery	Persist only as left systemic artery
Fifth pair	Persist as second branchial arteries	Persist as third branchial arteries	Persist as branchial arteries	Disappear	Disappear	Disappear	Disappear
Sixth pair	Persist as fifth branchial arteries	Persist as fourth branchial arteries	Persist as right and left pulmo-nary arteries	Persist as right and left pulmo-nary arteries	Persist as right and left pulmo-nary arteries	Persist as right and left pulmo-nary arteries	Same as birds

16.4 Comparative anatomy of heart in vertebrates.

Heart is a muscular pump that pumps blood through blood vessels and maintains blood circulation. Heart also channelizes pure and impure blood to appropriate parts of the circulatory system thereby preventing their mixing. The comparative heart structure in vertebrates is given below :-

1. In Teleosts

Heart of fishes consists of 3-chambers of which a sinus venosus, an auricle and a ventricle. No conus arteriosus. Sinus venosus is a thin walled sac. It receives deoxygenated blood by two precaval veins or ductus Cuveiri. It opens to the auricle by sinuauricular aperture, guarded by valves. Auricle is a thin-walled single chamber of the heart. It opens into the ventricle by auriculoventricular aperture. This aperture is guarded by valves. Sinus venosus and auricle both consti-tute the receiving cham-bers of the heart. Ventricle is single, conical, thick- walled, forwarding chamber of the heart. There is no conus arteriosus. The bulbus aorta is a dilated part at the base of the ventral aorta, and not regarded as the part of the heart. It is the part of the arterial system. It is a kind of venous heart because only deoxygenated blood flows through sinus venosus and from auricle to ventricle. The flow of blood maintains uni-directional flow. Hence it is called single circuit heart and is called prim-itive type heart among vertebrates.

2. In Amphibia

It is 5 chambered. A sinus verosus, two auricles, single ventricle and a conus arteriosus . Out of 5 chambers, two auricles and single ventricle are regarded as permanent chambers, and sinus veno-sus and conus arteriosus are considered as accessory chambers. Sinus Venosus is a dorsally placed, thin walled triangular sac, formed by the union of two precavals and a post caval. It receives deoxygenated blood by three vena cavae. It opens into right auricle through sinuauricular aperture which is guarded by sinuauricular valve. It is well developed. There are two unequal sized auricles. The left auri-cle is smaller than the right. Two auricles and a sinus venosus are the receiving parts of the heart. The two auricles are placed anterior to the ventricle. These auricles are separated internally by inter-auricular septum. Both the auricles are sharply marked off from the ventricle externally by a narrow constriction, called coronary sulcus. The left auricle receives oxygenated blood from the lungs, through two pulmonary veins. The right auricle receives deoxygenated blood from the sinus veno-sus through sinuauricular aperture. Two auricles open into the ventricle by a common auriculo ventricular aperture. This aperture is guarded by membranous valves, called auriculoventricular valves. The valves remain attached with the wall of the ventri-cle by fine thread-like Chordae tendineae. Ventricle is single, thick-walled highly muscular forwarding chamber, with

the apex pointed towards the caudal end. The inner wall of the ventri-cle is thrown into muscular ridges, known as columnae carnae. From the base of the ventricle arises a stout tube-like structure called conus arteriosus (Pylangium) which proceeds forward as truncus arteriosus (Synangium). The lumen of the conus arteriosus is divided into two channels by a spiral valve. Regarding mechanism of circulation the right auricle receives deoxygenated blood and left auricle receives oxy-genated blood. The two auricles contract and the blood is driven to the ven-tricle. The blood mixes into the lumen of the ventricle and by contraction, reaches into the conus arteriosus.

3. In Reptilia

In most of reptiles , there are 3 permanent chambers of which two auricles and an incompletely divided ventricle, but there is no conus arteriosus . In crocodiles, the heart is completely 4-chambered of which the two auricles, and two completely divided ventricles. In crocodiles, no sinus venosus and conus arteriosus The sinus venosus of reptiles represents from larger size (turtles) to small or vestigial in other groups. Conus Arterisus is absent.

The heart of reptiles represents a transitional stage which approaches a double circuit stage but has not reached it completely due to lacking of complete separation of the ventricle. In crocodiles the heart is completely 4-chambered. The right part always gets deoxygenated blood and the left part gets oxygenated part. All the apertures are guarded by muscular valves that pre-vent the back flow of blood. The deoxygenated blood goes to the lungs through the pulmonary aorta from the right ventricle.

4. In Aves

All birds have 4 chambered heart. Conus arteriosus is absent, and sinus venosusis vestigial. Right ventricle partly covers the left. Sinus Venosus is also vestigial. Auricles are comparatively thick walled receiving chamber and placed anterior to ventricle. The two auricles are separated internally by inter auricular septum. Ventricle is a thick walled, highly musctilar forwarding chamber of the heart. It is divided into two by a complete muscular septum. Conus arterisus is absent. The heart of bird is a kind of double circuit heart and there is no chance of mixing up of deoxygenated and oxygenated blood.

5. In Mammalia

All mammals have 4 chambered heart. No conus arteriosus and sinus venosus is vestigial Right ventricle partly covers the left. The sinus venosus is absent in adult mammals. The right auricle receives deoxy-genated blood from the body through the anterior and posterior vena cavae. The three venae cavae open separately into the right auricle. The left auricle receives oxygenated blood from the lungs through four pulmonary veins. The two auricles open into the ventricles by separate apertures. The

left auriculo-ventricular aperture is provided with bicuspid or mitral valve. Ventricle is a thick-walled, highly muscular forwarding chamber of the heart. It is divided into two by a complete muscular septum. The right ventricle gives rise to pulmonary arch and the left ventricle gives rise to single right aortic arch.

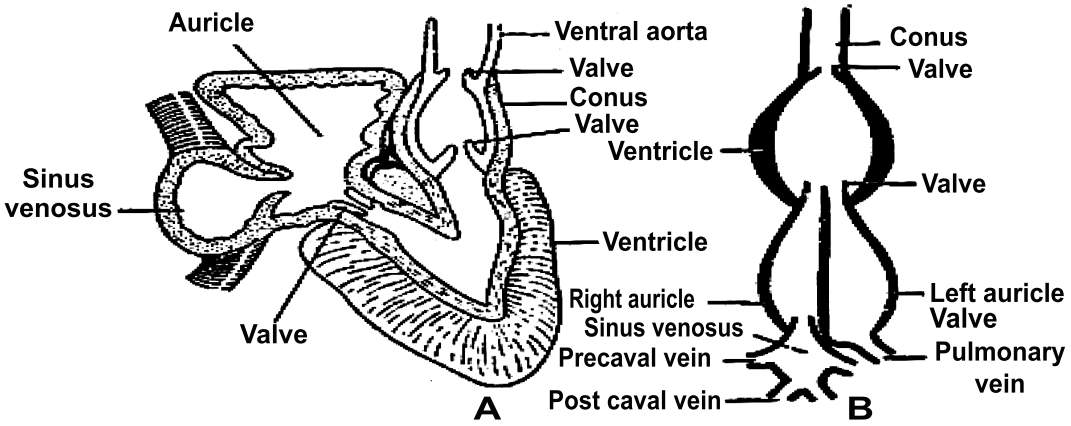

Figure 43

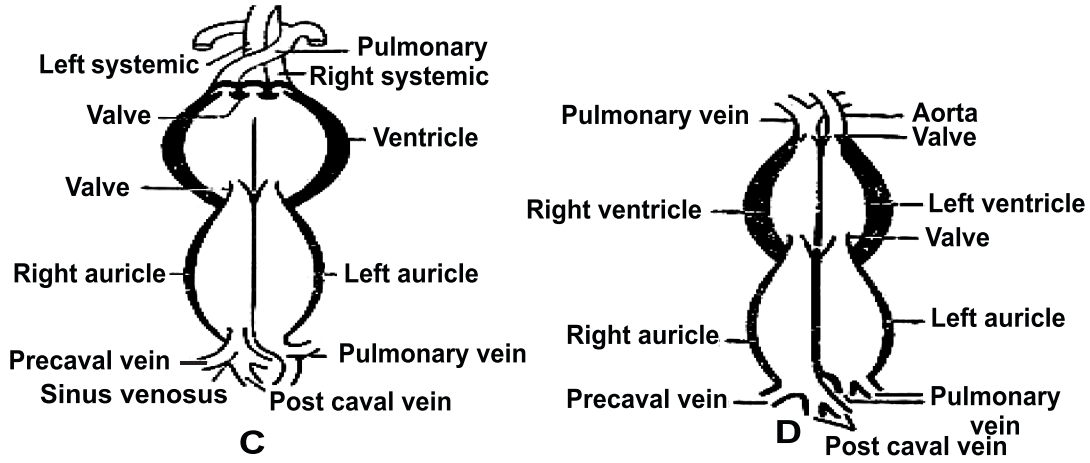

Figure 44 : **A. Pisces Heart B. Amphibian Heart C. Reptilian Heart D. Mammalian Heart**

16.5 Conclusion

From the above facts it is clear that in most fishes, the aortic arches deliver deoxygenated blood to the respiratory surfaces of the gills and then distribute oxygenated blood to tissues of the head (via the carotids) and remainder of the body. The double systemic arches (left and right) present in amphibians and reptiles become reduced to a single systemic arch (the right in birds, the left in mammals) .Furthermore, the appearance of six aortic arches during the embryonic development of living gnathostomes suggests that this is the ancestral pattern.

16.6 Summary

Vertebrate circulatory system has eveolved from the early chordate circulatory system with a single layered tube in Tunicates (Urochordata) or an Amphioxus (Cephalochordata) to a vertebrate circulatory system with a two chambered heart made up of one atrium and one ventricle in gnathostome fish to a system with three chambered heart made up of two atria which may be partially divided or completely separated in amphibian tetrapod. Subsequently in reptilia,birds and mammalia the heart is evolved to a four chambered. Similarly from basic six pair aortic arches it is evolved to three in number.

16.7 Glossary

Aortic arch – It is the section of the aorta between the ascending and descending aorta. As it arises from the ascending aorta, the arch runs slightly backward and to the left of the trachea.

Pericardium – It is the fibrous sac that encloses the heart and normally it is filled up with fluid which is known as pericardial fluid.

16.8 Further reading

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16.9 Model questions

Which vertebrate class have 3 chambered heart ?

In which animal do we find double circuit circulation ?

What is foramen panizza ?

How many aortic arches are present in birds ?

Which artery circulates oxygenated blood to the heart ?

What is ductus cuvier ?

What is called ductus venosus?

Unit - 17 ❑ Comparative anatomy of Excretory system and Kidney in Vertebrates.

Structure

17.1 Objective

The primary objective of this unit is to elaborate the mechanism and structural diversity occurs in the excretory system of vertebrate animals along with the course of evolution. The mechanism of elimination of waste products from the body of the animal is known as excretion and with the help of this unit learner can understand the comparative aspects of this important system.

17.2 Introduction

All vertebrates are not living in the same habitat and thats why the their excretory products and modes of secretion are different.

Aquatic and terrestrial organisms live under different situations; the former enjoy a abundance of water while the latter must use energy to maintain the water inside the body. Urine is the primary excretory product. Terrestrial animals have adapted to various degrees

to the harsh conditions of life on the land, best exemplified by the animals living in deserts, which try to minimize their daily urine output. Camels, for instance, can survive without drinking for several days.

The excretory system functions in ridding the body of nitrogenous and other wastes. It also regulates the amount of water and ions present in the body fluids.

17.3 Origin of vertebrate excretory system

The vertebrate excretory system is a holonephros. The entire organ arises from the one source, namely, from the intermediate cell-mass which unites the somite with the lateral plate, and is originally segmental. The part of the intermediate cell-mass adjacent to the somite develops into the nephrotome or nephric chamber, and the part connecting it with the body cavity becomes the peritoneal canal. The tubule is an outgrowth from the dorsal wall of the chamber and the duct arises from the union, in front and behind, of the distal extremities of the tubules and is therefore primitively segmental. The excretory system functions in ridding the body of nitrogenous or nitrogen containing compounds, and other waste products. It also regulates the amount of water and ions present in the body fluids.

17.4 Comparative account of vertebrate excretory system

According to the concentration of solutes in the body fluid of animals , all vertebrates can be divided into two groups , isotonic and nonisotonic animals. The concentration of solutes in isotonic animals is approximately equal to that of their environment. As a result, they do not gain or lose water. The concentration of solutes in the tissues of isotonic animals is approximately equal to that of the ocean. The high concentration of solutes in chondrichthyes is due mostly to the presence of urea. All cartilaginous fish (chondrichthyes) are the example of isotonic animals.

Excretory system in pisces

In aquatic habitat pisces have developed specialized excretory structures to cope with the challanges of living in the water.Their primary excretory organ is the kidney which regulate water and ion balance in the body.

In marine bony fish the rate of water loss is high . They drink water seawater at a rate of approx. 1% of their body weight/hour. Specialized cells in the gills excrete excess salts.

Freshwater bony fish tend to gain water from their environment due to osmosis. They produce large quantities of dilute urine (approx. 1/3 of their body weight/day) and do not drink water. Salt-absorbing cells in he gills use active transport (energy is required) to pump salts into their body.

All the elasmobranch pisces excrete nitrogenous waste primarily as urea which helps them to maintain osmotic balance in water.

Excretory system in Amphibia

Amphibians are those animals which are transitioning from aquatic larvae to terrestrial adults. Practically these animals exhibit dual life stages that demands adaptable excretory mechanism. In larval forms excretion occurs through gills, skin and kidney. In adult forms they utilized specialized skin glands and kidney for waste elimination. The skin of adult amphibians plays an important crucial roles in water and ion balance.

Excretory system in Reptilia

The excretory system in reptilia vary across different species and habitats. Most of the reptiles posses kidney as excretory organ which removes waste products and regulates water and electrolytes . But the species which lives in marine habitat have modified salt glands for elimination of excess salts to mantain osmotic balance in the high saline environments.

Excretory system in Aves or Birds

All birds have distinct excretory structures for conservation of water and elimination of waste. Their primary excretory organ is the kidney that produce uric acid (a compound with low water content) for minimizing the water loss from the body. Normally in birds uric acid is excreted out as a paste with feces. This mechanism helps the birds to reduce the need of high water consumption for the elimination of waste produced in the body through different metabolic process.

Excretory system in Mammalia

Mammalian excretory system consist of kidney, ureter, bladder and urethra. These structures plays a crucial role in maintaining homeostasis by regulating the composition and volume of the body fluid. This urinary system in mammalia is responsible for removing waste products generated by cellular metabolism, to maintain the fluid electrolyte balance which ultimately regulates the blood pressure.

The kidney of marine mammals like seals ,whales porpoise etc have are able to excrete high concentration of salts with urine and that's why they are able to drink sea water.

Some terrestrial mammals like kangaroo rat do not need to drink water because the metabolic water produced by cellular metabolism is enough to remove the waste material (these animals are normally nocturnal for the need of body water conservation). Not only that the large intestine of these animals is able to absorbs the total water peresent in the intestine and that's why their feces are dry and hard pellets.

Inference

Organs which eliminates the nitrogenous waste is known as excretory system. In vertebrates urinary apparatus is known as excretory organ. The main excretory organ in vertebrates is kidney but kidney is absent in protochordata. Kidney is different in structure in different classes of vertebrates as well as in animals which lives in different habitat. Protochordates generally used following organ as excretory organ :

Balanoglossus have glomerulus, *Ascidia* have pyloric glands ,renal vesicle,pyloric vesicle and neural glands , *Amphioxus* have solenocytes.

17.5 Comparative anatomy of Kidney of Vertebrates.

A pair of kidney is present in all vertebrates but during the evolution of vertebrates a series of kidney types originated and replaced as the functional kidney. It is true that whatever may the kidney types present in different vertebrates but each has a basic structure . The primary basic structure of kidney is that it is composed of a large number of units called nephrons. The number of units or nephrons ,their complexcity and arrangements is different in different groups of vertebrates. There are three types of nephrons found in different vertebrates.

I.The first type is present in early fresh water vertebrates. An animal lived in a medium more dilute than its own fluids and hence is in danger for over dilution of these fluids by osmosis through the surface of the body and of the gut.

II. The second type is present in marine teleostian fishes where high salinity of the surrounding medium is present. In this type, water should be conserved and much salt eliminated. So the glomeruli are frequently reduced or absent.

III. The third type is present in birds and mammals. These animals developed a different method of conservation of water. There is a normal glomerulus of large size and consequent high water output. The complex tubule and the presence of loop of Henle result in absorption of much of the water, the product is a relatively concentrated urine.

17.5.1 Types of kidney found in vertebrates :

During the evolution of the vertebrates, a series of kidney types replaced each other as the functional excretory organs.

1. Archinephors kidney

The primitive vertebrates possess an excretory organ which is referred to as an archinephros or holonephros. This is consisted of a pair of archinephric ducts located on the dorsal side of the body cavity and is extending the length of the coelom. Each duct is joined by a series of segmentally arranged tubules, one pair of tubules to a segment. In the other end, the tubule is opened into the coelom by a ciliated, funnel-shaped, peritoneal opening called the nephrostome. No adults, living vertebrate possesses an archinephros, but it is present in the larval form of the hagfish *(Myxine)* and in the larvae of some of the caecilians (Apoda).

2. Pronephros kidney

The pronephros is actually consisted of a varying number of anteriorly located pronephric tubules together with a pair of archinephric ducts duct (which called here pronephric duct). The tubules and ducts lay in the dorsolateral mesoderm on either side of the mesentry that supported the gut. The tubules were segmentally arranged, connected with the near pronephric duct at its anterior end. The outer end of the tubules

opens into the coelom by means of nephrostomes. The nephrostome and the part of the tubule near it are ciliated. Most forms are possessed internal glomeruli. These are knots of interarterial capillaries, each surrounded by a double wall structure called Bowman's capsule, the two together are known as renal or Malpighian corpuscle. The pronephros is a functional structure in many immature fishes and in the larvae of some of the amphibians and appears transitorily in the embryos of all the higher vertebrates.

3. Opisthonephroskidney

Since the pronephros in most cases is a transient structure, the opisthonephros is served as the adult kidney in lampreys, most fishes and amphibians. Biologists have realized that the opisthonephros of cyclostomes, fishes and amphibians is not quite comparable to the mesonephros of embryonic amniotes even though the two are structurally similar in many ways. The vertebrates that possessed an opisthonephros, there is a general tendency toward a concentration of kidney tubules toward the posterior end of the organ. The anterior portion frequently losses its significance as an excretory organs and in the male, it may became part of the reproductive system.The opisthonephros is the functional kidney of the adult lamprey, the cartilaginous fishes, the bony fishes and in the amphibians.

4. Mesonephros kidney

Although the mesonephros is basically an embryonic kidney in amniotic vertebrates , it functions for a short time after birth in reptiles, monotremes and marsupials. In the meantime, a new kidney to be used by the amniotes during the rest of life, the metanephros, is in the process of development. When the metanephros took over the functions of a kidney, the mesonephros involuted and only remenants remained after birth. The mesonephros of amniote embryos have essentially the same structure as the kidneys of fishes and amphibians except that nephrostomes are rudimentary in most birds and seldom appeared in mammals. A major difference between the mesonephric kidney and the metanephric kidney of higher vertebrates is the relative inability of the mesonephros to concentrate urine. Mesonephric kidney functions in the embryos of reptiles, birds and mammals.

5. Metanephros kidney

The metanephric kidney develops from the most posterior portion of the mesomere and is the most compact of any of the vertebrate renal structures. The metanephric kidney is basically made up of the same structure as the mesonephros kidney. No nephrostomes (peritoneal funnels) are ever present in the metanephros. The metanephric tubules are somewhat more complex in the mammals and (to a lasser extent) in the birds then are the mesonephric tubules. In these vertebrates, each tubule develops a long loop called the loop of Hanley with ascending and descending portions between the proximal and distal convoluted segments. These loops functions primarily in the re-absorption of water. The metanephric kidney had a dual origin, the metanephric diverticulum, which gives rise to the ureter, the renal pelvis and the collecting duct system and the intermediate mesoderm from which the tubular units of the kidney arose.

17.5.2 Comparative anatomy of metanephric kidney :

Now it is quite clear that metanephric kidney is found in reptiles, birds and mammals and therefore it is necessary to know the difference in structure and function

of metanephric kidney in these groups of vertebrates. Many metanephric kidneys are lobulated as in reptiles, birds and others, each lobe consisted of clusters of many tubules. Following are the comparative account :

In reptiles, the metanephric kidneys are restricted to the posterior half of the abdominal cavity and are usually confined to the pelvic region. They are generally small and compact but their surfaces are lobulated. They are elongated or slender in shape. Pelvis is absent. Kidney is two lobed structure.

In birds, the metanephric kidneys were situated in the pelvic region of the body cavity and the two frequently united at their posterior ends.They are flat shaped. Their surface is lobulated, deep fissures between the lobules are present, serving for the passage of the branches of the renal veins.Pelvis is absent. Kidney is three lobed structure.

In mammals, the typical kidneys are compact bean shaped attached to the dorsal body wall. They are retroperitoneal. The ureter leaves the medial side at a depression called the hilum. At this point, a renal vein also leaves the kidney and a renal artery

and nerves enter it. The metanephros is surrounded by a capsule of connective tissue under which lie the cortex.Pelvis is present. Kidney is a single lobed structure.

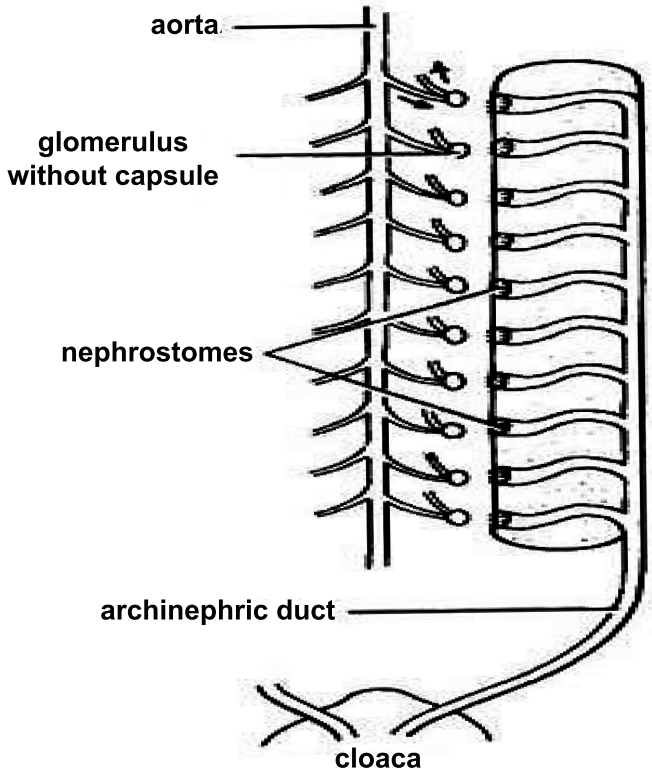

Figure 45 : **Archinephros kidney**

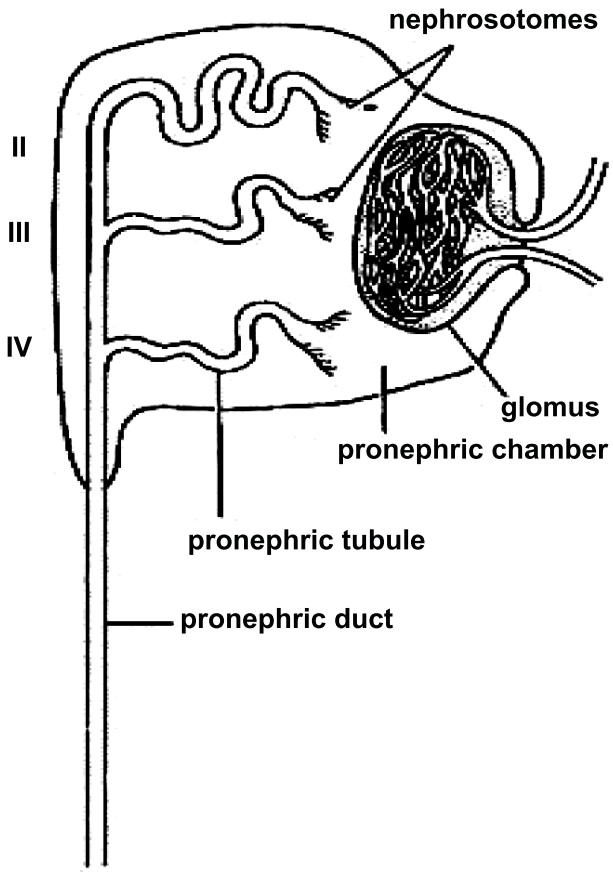

Figure 46 : **Pronephros kidney of Frog larva**

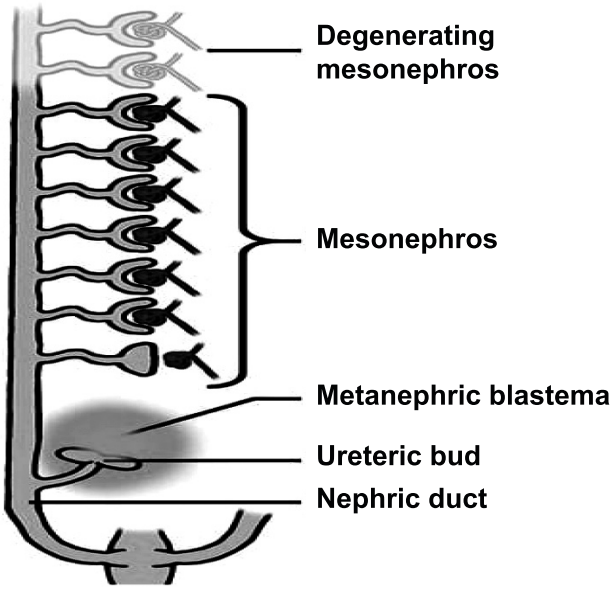

Figure 47 : **Mesonephros kidney**

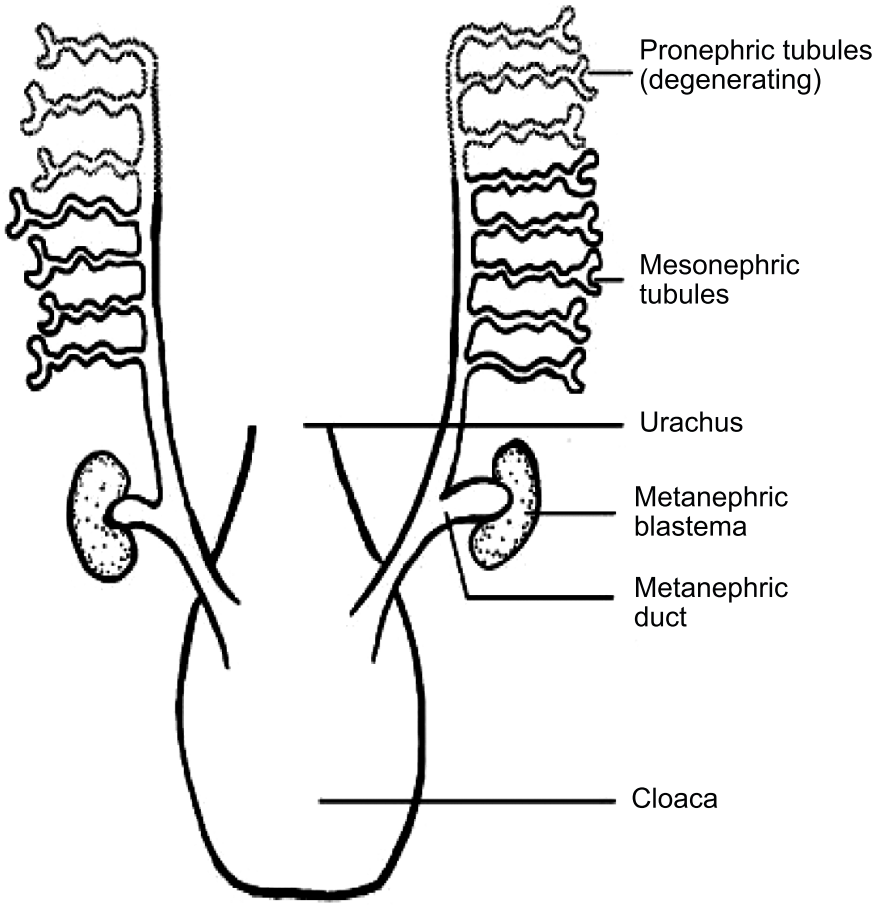

Figure 48 : **Metanephros kidney**

17.6 Conclusion

Studies of the embryonic development of primitive vertebrates, such as the dogfish shark, clearly show that the excretory system arises from a series of tubules, one pair in every segment of the body between the heart and the tail. The central tendency in the evolution of kidney in vertebrates is to increase the rate of glomerular filtration and proximal reabsorption.

17.7 Summary

From the above discussion it is clear that due to the need to regulate the body fluid homeostasis have led to pre adaptation of the vertebrate kidney to different environmental condition and to development of three kidney forms the pronephros,mesonephros and metanephros. The kidney of vertebrates are unique compared to other internal

organs , since three different kidneys are sequentially developed replacing each other and reflecting the evolution of kidneys in vertebrates.

17.8 Glossary

Glomerulus- One of the tiny filtering unit inside the kidney

Loop of Henle- It is thedescending and ascending portions between the proximal and distal convoluted tubules; those of cortical nephrons do not extend into the medulla, whereas those of juxtamedullary nephrons do extend into the medulla

Nephrons- It is the functional units of the kidney that carry out all filtration and modification to produce urine

Urethra- It transports urine from the bladder to the outside environment

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17.10 Model questions

State the main function of the urinary or excretory system.

What are nephrons?

What are ureters?

What is the urethra?

Unit-18 ❑ Comparative anatomy of Brain in Vertebrates.

Structure

18.1 Objective

With the help of this unitthe learners are able to understand the complex structure of vertebrate brain and the structural variation occurs in different groups of vertebrate animals. The brain is the central organ of nervous system in all vertebrate animals and it is evolved and developed according to the habits and behaviour of each group of vertebrate animals.

18.2 Introduction

All vertebrate brains share a common underlying form which appears most clearly during early stages of development of a vertebrate animal and it is located in the head, usually close to the sensory organs for senses such as vision. The earliest form of the brain appears as three swellings at the front end of the neural tube which grown during embryonic development; these swellings eventually become the forebrain, midbrain and hindbrain (prosencephalon, mesencephalon and rhombencephalon respectively). In the initial stages of brain development, the three areas are roughly equal in size. In many classes of vertebrates, such as Pisces and Amphibians, the three parts remain similar in size in the adult, but in Mammals the forebrain becomes much larger than the other parts, and the midbrain becomes very small.

18.3 Basic structure, divisions and sub divisions of vertebrate brain

Vertebrate brain hasthree primary divisions which are prosencephalon, mesencephalon and rhombencephalon. Each primary divisions are subjected to various modifications and changes in different vertebrate groups. However a typical vertebrate brain following parts are found :

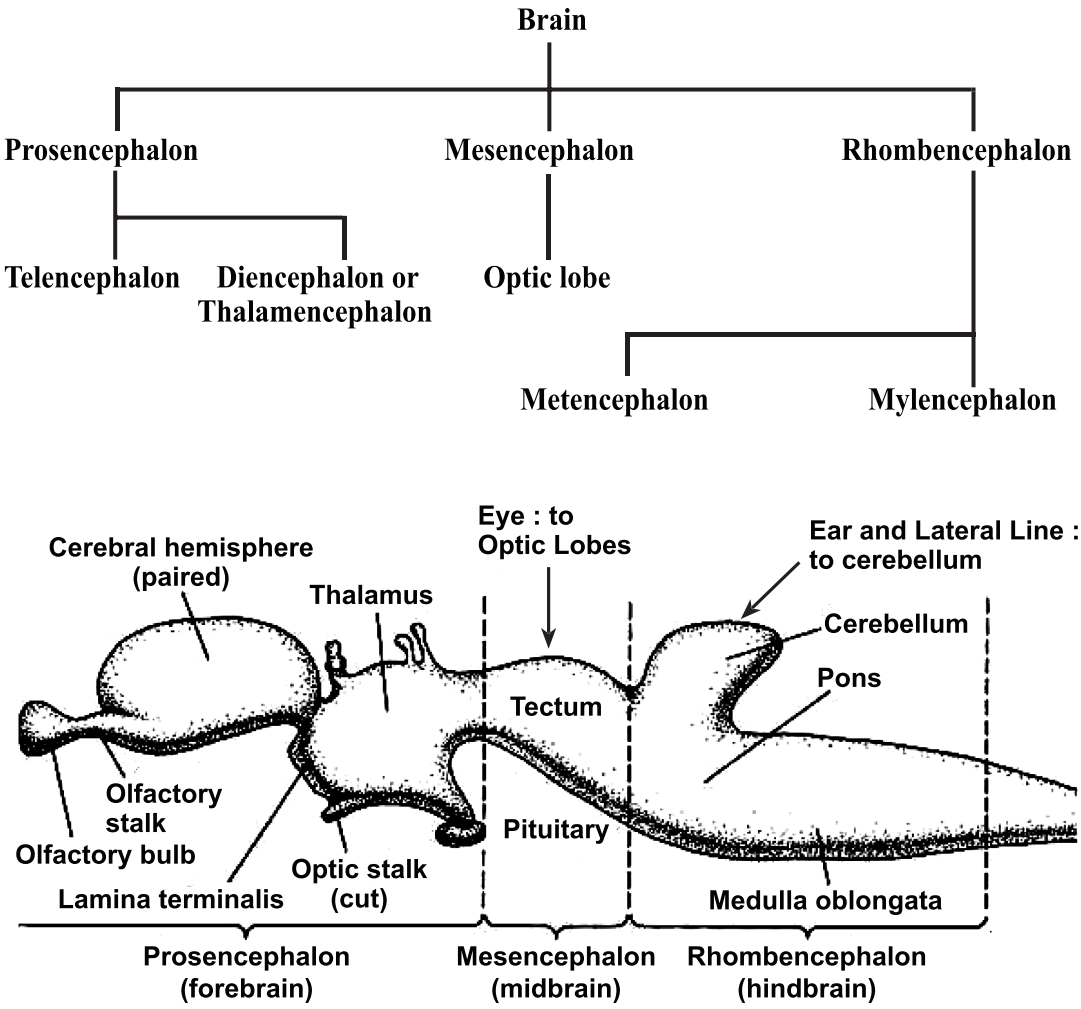

Figure-49 : **Basic divisions and sub divisions of vertebrate brain**

18.4 Comparative account of vertebrate brain

1. In Cyclostomes

The brain is divisible into three primary parts viz; Forebrain, Midbrain and Hindbrain. The forebrain includes large paired olfactory lobes. The Cerebral hemispheres are small attached to the diencephalon. The midbrain possesses a pair of

large optic lobes rather dorsally placed. The hind brain is differentiated into a small transverse dorsal band, the Cerebellum and much larger ventral Medulla Oblongata. The ventricles within the brain are four as in other vertebrates. In fundibulum bears a hypophysis and pituitary body.

2. In Cartilaginous Fishes

In Cartilaginous Fishes, the olfactory organs are enormous so that olfactory lobes of brain are correspondingly large, attached to Cerebrum by short but stout olfactory tracts. Optic lobes and pallium are relatively moderate in size. Midbrain cavity is quite large and extends into optic lobes. Pineal apparatus is well developed. Features of Hindbrain are less pronounced. Cerebellum is especially large due to active swimming habit.

3. In Bony Fishes

In bony Fishes brain is more specialized than in Elasmobranchs. Olfactory lobes, Cerebral hemispheres and Diencephalon are smaller while optic lobes and cerebellum larger than in a shark. The anterior part of the Cerebellum forms valvula cerebella which extend under the optic lobes; it is characteristic of bony Fishes and controls active movements. The medulla oblongata is well developed with special lobes for entry of lateral line nerves.

4. In Amphibians

The brain of Amphibians is remarkably unspecialized and is scarcely more advanced than that of cartilaginous fishes and lung fishes The cerebral hemispheres are more separate from one another than in fishes, so they share little common ventricle. Smaller olfactory lobes and larger optic lobes indicate a greater reliance on sight rather than smell. Corpus striatum (floor of cerebrum) receives greater number of sensory fibres projected forward from thalamus than in fishes. The walls of midbrain are thickened and reduce the lumen into a narrow passage called aqueduct. Medulla is

small and cerebellum is poorly developed. A small pineal body is present in all the modern Amphibians.

5. In Reptilians

Reptilian brain shows advancement in size and proportions over that of Amphibians because of complete terrestrial mode of life.

The brain is an arrow shaped, elongated and nearly straight.

Olfactory bulbs tend to be smaller than for fishes. Olfactory tracts are long. A fine vomeronasal nerve from the organ of Jacobson goes to the olfactory bulbs.

A pair of auditory lobes is found posterior to optic lobes which are not hollow.

The Cerebrum is large because of the expansion of the corpus striatum and associated neocortex. Cerebellum is somewhat pear shaped and larger than in Amphibians.

6. In Birds

Avian brain is proportionately larger than that of a Reptile, and is short and broad. Olfactory lobes are small due to poor sense of smell.

Two cerebral hemispheres are larger, smooth and project posteriorly over the diencephalon to meet the cerebellum.

The enlargement of cerebral hemispheres is due to very large and complex corpora striata which are characteristic of birds.

The cerebral hemispheres are responsible for an intelligent behavior in birds, and they control the reflex behavior governing the lives of birds.

The dorsal thalamus is even more developed than in Reptiles. Optic nerves, chiasma and tracts are large.

Optic lobes are particularly large and are layered within. They have connections from all sense organs and with the cerebrum. Squeezed between the cerebrum and cerebellum, the optic lobes have uniquely lateral position.

The Cerebellum is larger than in other vertebrates except some mammals. It is highly convoluted, and the organ is high and narrow.

Related to the marked development of the cerebellum are the appearance of the pons under the brain stem and enlargement of the olivary nuclei (both superior and inferior) within the broad medulla.

7. In Mammalians

The brain reaches its highest development in mammals. The cerebral hemispheres reaching the status of a dominant integrating part of the brain and acting as coordinating centers of the brain.

The cerebral hemispheres are smaller and smooth in Prototheria and larger in Metatheria and become greatly enlarged and divided into lobes in Eutheria.

In mammals such as man and sheep, surface of cerebral hemispheres is immensely convoluted with a number of elevations separated by furrows. This folding increases the surface area or gray matter containing nerve cells, resulting in greater intelligence without adding to the size of the brain.

Olfactory lobes are relatively small but clearly defined and covered by the hemispheres. Diencephalon and midbrain are also completely covered by the cerebral hemispheres.

Characteristic of mammals are 4 solid optic lobes, called corpora quadrigemina, on the roof of the midbrain.

The third ventricle or iter of midbrain is a laterally compressed vertical passage, called cerebral aqueduct.

Cerebellum is also large, conspicuously folded and may overlie both midbrain and medulla. Usual folds are a median vermis, two lateral flocculi and their mushroom like projections, the paraflocculi.

The other chief topographical features of mammalian hindbrain include the pyramids carrying voluntary motor impulses from higher centers, the pons varoli with crossing fibres connecting opposite sides of cerebrum and cerebellum, and the trapezoid body of transverse fibres relaying impulses for sound.

The medulla oblongata lies ventrally and is much thickened. It has centers which control respiration, heart beat and blood vessels; it also has conduction pathways for impulses passing from the cerebral hemispheres to the spinal cord and again in the opposite direction.

The hindbrain contains centers for the regulation of digestion, respiration and circulation.

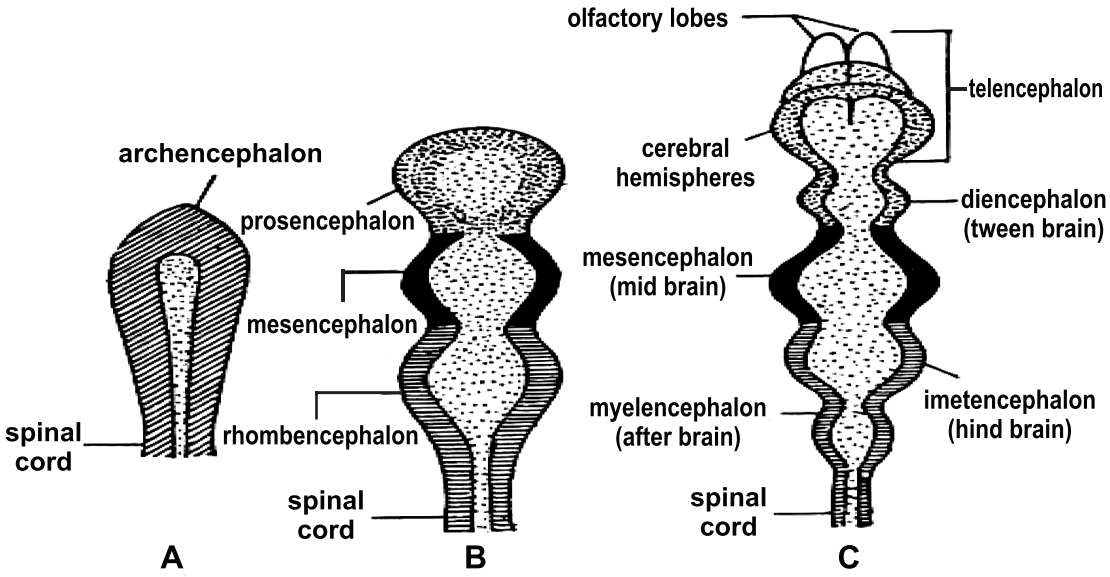

Figure-50 : **Origin of divisions of vertebrate brain**

18.5 Evolutionary perspective of vertebrate kidney structure

From the above discussion it is quite clear that each of the major taxa of vertebrates, brain structure varies substantially, with some brains smaller relative to body size and

less elaborate in terms of cytological architecture and others larger and more elaborate. The former can be referred to as **type I brains** and the latter as **type II brain.**

This type I–type II distinction is a matter of degree, and where the line is drawn is necessarily somewhat arbitrary.

Of the jawless vertebrates, or agnathans, lampreys have a relatively simple, or **type I,** brain in terms of its number of neurons and their degree of migration away from the ventricular surface where they are generated during embryological development.

In contrast, hag fishes have an enlarged and elaborated **type II** brain , characterized by considerably more neurons that are produced in and also migrate away from the ventricular surface and that form large aggregations of nuclei and/or laminated structures.

Similarly within cartilaginous fishes, Chimaeras (rat fishes), and squalomorph and squantinomorph sharks have type I brains , while galeomorph sharks and skates and rays have type II brains.

The ratio of brain size to body size also varies considerably across different vertebrate groups. It should be remembered that most of the diversity in brain complexity occurs in the dorsal part of the brain.

18.6 Conclusion

The brains of vertebrates acquired their basic forms such as the forebrain (telencephalon and diencephalon), midbrain, and hindbrain in the early stage of evolution, and have changed the morphology and function of each region while maintaining the basic structures during evolution. Embryological development of vertebrate brain indicates that formation of neural plate and neural tube from which the brain is developed is same in all the vertebrate animals and it is from the ectodermal cells after the neurogenic embryonic induction.

18.7 Summary

From the above study it compels us to conclude the following facts ;-

1. Brain has usually three parts forebrain, midbrain and hindbrain in all vertebrates.

2. Reptilian cerebral hemispheres are larger than amphibians because of greater thickness and enlargement of corpora striata.

3. Reptilian has a pair of auditory lobes are found posterior to optic lobes.

4. Cerebellum is like pear - shaped and larger than in amphibians.

5. Bird’s cerebellum is greatly enlarged with several superficial folds (flocculi) .

6. Corpus callosum not found in Prototheria and Metatheria bur found in other groups opf mammals.

18.8 Glossary

Olfactory lobes- Part of prosencephalon and acting as sense of smell.

Cerebellum- A large structure located at the roof of the hindbrain that helps to control the coordination of movement .

Cerebrum -The largest part of the human brain associated with higher order functioning, such as thinking, perceiving, planning, and understanding language,

Corpus Callosum-The large bundle of nerve fibers linking the left and right cerebral hemispheres.

Gray Matter- Portions of the brain that are gray in color because they are composed mainly of neural cell bodies

Hindbrain-The most posterior part of the brain, comprising the pons, medulla, and cerebellum.

Limbic System-A group of structures deep within the brain involved in motivation and emotion.

18.9 Further reading

1. Jollie, M. (1962): Chordate Morphology;

2. Weichert, C.K. (1970): Anatomy of the chordates;

3. Hildebrand,M.(1974): Analysis of Vertebrate Structure;

4. Romer, A.S. & Parsons, T.S. (1978): The Vertebrate Body;

5. Kent, G.c. & Carr, R.K.(2001): Comparative anatomy of the Vertebrates ;

6. Kardong, K. (2011): Vertebrates – Comparative Anatomy, Function, Evolution.

7. Kent G.C. (2015) Comparative Anatomy Of The Vertebrates 9th Edition ,CBS Publishers

18.10 Model questions

Which germinal layer is responsible for brain formation ?

Which type of stimulation is required for transformation normal cell to neurogenic cells?

What is ventricle of brain ?

What do you mean by type-I and II brain ?

In which vertebrate the brain is highly developed ?