ANIMAL DIVERSITY – I (NON-CHORDATES)
PROTOZOA
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INTRODUCTION
Protists are a heterogeneous group of living things, comprising those organisms that are one-celled or acellular. Some protists are plant-like in that they have chlorophyll or some other pigment for photosynthesis, and may have a cellulose wall, and are so called Protophyta. Others are animal-like, having no chlorophyll or cellulose wall, and feed on organic matter and are so called Protozoa.

Protozoa (in Greek proto = first and zoa = animal) is a diverse assemblage of some 80,000 single-cell organisms that show some characteristics usually associated with animals, most notably mobility and heterotrophy. They possess typical eukaryotic membrane-bound cellular organelles and are ubiquitous or cosmopolitan, the species occurring throughout the earth. The protozoans exhibit all types of symmetry, a great range of structural complexity, and adaptations for all types of environmental conditions. Most protozoans are too small to be seen with the naked eye but can easily be found under a microscope (most are around 0.01-0.05 mm, although forms up to 0.5 mm are still fairly common). They play an important role in their ecology. Protozoa occupy a range of trophic levels. As predators upon unicellular or filamentous algae, bacteria, and microfungi, protozoa play a role both as herbivores and as consumers in the decomposer link of the food chain. They also play a vital role in controlling bacteria population and biomass. As components of the micro- and meiofauna, protozoa are an important food source for microinvertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important. Protozoa are also important as parasites and symbionts of multicellular animals.

Protozoa may occur singly or in colonies (e.g. Volvox); may swim freely or be in contact with a substratum or be sedentary; may be housed in a shell (lorica) (e.g. foraminferas), clothed in scales or other adhering matter, or be naked; they may or may not be pigmented. They may be parasitic (e.g. Trypanosoma) or symbiotic living attached to or inside other organisms (e.g. Joenia), even inside their cells. Free living protozoa occur wherever moisture is present-in the sea, in all types of fresh water, and in soil.

ORGANELLES
The protozoan possesses all the typical cellular structures and performs all the basic cellular processes. The body is usually bounded by a cell membrane. Below the cell membrane is present a cytoskeleton which is composed of slender filamentous proteins, microtubules or vesicles. Distinct organ or tissues are absent but certain specialized structures such as cilia, flagella, contractile vacuoles, myonemes etc., usually occur to perform certain special functions. These structures which are parts of a single cell are termed organelles or organoides or organites, in contrast to the multicellular organs of Metazoa.
REPRODUCTION
Asexual reproduction by mitosis is most common mode of reproduction in Protozoans. Division of the organism into two or more progeny cells by binary fission or multiple fission takes place. However, when one progeny cell is smaller than the other, the process is called budding. The protozoans reproduce sexually by conjugation of the adults or by fusion of gametes.

Encystment is the characteristic feature of many protozoans, including the majority of fresh water species. It commonly occurs to help in dispersal as well as to resist unfavorable conditions of food, temperature and moisture.

NUTRITION
As all other organisms, protozoa also require nutrients for the building up its body and for getting energy necessary for all vital activities. The organism can be autotrophic, synthesizing organic substances from the supply of inorganic nutrients utilizing chemical energy (chemiautotrophs) or radiant energy (phototrophs). They could also be totally heterotrophs, where they require ready-made food material from other sources or could be amphirotrophs and can switch to any of the two modes (auto- or hetero-) as required. Besides these modes, the protozoans could also have saprozoic mode of nutrition in which they obtain nutrition by diffusion through general body surface or could also be parasitic in which they live in the body of some other living being and get nourished at the expense of the host.

LOCOMOTION
Locomotion or movement in protozoa is performed by specialized locomotory organs. Based on locomotion, protozoa are grouped into:

- **Flagellates** with long flagella e.g., *Euglena*
- **Amoeboids** with transient pseudopodia e.g., *Amoeba*
- **Ciliates** with multiple, short cilia e.g., *Paramecium*
- **Sporozoa** non-motile parasites; form spores e.g., *Plasmodium*

Flagella are extremely fine, delicate and highly vibratile thread like extensions of protoplasm, which are used for swimming and for creating food currents. Pseudopodia are the motile organs of temporary nature that are extruded out from body protoplasm of those protozoans that are devoid of tough pellicle. Cilia are slender, fine and short hair like processes of ectoplasm. They help in locomotion and food capturing. They are much shorter than flagellum and are present in far greater number.
Classification of Protozoa (from Barnes-fifth edition)

- **Kingdom - Protista**
  - **Subkingdom - Protozoa**
    - **Phylum - Sarcomastigophora**
      - Subphylum - Mastigophora
      - Subphylum - Sarcodina
    - **Phylum - Apicomplexa**
    - **Phylum – Microspora** e.g. *Nosema*
  - **Sub Kingdom - Protophyta**
    - **Phylum - Ciliophora**
Subphylum - Sarcodina

Superclass - Rhizopoda
- Class - Lobosa
  - Subclass - Testacealobosa
    - Order - Arcellinida e.g. Arcella
    - Order - Pelobiontida e.g. Pelomyxa
  - Subclass - Gymnamoeba
    - Order - Aconchulinida e.g. Vampyrella
    - Order - Testaceafilosida e.g. Euglypha

Superclass - Actinopoda
- Class - Filosa
- Class - Granuloreticulosa
- Class - Polycystina e.g. Thalassicola
- Class - Acantharia e.g. Acanthometra
- Class - Phaeodaria e.g. Aulacantha
- Class - Heliozoa e.g. Actinophrys
Phylum - Apicomplexa

Class - Sporozoa
- Subclass – Gregarinia e.g. Gregarina, Monocystis
- Subclass – Coccidia e.g. Plasmodium

Class – Piroplasmea e.g. Babesia

Phylum - Ciliophora

Class - Kinetofragminophora
- Subclass – Gymnostomata e.g. Didinium
- Subclass – Vestibulifera e.g. Balantidium
- Subclass – Hypostomata e.g. Nasula
- Subclass – Suctoria e.g. Ephelota

Class - Oligohymenophora
- Subclass – Hymenostomata e.g. Paramecium

Class - Polyhymenophora
- Subclass – Peritricha e.g. Vorticella

Order – Heterotrichida e.g. Blepharisma
- Order – Odontostomatida e.g. Saproditium
- Order – Oligotrichida e.g. Codonella
- Order – Hypotrichida e.g. Euplotes
GENERAL CHARACTERS OF PROTOZOA
The protozoans are an assemblage of single-cell organisms possessing typical membrane-bound cellular organelles. They consist of a number of different unicellular phyla, which together with many plant-like unicellular organisms are placed in the Kingdom Protista.

I) Phylum Sarcomastigophora
These protozoa possess flagella or pseudopodia as locomotor or feeding organelles and a single type of nucleus. The phylum is further divided into two subphyla, Mastigophora and Sarcodina.

A) Subphylum Mastigophora
The mastigophorans possess flagella as adult organelles. They are further divided into two classes phytomastigophora and zoomastigophora.

A.1) Class Phytomastigophora
Mostly free-living, plantlike flagellates with or without chromoplasts and usually one or two flagella. The class has following orders.

- Order Chrysomonadina: Small flagellates with yellow or brown chromoplasts and two unequal flagella. e.g. **Chromulina, Synura**
- Order Silicoflagellida: Flagellum single or absent and chromoplasts brown. e.g. **Dictyocha**
- Order Coccolithophorida: Tiny marine flagellates covered by calcareous platelets- coccoliths. Two flagella and yellow to brown chromoplasts. e.g. **Coccolithus**
- Order Heterochlorida: Two unequal flagella and yellow-green chromoplasts. e.g. **Heterochloris**
- Order Cryptomonadida: Compressed, biflagellate, two chromoplastids, usually yellow to brown or colorless. e.g. **Chilomonas**
- Order Dinoflagellida: Equatorial and a posterior longitudinal flagellum. Brown or yellow chromoplasts and stigma usually present. e.g. **Ceratium**
- Order Ebriida: Biflagellate, with no chromoplasts. e.g. **Ebria**
- Order Euglenida: Elongated green or colorless flagellates with two flagella arising from an anterior recess. Stigma present in colored forms. e.g. **Euglena**
- Order Chloromonadida: Small, dorsoventrally flattened flagellates with numerous green chromoplasts. Two flagella, one trailing. e.g. **Gonyostomum**
- Order Volvocida: Body with green, usually single, cup-shaped chromoplasts, stigma, and often two to four apical flagella per cell. e.g. **Chlamydomonas, Volvox**
A.2) Class Zoomastigophora

Flagellates with neither chromoplasts nor leucoplasts. One to many flagella, in most cases with basal granule complex. Many commensals, symbionts and parasites.

Order Choanoflagellates: Freshwater flagellates, with a single flagellum, sessile, sometimes stalked. e.g. *Proterospongia*

Order Rhizomastigida: Amoeboid forms with one to many flagella. e.g. *Dimorpha*

Order Kinetoplastida: One or two flagella emerging from the pit. Mostly parasitic. e.g. *Leishmania, Trypanosoma*

Order Retortamonadida: Gut parasites of insects or vertebrates, with two or four flagella. e.g. *Chilomastix*

Order Oxymonadida: Commensal or mutualistic with one to many nuclei, each nucleus associated with four flagella. e.g. *Oxymonas*

Order Trichomonadida: Parasitic flagellates with four to six flagella. e.g. *Trichomonas*

Order Hypermastigida: Many flagellates with kinetosomes arranged in a circle, plate or spiral rows. Symbionts in guts of termites, cockroaches and wood roaches. e.g. *Lophomonas*

A. 3) Superclass Opalinata:

Body covered by longitudinal, oblique rows of cilia, two or many monomorphic nuclei. Binary fission is symmertrogenic. Syngamous sexual reproduction. Gut commensals of anurans. e.g. *Opalina*

B) Subphylum Sarcodina

Adult protozoa possess flowing extensions of the body called pseudopodia which are either used for capturing prey or for locomotion. Flagella, if present are only in developmental stages. They are either symmetrical or have a spherical symmetry. They possess relatively few organelles and therefore, considered to be the simplest protozoa. The subphylum is divided into two superclasses.

B.1) Superclass Rhizopoda:

Lobopodia, filopodia, reticulopodia are used for locomotion. It is further divided into three classes.

B.1.1) Class Lobosa:

Pseudopodia, usually lobopodia. It has two subclasses.

B.1.1.1) Subclass Gymnamoeba:

Amebas that lacks shell
Order Amoebida: Naked amebas that lack flagellated stages. e.g. *Amoeba, Entamoeba*

Order Schizopyrenida: Naked amebas with flagellated stages. e.g. *Acanthamoeba*

Order Pelobiontida: Naked, multinucleate amebas with one pseudopod and no flagellated stages. e.g. *Pelomyxa*

B.1.1.2) Subclass Testacealobosa:

Amebas with shells.

Order Arcellinida: Body enclosed in a shell or test with an aperture through which the pseudopodia protrude. e.g. *Arcella*

B.1.2) Class Filosa:

Amebas with filopods.

Order Aconchulinida: Naked amebas. Freshwater and parasites of algae. e.g. *Vampyrella*

Order Testaceafilosida: Shelled amebas. Mostly in freshwater and soil. e.g. *Euglypha*

B.1.3) Class Granuloreticulosa:

Organisms with delicate granular reticulopodia.

Order Foraminiferida: Marine organisms with multichambered shells. e.g. *Globigerina*

B.2) Superclass Actinopoda:

Primarily floating or sessile Sarcodina with actinopodia radiating from a spherical body.

B.2.1) Class Acantharia:

Radiolarians with a radiating skeleton. Axopodia present. e.g. *Acanthometra*

B.2.2) Class Polycystina:

Radiolarians with a siliceous skeleton and a perforated capsular membrane. e.g. *Thalassicola*

B.2.3) Class Phaeodaria:

Radiolarians with a siliceous skeleton but a capsular membrane containing only three pores.

  e.g. *Aulacantha*

B.2.4) Class Heliozoa:
Without central capsule. Naked or if skeleton present, it is of siliceous scales and spines. e.g. *Actinophrys*

II) Phylum Apicomplexa
Most known sporozoans and all those of known economic and medical importance belong to the phylum apicomplexa, so called because of a complex of ring like, tubular, filamentous organelles at the apical end, whose function is not very well known. Spores are usually present but they lack polar filaments. All species are parasitic. The phylum has two major classes.

Class Sporozoa:
Reproduction sexual and asexual. It has two subclasses
  A.1) Subclass Gregarinia:
      Mature trophozoites are large and occur in the gut and body cavities of annelids and arthropods. e.g. *Gregarina, Monocystis*
  A.2) Subclass Coccidia:
      Mature trophozoites are small and intracellular. e.g. *Plasmodium, Toxoplasma*

Class Piroplasmea:
Parasites of vertebrate red blood cells transmitted by ticks. No spores. e.g. *Babesia*

III) Phylum Microspora
The phylum Microspora contains intracellular parasites, especially of insects. The name Microspora is derived from the spore, which contains polar filament that can be everted. e.g. *Nosema*

IV) Phylum Ciliophora
The ciliates constitute the largest phylum of protozoa. They are also the most animal-like and exhibit a very high level of organelle development. They possess cilia for locomotion and in many species for suspension feeding. The body wall of ciliates is a complex living pellicle, containing alveoli, trichocysts and other organelles. Ciliates reproduce asexually by transverse fission and sexually by conjugation. It possess three classes.

A) Class Kinetofragminophora:
Isolated kineties in oral region of body bearing cilia but not compound ciliary organelles. It is divided into the following subclasses:
   Subclass Gymnostomata:
      Cytostome at or near surface of body and located at the anterior end or laterally. Somatic ciliation generally uniform. e.g. *Coleps, Didinum*
Subclass Vestibulifera:
Cytostome within a vestibulum bearing distinct ciliature. Free living or symbiotic. e.g. *Balantidium*

Subclass Hypostomata:
Body cylindrical or dorsoventrally flattened, with ventral mouth. Free living and many symbiotic species. e.g. *Nasula*

Subclass Suctoria:
Sessile, generally stalked, with tentacles at the free end. Cilia lacking in the adult but present in the free-swimming larval stage. Most are ectosymbionts on aquatic invertebrates. e.g. *Ephelota*

B) Class Oligohymenophora:
Oral apparatus usually well developed and containing compound ciliary organelles. It has two subclasses:

Subclass Hymenostomata:
Body ciliation commonly uniform and oral structures not conspicuous. e.g. *Paramecium*

Subclass Peritricha:
Mostly sessile forms with reduced body ciliation. Oral ciliary band usually conspicuous. e.g. *Vorticella*

C) Class Polyhymenophora
Oral region with conspicuous adoral zone of buccal membranelles. Some species with uniform body ciliation, others with compound organelles, such as cirri. It has only one subclass:

Subclass Spirotricha: The subclass is further divided into four orders:

Order Heterotrichida: Mostly large ciliates with uniform body ciliation. e.g. *Blepharisma*

Order Odontostomatida: Laterally compressed, wedge-shaped ciliates with reduced body ciliation. e.g. *Saprodinium*

Order Oligotrichida: Ciliates with reduced somatic ciliature but with extensive projecting buccal ciliary organelles. e.g. *Codonella*

Order Hypotrichida: Dorsoventrally flattened ciliates with cirri on the ventral side. e.g. *Euplotes, Stylonychia*

**Euglena**
The class Phytomastigophora comprise of enormous number of unicellular organisms which resemble each other in the possession of one or more, long slender vibratile
protoplasmic fibrils or flagella as organs of locomotion. *Euglena* being the most studied representative of the class is commonly found in freshwater ponds and puddles and could even impart a green color to the water.

**STRUCTURE:** The body is elongated and usually spindle-shaped or cylindrical. The anterior end, which is directed forward during locomotion, is blunt and rounded. The middle part is blunt and rounded while the body is pointing posteriorly.

The most common species, *E. viridis* is a green *Euglena* and about 50µ long (Fig. 1.). The shape of the body is maintained by a thin but firm covering called pellicle which is marked with very delicate spiral striations called myonemes. At the anterior end, there is a funnel like opening, the cell mouth or cytostome, which leads into cell gullet or cytopharynx. Cytopharynx expands into a large permanent spherical vesicle or reservoir, on the wall of which are located the separate basal bodies which give rise to two unequal flagella. The shorter flagellum does not emerge from the reservoir, and its tip may be applied to the longer flagellum in such a way that there may seem to be just one flagellum with two roots. The longer flagellum is thick and easily seen in living organism. Minute hair-like contractile processes, called mastigonemes of unknown function, are present in single longitudinal row along one side of the flagellum. This type of flagellum is known as *stichonematic*. A pigmented spot, or stigma, shades a swollen basal area of the long flagellum, which contains a pigment, called *haematochrome*, considered to be photoreceptive in nature. A large contractile vacuole is found attached to one side of the reservoir into which it periodically discharges its watery contents.

The cytoplasm of the body of *Euglena* is differentiated into a clear dense outer layer or ectoplasm, surrounding a more fluid-like granular central mass or the endoplasm. A single, large, spherical or oval nucleus lies centrally, which contains several nucleoli and is surrounded by a nuclear membrane. The chloroplasts, in which the chlorophyll is concentrated, are elongated or ovoid. Among the chloroplasts there are smaller bodies consisting of paramylum, a carbohydrate reserve chemically related to starch. The centre for synthesis of paramylum, called pyrenoids, may be closely associated with the chloroplasts, or they may be separate.

*Euglena*, like green plants, is photosynthetic in the light. Nitrogen and other elements essential for the formation of amino acids are absorbed in mineral salts. Although it may be regarded as an autotroph as long as it is in the light and is provided with essential elements in the form of inorganic compounds, it is dependent upon external sources of vitamin B\textsubscript{12}, which is synthesized by bacteria and some other microorganisms. *Euglena* is not known to ingest particulate organic material but can utilize organic nutrients in solution.

**Pellicle in *Euglena*:** The shape of *Euglena* remains constant because the body is enclosed by a distinct, tough, heavy pellicle or periplast, lying beneath the plasma membrane. Pellicle consists of certain grooves called myonemes that get lubricated by certain muciferous bodies present beneath the pellicle.
LOCOMOTION: The presence of flagella is the distinguishing feature of flagellates and most species possess two. They may be of equal or unequal length and one may be leading and one trailing as in *Paranema*, however in *Euglena* the two flagellum being unequal, with one remaining within the reservoir, only the long flagellum is the locomotory flagellum.

*Euglena* performs two different kinds of movement i) flagellar and ii) euglenoid.

Flagellar Movement: In flagellates, flagellar propulsion follows essentially the same principle as that of a propeller, the flagellum undergoes undulations that either push or pull. The undulatory waves pass from base to top and drive the organism in the opposite direction, or more rarely the undulations pass from tip to base and pull the organism (Fig. 2a) Many theories have been put forward to explain the flagellar locomotions in *Euglena*.

Simple conical gyration: The movement of flagellum is such that the body moves in a spiral rotation like a rotating plane which remains inclined at an angle of 30º to the axis of movement (Fig. 2b, c).

Paddle stroke: This type of movement is during rapid locomotion, the flagellum performs sideways lashes or paddle strokes. Each stroke has an effective stroke and a recovery stroke, due to which body is propelled forward (Fig. 2d).

Euglenoid Movement: The body of *Euglena* undergoes “peristaltic movements” as a wave of contraction and expansion passes over the entire body. The movement is due to highly elastic pellicle (Fig. 2e). This movement enables *Euglena* to move over solid objects. It also occurs after the flagellum is dropped before encystment. This movement occurs occasionally and is not the real method of locomotion in *Euglena*.

NUTRITION: Phytoflagellates are primarily autotrophic and contain chlorophyll. Different phytoflagellate groups are characterized by different combinations of chlorophyll types and accessory pigments and they store reserve foods as oils or fats or various forms of carbohydrates. The chief mode of nutrition in *Euglena* is holophytic/autotrophic/plant like. By the process of photosynthesis, *Euglena* can make its own food. CO₂ captured from sunlight by chlorophyll present in the chloroplast, is split. O₂ is set free, while carbon reacts with water or H₂O molecule to form paramylum or paramylon, a kind of carbohydrate which gets deposited in cytoplasm or endoplasm. However, in the absence of sunlight, *Euglena* can obtain food by saprophytic or saprozoic nutrition i.e. utilizes the decaying food material dissolved in water and absorbed through the general body surface. If kept in dark or if grown in media rich in certain organic nutrients, some photosynthetic species of *Euglena* will lose their chlorophyll and will resemble members of the genus Astasia. This suggests that members of the genus Astasia and perhaps some other colorless genera have been derived from photosynthetic species.

RESPIRATORY SYSTEM: The semi permeable pellicle is responsible for the exchange of gases. O₂ passes in while CO₂ is released through pellicle. Oxidation
reactions are carried out by mitochondrial enzymes with the help of incoming oxygen. Some of the CO$_2$ is also utilized during photosynthesis.

CIRCULATORY SYSTEM:

Osmoregulation: Contractile vacuole is responsible for removal of excessive water from the body. Being a fresh water form, the concentration of body fluids is higher in *Euglena* so water diffuses in passively. Cytoplasm in turn drains the excess water in small accessory vacuoles which in turn drains the water in large contractile vacuoles which contracts to throw the water in reservoir, from where it is then thrown out of the body.

EXCRETORY SYSTEM: Most of the nitrogenous waste products produced as by-products of various reactions occurring in the body are thrown out from the general body surface. Some of these materials are also emptied by contractile vacuoles into the reservoir from where they are thrown out.

NERVOUS SYSTEM: In many species of flagellates, including some non-photosynthetic types, a stigma is closely associated with the reservoir. It consists of small granules of a carotenoid substance embedded in a colorless stroma and serves as a light sensitive organelle.

REPRODUCTIVE SYSTEM: In the majority of flagellates, asexual reproduction occurs by binary fission and most commonly the organism divides longitudinally. Division is thus said to be symmetrogenic i.e. producing mirror-image daughter cells. However in most flagellates, sexual reproduction is still poorly known.

In *Euglena*, the organism multiplies asexually by binary fission or multiple fission either in the free or encysted state. Under favorable conditions of water, temperature and food, *Euglena* divides by longitudinal binary fission to produce symmetrogenic individuals (Fig. 3). Multiple fission is common during unfavorable conditions like lack of food and oxygen, draught, excessive heat. To tide over such adverse conditions, encystment takes place as a protective measure. Such encysted individual may undergo single or several divisions resulting in new individuals.

*Paramecium* Ciliates are the largest and most homogenous of all the protozoans, widely distributed in both fresh and marine waters and in the water films of soil. All possess cilia or compound ciliary structures as locomotor or food acquiring organelles at some time in the life cycle. Also present is an infraciliary system, composed of ciliary basal bodies or kinetosomes, below the level of cell surface and associated with fibrils that run in various directions. Most ciliates have a cell mouth or cytostome and are characterized by the presence of two types of nuclei—one vegetative (macronucleus—concerned with the synthesis of RNA as well as DNA) and the other reproductive (micronucleus—concerned primarily with the synthesis of DNA). The most studied ciliate is *Paramecium*, also called slipper animalcule. It is most common in freshwater ponds, pools, ditches, streams, rivers, lakes and reservoirs. Common species of *Paramecium*
includes *P. caudatum, P. aurelia, P. bursaria*. The media used for propagating *Paramecium* is hay infusion medium and also Chalkey’s medium (containing NaCl, NaHCO$_3$, KCl, CaCl$_2$ etc.).

**SIZE, SHAPE and STRUCTURE of Paramecium caudatum**

Body shape of most ciliates is usually constant. Although the majority of them are solitary and free swimming, there are both sessile and colonial forms. The body of certain ciliates is present inside a girdle like encasement called lorica, which is either secreted or composed of foreign material cemented together.

*P. caudatum* are minute organisms with largest species measuring 170-290µ in length. The body is covered by a complex pellicle or periplast. Pellicle is a thin, firm, elastic and cuticular membrane. Due to the firm pellicle, the shape of *Paramecium* looks rather elongated or slipper shaped and hence is called slipper animalcule. Under high power of microscope, the surface of pellicle seems to be divided into a great number of very small polygonal or hexagonal areas or ciliary fields formed by crossing of obliquely running ridges bearing the opening of trichocysts.

The body of *Paramecium* has a distinct lower, ventral or oral surface which is flattened and an upper dorsal or aboral surface which is convex. It swims with one end (slender, rounded, blunt, and anterior) in front and more pointed posterior end at the back. The endoplasm of *Paramecium* is semi-fluid and shows streaming movements called cyclosis. It contains food vacuoles, reserve food granules, mitochondria, golgi bodies, ribosomes, contractile vacuoles. A large macronucleus lies in the middle of the body while a smaller micronucleus is present on the surface depression of the macronucleus (Fig. 4).

Pellicular System: The pellicular system has been well studied in *Paramecium* (Fig. 5). There is an outer limiting plasma membrane, which is continuous with the membrane surrounding the cilia. Beneath the outer membrane is a single layer of closely packed vesicles, or alveoli, each of which is moderately to greatly flattened. The outer and inner membrane bounding a flattened alveolus thus forms a middle and inner membrane of the ciliate pellicle. Between adjacent alveoli emerge the cilia and mucigenic or other bodies. Beneath the alveoli is located the infraciliary system i.e. the kinetosomes and fibrils. The alveoli contribute to the stability of the pellicle and perhaps limit the permeability of the cell surface.

Alternating with the alveoli are bottle shaped organelles, the trichocysts, which forms a second, deeper, compact layer of the pellicular system. The trichocyst is a peculiar rod like organelle which functions in defense against the predators.

Toxicysts are vesicular organelles found in the pellicle of gymnostomes which are again for defence purposes. Mucocysts are another group of pellicular organelle found in many ciliates, discharge a mucoid material and function in formation of cysts or protective coverings.
Kinety System: The ciliature can be divided into body (or somatic) ciliature, which occurs over the general body surface and the oral ciliature, which is associated with the mouth region. Each cilium arises from a basal body or kinetosome located in the alveolar layer (Fig. 6). The kinetosomes that form a particular longitudinal row are connected by means of fine striated fibres called the kinetodesmata. A Kinetodesmata is actually a cable of still smaller kinetodesmal fibrils, each of which originates from a kinetosome. The cilia, kinetosome and kinetodesmata together make up a Kinety. A Kinety system is characteristic of all ciliates.

LOCOMOTION: Ciliates are the fastest moving of all protozoa. Two types of movements are generally present in *Paramecium*: body contortions and ciliary locomotion.

The beat of individual cilia, rather than being random or synchronous is part of the metachronal waves that sweep along the length of the body. *Paramecium* can execute considerable contracting and twisting movements in squeezing through the tangled masses of minute water weeds, through small apertures. It has a streamlined body shape that enables it to go through the water with least friction. During movement, cillum oscillates like a pendulum. Each oscillation comprising an effective stroke or the strong backward lash. The cillum becomes slightly curved and rigid and strikes the water like an oar so that the body is propelled forward in the water in the opposite direction of the stroke, the quick recovery stroke, which follows immediately is about five times faster with the cillum kept in a limp or much flexed state to offer resistance to the water (Fig. 7a, b).

All the cilia of the body do not move simultaneously and independently but progressively in a remarkable coordination and metachronal rhythm (Fig. 7c).

The cilia in a longitudinal row do not beat all at once but in a characteristic wave beginning at the anterior end and progressing backwards. Therefore, a cillum in a longitudinal row will always move in advance of the one behind it (metachronously). But all the cilia of a transverse row beat synchronously or simultaneously. A swimming *Paramecium* does not follow a straight tract but rotates spirally like rifle bullet over to the left side (Fig. 7d). The reason behind this is first the body cilia do not beat directly backwards but somewhat obliquely towards right so that the animal rotates over to the left on its long axis. Secondly the cillum of the oral groove strike obliquely and more vigorously so as to turn the anterior end continually away from the oral side and move in circles. But the combined effect is to move the animal forward in a left spiral course or anticlockwise (Fig. 7e). The rate of ciliary movement in *Paramecium* is about 10-11 times/second.

DIGESTIVE SYSTEM: Ciliates possess a distinct mouth or cytostome (secondarily lost in some groups). In most ciliates, mouth is displaced posteriorly. It opens into a canal or passageway called the cytopharynx, which is separated from the endoplasm by a membrane. It is this membrane that enlarges and pinches off as a food vacuole. The walls of the cytopharynx is lined with microtubular rods (nematodesmata), which
provide support to the walls of the pharynx and assist the inward transport of food vacuoles.

In majority of ciliates, cytostome is preceded by a preoral chamber that aids in food capture and manipulation. The preoral chamber takes the form of a vestibule, which varies from a slight depression to a deep funnel, with cytostome at its base. In other ciliates, the preoral chamber is typically a buccal cavity, which differs from a vestibule by containing compound ciliary organelles instead of simple cilia. There are two basic types of ciliary organelles: the undulating membrane and the membranelle. An undulating membrane is a row of adhering cilia forming a sheet. A membranelle is derived from two or three short rows of cilia, all of which adhere to form a more or less triangular or fan shaped plate.

*Paramecium* possesses a well formed oral apparatus for food ingestion (Fig. 8). The oral groove along the side of the body leads ventrally and posteriorly into a tubular chamber or vestibule. It leads through a large oral opening into a wide tubular passage, the buccal cavity. A definite aperture, the cell mouth or cytostome, lying at the bottom of deep buccal groove, leads into a short tube, the cytopharynx which forms a food vacuole at its inner end. Vestibule is lined by simple somatic cilia. Buccal cavity possesses compound cilia. A row of fused cilia, forming an endoral membrane, runs transversely along the right wall and encircles the opening of vestibule into the buccal cavity. Besides three membranelles-ventral peniculus, dorsal peniculus and quadrulus are also present at left side, each consisting of four rows of cilia. A minute aperture called the cell anus or cytoproct or cytopyge, opens in the pellicle, near and behind the cytopharynx on the right side of the body, through which undigested food is egested. Food consists of small living organisms, especially bacteria, small protozoa, unicellular plants and small bits of animals and vegetables.

Feeding Mechanism- *Paramecium* is a selective feeder. It is not a carnivore type and feeds while stationary or moving slowly. While feeding, cilia of oral groove beat more strongly then the body cilia forming a vortex. Food particles are soaked with the water current into the oral groove and then flow to the vestibule from where by means of ciliary tract, the food is directed to buccal cavity. Not all particles are actually ingested, some get rejected before entering the vestibule so *Paramecium* is called selective feeder. The selected food then goes to the cytostome through the ciliary movements of endoral membrane, quadrulus and peniculus lining the buccal cavity. Food particles accumulate at the end of the cytopharynx, which opens into endoplasm from which food vacuoles are formed. Food vacuole formation takes about 1-5 minutes depending on food supply. These food vacuoles circulate around the body along a definite course by a low steaming movement of cytoplasm called cyclosis. Digestion of food particles occurs during the process, accompanied by changes in pH. Digestive juices containing enzymes (proteases, carbohydrases, esterases etc) are secreted by lysosomes into food vacuoles, the pH of which turns from alkaline to acidic and then to alkaline again. Cyclosis also helps in distribution of digested food material to all body parts. Reserve food is stored in the form of glycogen and fat droplets in the endoplasm. The
undigested residual material is eliminated from the body through anal pore or cytopyge. About 15% of ciliates are parasitic and there are many ecto- and endocommensals. Some ciliates like *P. bursaria* display symbiotic relationships with algae.

**RESPIRATORY SYSTEM:** Respiration is through semi permeable membrane, pellicle. Oxygen rich water is taken in while the metabolic waste products pass through pellicle by the process of osmosis or are eliminated by contractile vacuole.

**CIRCULATORY SYSTEM:**

Osmoregulation: Contractile vacuoles are found in both marine and fresh water species. In some species a single vacuole is located near the posterior, but many species possess more than one vacuole. In *Paramecium*, one vacuole is located at both the posterior and anterior of the body. The contractile vacuoles contract and expand at regular intervals. Water from cytoplasm is gathered by 6 to 10 radiating canals, which converge and discharge into each contractile vacuole. When the vacuole has grown to its maximum size, it bursts and discharges to the exterior probably through an opening in the pellicle.

**REPRODUCTIVE SYSTEM:** Ciliates differ from almost all other organisms in possessing two distinct types of nuclei – a usually large macronucleus and one or two small micronuclei. Macronucleus is also called Vegetative nucleus as it is not essential in sexual reproduction and is responsible for normal metabolism, for mitotic division and for control of cellular differentiation. It has about 100 to 1000 times more DNA than micronucleus. DNA in micronucleus is not organized into chromosome but into gene size units. The amplification of genes in macronucleus increases the rate of synthesis of gene products which are to be utilized in the assembly of complex ciliate organelles.

*Paramecium*, under good conditions of food, reproduces asexually by transverse binary fission. It also undergoes sexual reproduction by means of conjugation, autogamy, cytogamy, endomixis, hemixis under adverse conditions like scarce food supply.

a) **Asexual Reproduction/ Transverse Binary Fission:** Under normal conditions, asexual reproduction is always by means of binary fission which is typically transverse, the division plane cutting across the kinetics-the longitudinal rows of cilia and basal bodies. This is in contrast to the symmertogenic fission of flagellates in which the plane of division cuts between the rows of basal bodies (Fig. 9). To begin with, *Paramecium* stops feeding and its oral groove disappear. Micronucleus divides by the complicated process of mitosis. Macronucleus divides amitotically by simply becoming elongated and constricted in the middle. Meanwhile, a transverse constriction forms around the middle of the body and continues to grow deeper ultimately dividing the cytoplasm into two halves or daughter Paramecia, the anterior one called the Proter and the posterior Ophisthe. Each daughter receives one contractile vacuole from the parent and forms a second contractile vacuole *de novo*. 
Thus two daughter Paramecia, almost equal sized and each with a complete set of cell organelles are obtained from a single parent. These grow to full size before dividing again by fission. The process of binary fission gets completed in 30-120 minutes depending upon food availability and temperature. All the individuals produced from one individual are called clones.

b) Sexual Reproduction: Of all the sexual processes occurring in *Paramecium*, the most common is Conjugation. In conjugation, two sexually compatible members of a particular species adhere commonly in the oral or buccal region of the body. Following the initial attachment, there is degeneration of trichocysts and cilia and a fusion of membranes in the region of contact. Two such fused ciliates are called Conjugants (Fig. 10). Attachment lasts for several hours. During this period, a reorganization and exchange of nuclear material occurs. Only micronuclei are involved in conjugation; the macronucleus breaks up and disappears during or following micronuclear exchange. This step involved in exchange of micronuclear material between two conjugants is constant. After two meiotic divisions of the micronuclei, all but one of them degenerates. This one then divides, producing the gametic micronuclei that are genetically identical. One is stationary; the other migrates into the opposite conjugant. There the gamete’s nuclei fuse with one another to form a zygote nucleus or synkaryon. Shortly after nuclear fusion, the two ciliates separate, each is now known as exconjugant. Each exconjugant then restores its normal nuclear condition without any cytosomal division. However, in *P. caudatum*, which also possesses a single nucleus of each type, the synkaryon divides three times, producing eight nuclei. Four become micronuclei and four become macronuclei. Three of the micronuclei degenerate. The remaining micronucleus divides during each of the subsequent cytosomal divisions and each of the four resulting offspring cells receives one macronucleus and one micronucleus. In those species that have numerous nuclei of both types, there is no cytosomal division; the synkaryon merely divides a sufficient number of times to produce the requisite number of macronuclei and micronuclei.

The frequency of conjugation is extremely variable. The significance of the process lies in nuclear reorganization which helps in rejuvenescence and is necessary for continued asexual fission. If nuclear reorganization does not occur, the asexual or clonal line dies out, apparently because of decline in function of macronucleus. The periodic occurrence of conjugation however ensures inherited variation.

Another type of nuclear reorganization called Autogamy or Self fertilization is also common in which two micronuclei of the same organism fuse together forming a synkaryon. The macronucleus degenerates and the micronucleus divides a number of times to form eight or more nuclei. Two of these nuclei fuse to form a synkaryon and the others degenerates and disappear. The synkaryon then divides to form a new micronucleus and macronucleus as occurs in conjugation.

Cytogamy resembles conjugation in that two Paramecia temporarily fuse by their oral surfaces. The early nuclear divisions are also similar to that of conjugation.
but there is no nuclear exchange between two individuals and no cross fertilization. The two gametic nuclei in each parent are said to fuse to form synkaryon as in autogamy.

Endomixis involves total internal reorganization without amphimixis, within a single individual in a culture of pedigreed race of *Paramecium* taking place in absence of conjugation. Endomixis occurs only in certain lower ciliates.

Hemixis involves division of macronucleus into two to many unequal fragments to be absorbed by the cytoplasm. Its significance is not clear.

Encystment: Most ciliates are capable of forming resistant cysts in response to unfavorable conditions, such as lack of food or desiccation. It also provides a condition in which the organism can be transported by wind or in mud on the feet of birds or other animals. *Paramecium* does not undergo encystment.

**Entamoeba**
The members of the subphylum, Sarcodina, include those protozoa in which adult posses flowing extensions of the body called pseudopodia. Pseudopodia are temporary projections of the body surface and the cytoplasm that function for locomotion and feeding. To this subphylum belong the familiar amoeba and many other marine, freshwater and terrestrial teaxs. The sarcodina are usually microscopic. Parasites of this order are usually much smaller then the well known free living *Ameoba proteus*, many average 10 µm in diameter and many are usually only seen only in the cyst stage. Most of the species have only one nucleus except in the cyst form.

The Genus *Entamoeba* that belongs to order Amoebida, is usually found in the intestine of invertebrates and vertebrates. Of all the parasitic species of amoeba infecting men, the most dangerous and the widespread is *Entamoeba histolytica*. Besides men, it is also common in the apes, monkeys and may also be found in pigs, dogs, cats and rats. It occurs as two races or strains: a smaller common non pathogenic form and much larger virulent form. About 400 million people are infected with *Entamoeba histolytica* but only fractions of them have its symptoms. The incidence of amoebic dysentery or amoebiasis caused by this parasite is high in Mexico, China, India and parts of South America.

It is generally found in the mucous and sub mucous layers of the large intestine of man and has both histolytic and cytolytic powers. It secretes a toxic substance which dissolves and destroys the mucous lining of the intestine. It gradually reecess from the dead tissue towards healthy mucosa thus burrowing deeper into the gut wall. In chronic cases the parasite may enter the venous circulation and is arrested in liver, lungs, brain, and spleen leading to secondary complications.

Mature, motile *Entamoeba histolytica* averages about 25µm in diameter (Fig. 11 A, B). The cytoplasm consists of a clear ectoplasm and finely granular endoplasm. The endoplasm may include food vacuoles filled with red blood cells in various stages of digestion. Clear vacuoles may also be present. Movement is usually irregular
associated with pseudopodia. *Entamoeba histolytica* is monopodial. The food includes bacteria or other organic material found in the intestine. Red blood cells are only found in pathogenic forms.

**LIFE CYCLE AND REPRODUCTION:**

*E. histolytica* is monogenetic as whole life cycle is completed in a single host. Man and monkeys are the natural hosts of *E. Histolytica*. Wild rats and dogs are supposed to be the reservoir host and possible source of infection to man.

In its life cycle, *Entamoeba histolytica* passes through three distinct morphological stages or forms (1) trophozoite (2) precystic (3) cystic.

Trophozoite Stage: Also called Trophic or magna form, it is active motile growing and feeding form, which is pathogenic to man. It is colorless, transparent and irregular mass of living substance about 20-30 µm in diameter and resembles common amoeba in structural details. Body is covered with thin transparent, plasma lemma that encloses a body cytoplasm which is distinguished into an outer, clear, non granular ectoplasm and inner granular endoplasm. Endoplasm has a single nucleus and several food vacuoles (Fig. 12a). Reproduction occurs only in the trophic form. The trophozoite multiplies asexually by simple binary fission, within the walls of the large intestine.

Precystic Stage: This is also called the Minute Form as the organism is smaller in size ranging from 10-20µ in diameter. It generally forms after a period of feeding and reproduction. Vacuoles disappear and amoebas become rounded. Soon a cyst wall begins to form, these uninucleate stages are Precysts. Endoplasm is free of RBCs (Fig. 12b). The minute form lives only in the lumen of large intestine and is seldom found in tissues. It is non-parasitic and non-feeding stage and is non-pathogenic to man. It develops into trophozoite stage by penetrating the mucosa and submucosa of host intestine, ingesting RBCs and growing in size.

Cystic Stage: The stage involves the division of uninucleated form into binucleated and finally tetranucleated or quadrinucleated cyst (Fig. 12c). Mature quadrinucleate cysts are most infective stage of the parasite which is unable to develop in the host in which they are produced. Hence they require the transference to fresh susceptible hosts. These cysts, if kept moist, can live for a week to a few months, depending on temperature. They are killed by drying. The tetranucleated cysts pass out of the body with feces and become the infective stage. They appear as minute, shining greenish, refractile spheres. Forty five million cysts may be discharged in the feces of one infected person in one day. Cysts normally enter a new host in drinking water or food. They may be carried mechanically by such insects as flies and cockroaches or by people with unclean hands.

Encystment: Encystment or Encystation is the process of transformation of trophozoites to cysts. The precystic forms undergo encystations only in the lumen of large intestine and never within the tissues. The whole process gets completed within few hours.
Excystation: When eaten by a new host, a cyst is carried to the small or large intestine, where it escapes the confinement of the cyst wall. The process of transformation of cyst to trophozoites is Excystation. It starts with increased activity of amoeba within its cyst which occurs only when the cyst reaches small intestine as cyst wall is resistant to action of gastric juices of stomach. In small intestine, the cyst wall dissolves by the action of trypsin and excystation follows. As a result, a single tetranucleate amoeba called metacystic form gets liberated (Fig. 12d).

Metacyst: Metacyst undergoes series of nuclear and cytoplasmic divisions producing eight little uninucleate daughter amoebula called metacystic trophozoites. The young amoebulae, being actively motile, make their way into large intestine, invading the mucous lining and grow into mature trophozoites.

PATHOGENICITY:
*Entamoeba histolytica* is the parasite causing diarrhea, dysentery, hepatitis, liver abscesses etc. in man. All these conditions, caused due to the infection by the parasite in man are collectively called Amoebiasis.

Amoebic dysentery: It is the condition in which infection is confined to intestine and is characterized by passage of blood and mucous in stool. The trophozoites of *E. histolytica* secrete a proteolytic enzyme, histolysin that cause dissolution and necrosis of mucosa and submucosa of large intestine. These areas of destruction are called ulcers which bleed profusely.

Chronic intestinal amoebiasis: Persons with strong resistance or those who suffer repeated attacks of amoebic dysentery are the victims of chronic intestinal amoebiasis. The person suffers regular diarrhea, bowel irregularities, pseudoconstipation, abdominal pain, headache, nausea, loss of appetite. Persons suffering from chronic intestinal amoebiasis acts as a carrier of disease.

Abscesses: When trophozoites reach other parts of body like liver, lung, brain etc. through blood circulation, it leads to destruction of these tissues and formation of abscesses.

The percentage of clinical amoebiasis compared to that of infection rate is low. A reason for the occasional change from commensal amoebas to pathogenic amoebas has yet to be determined. An alternation of host diet, an increase of host cholesterol, changes in the level of host sexual hormones, high ambient temperatures are all suggested to trigger the process.

Symptoms include vomiting, mild fever, diarrhea, blood and mucous in feces, tenderness over the sigmoidal region of colon and hepatitis.

CONTROL AND TREATMENT:

Personal hygiene and municipal hygiene can prevent the occurrence of amoebiasis. Most animal and people apparently possess a natural resistance to amoebic infection as indicated by the large percentage of infected hosts without amoebiasis. According to a
number of references, the recommended treatment for acute intestinal amoebic infections is metronidazole or tinidazole, followed by a course of a luminal amoebicide such as diloxanide furoate to eliminate cyst in the intestine and prevent reinfection.

**Plasmodium**

*Plasmodium* belongs to class Sporozoa. It lives in vertebrate tissue and blood cells and are transmitted by an insect vector. Schizogony occurs in vertebrate host, where as sporogony occurs in insect. Hence life cycle involves alteration of generation. No special organ of locomotion like flagella or cilia is present.

Over 100 species of *Plasmodium* parasitize a wide range of vertebrates, including birds, reptiles and mammals; however four are known to infect man causing different kinds of malaria. These are

*P. malariae*

*P. vivax*

*P. falciparum*

*P. oval*

Of all the diseases of mankind, malaria is one of the most widespread, best known and most devastating. It played a key role in the history of civilization because many areas of earth have been subjected to its ill effects leading to destruction and death caused by the parasite. Transmission of malaria takes place by female *Anopheles* mosquito (Fig. 13) and was first discovered by Sir Ronald Ross, an English army physician who was awarded Nobel Prize in 1902 for this discovery.

**LIFE CYCLE:**

*P. vivax* is digenetic. It lives in the RBCs and parenchyma cells of liver of man, its primary host and in the alimentary canal and salivary glands of mosquito, its secondary or intermediate host (Fig. 14).

Asexual Reproduction of *P. vivax* in Man:

The human invasion begins as follows:

Infection: When sporozoites are introduced into the blood of man with the bite of an infected female *Anopheles* mosquito, a series of cycle begins that involves different cells and tissues. While feeding mosquito punctures the skin by its beak like proboscis and injects some saliva which has anticoagulant. Along with this, thousands of sporozoites are also introduced into human blood at a single bite. This begins asexual phase of the parasite in man.

Sporozoites: These are minute slightly curved sickle shaped organism tapering at two ends and represent the infective stage of the parasite. They are 14 µ long and 1 µ broad and move with vibratory and gliding movements.
Liver Schizogony: Sporozoites disappear from blood stream and promptly enter reticulo-endothelial cells lining sinusoid or liver capillaries where they undergo schizogony that includes two phases

Pre erythrocyte phase: Inside liver cells it becomes a spherical & non pigmented trophozoite called cryptozoite. Its nucleus divides many times and in 8-9 days it grows into multinucleate schizont which ruptures to liberate tiny uninucleate cryptomerozoites into the liver space. They may either pass into blood to attack RBCs or enter fresh liver cells to continue exo-erythrocytic cycle. The duration between initial sporozoite infection and first appearance of parasite in blood is Pre-patent period.

Exo-erythrocyte phase: After reentering a liver cell each cryptomerozoite is called metacryptozoites which undergoes schizogony to produce several thousand metacryptomerozoites. The smaller sized ones re-enter RBCs to start erythrocyte cycle.

This reentering of cryptomerozoites does not occur in the cycle of *Plasmodium falciparum* and recrudescence is absent in falciparum malaria.

Erythrocyte Schizogony: When either pre-erythrocyte or exo-erythrocytic cryptozoite or crypto-merozoite attacks the RBC, the erythrocytic phase starts. Each merozoite burrows in a RBC and assumes a rounded disc like shape with a single large nucleus. Soon a vacuole appears in the parasite that pushes the nucleus to one side. In stained smears, the nucleus appears red, with ring-shaped blue cytoplasm, hence the name “signet-ring” given to the parasite at this stage. This trophozoite stage grows at the expense of hemoglobin of RBC of host which gets decomposed into aminoacids and hematin which are used by the parasite to synthesize its own proteins. The ring configuration alters as the plasmodia begin to grow within the blood cells. Corpuscles becomes larger, double its original size and slightly paler due to loss of hemoglobin. Full grown mature trophozoite almost completely fills the enlarged corpuscle and now becomes a schizont, ready to multiply asexually by a process called erythrocytic schizogony or merogony. The nucleus of schizont divides by multiple fission to form daughter nuclei and many small uninucleate cells termed the erythrocytic merozoite or schizoites are formed, arranged like the petals of rose flower or cluster of grapes and this stage is called rosette stage. After sometimes, the cell membrane of RBC bursts and merozoites with toxic products are set free in blood plasma which reinfect RBC. Destruction of RBC eventually causes the patient to become anemic. Fever occur every 48-72 hrs corresponding with fresh release of merozoites in blood.

Incubation Period: The interval between mosquito bite or introduction of sporozoites in human blood and first appearance of malarial symptoms is called “incubation period” and it ranges from 8-40 days.

Formation of gametocytes: After repeated schizogony, parasite number increases so much that they either lead to acute anemia or death of host. However food shortage or host immunity could cut short the existence of parasite. Consequently, schizogony is replaced by sexual phase with the production of gametocytes or gamonts. Some of the merozoites in the blood cells develop into sexual forms that grow into male...
microgametocytes or female macrogametocytes. When a mosquito bites man at this stage of the life cycle, the gametocytes are taken into the insect’s stomach where they mature into male and female gametes.

Sexual Reproduction of *P. vivax* in mosquito:

Following the transfer of gametocytes into mosquito, the process of gametogony or gametogenesis starts. If the mosquito is female *Anopheles*, the gametocytes alone resist the action of digestive juices and survive while all other accompanying stages get digested. The rupture of RBCs in mosquito’s stomach sets free the gametocytes which develop into gametes which are of two types-

Microgametes: Liberated microgametes are very active. The nucleus divides mitotically into 6-8 haploid fragments. At the same time 6-8 flagellums like long threads of cytoplasm pushout from the surface of gametocytes into which each daughter nuclei passes. These are male gametes or microgametes. Their formation is called exflagellation. The detached microgametes behave like the sperm cells of higher animals. By their lashing movements, they swim in the blood in stomach of mosquito to meet female gamete.

Macrogamete: They undergo slight reorganization to turn into female gametes, which are ready for fertilization.

Following attraction of male gametes to female gametes, they undergo fertilization to form a zygote. Zygote after sometimes becomes elongated and motile and perform writhing and gliding movement and is called vermiculcule or ookinete. It pierces through the epithelial lining of mosquito stomach and comes to lie against the basement membrane. Encystment of zygote ensues. Encysted zygote is called oocyst or sporont. Oocyst is diploid. It enters asexual multiplication known as sporogony. This sporogony phase of the life cycle requires 7 to 10 days and during this time, the infectivity of sporozoites increases more than 10,000 times. Sporozoites invade the entire mosquito—many of them enter the salivary glands and are in favorable position to infect next host (man) when mosquito feeds on its blood and cycle starts again.

**PATHOGENICITY:**

*Plasmodium* is non-pathogenic in mosquito. Despite utilizing host’s nutritive resources, it does not bring harm to the mosquito. However, in man infection with *Plasmodium* leads to malaria. Clinical signs and symptoms associated with several human plasmodial infections are similar but may differ as regards the intensity. One characteristic response of human hosts is the paroxysm, which begins with chills followed by a gradually mounting fever that may reach 41°C (106°F). Profuse perspiration may last a few hours as the temperature subsides. The entire paroxysm lasts from 6 to 10 hours and occurs every third day in *P. vivax*, *P. falciparum* and *P. ovale* infections. Paroxysms associated with malariae malaria are quartan because they occur every 72 hrs; with forth day chills and fever are thought to be triggered by the release of pyrogenic agents during the sporulation process. Falciparum malaria is the
most pathogenic of all the malarias due to pernicious malaria and blackwater fever caused by it. It is commonly fatal, especially in children and elderly. Symptoms include uncontrollable shivering, high fever and finally profuse sweating. Other symptoms include headache, bone and muscle pains, malaise, anxiety, mental confusion and ever delirium. Severe anemia and leucopenia are common.

In chronic malaria infections, liver and spleen become enlarged and jaundice may follow.

One could not however explain the ethnic differences in malaria. White people are more susceptible to malaria and blacks have greater tolerance. An abnormal condition in man called “sickle cell anemia” provides protection against Falciparum malaria.

PREVENTION AND TREATMENT:

In spite of the tremendous advances in malaria research made over the past decade, many basic problems are still unsolved. Masses of people in tropic and semi tropic countries lack economic resources to combat the mosquito menace or to treat the affected patients. There is shortage of well-trained specialists in epidemiology and entomology who understand malaria. To add to the woes, mosquitoes are increasingly becoming resistant to insecticides. The need of the hour is therefore to control the occurrence of malaria which can be achieved by

Destruction of *Anopheles* mosquito

Prophylaxis or Prevention of infection

Treatment of infection

Destruction of *Anopheles*’ larvae can be achieved by eradicating the breeding places of mosquito which include the stagnant water such as ponds, pits, puddles, gutters, drains, tin cans, cisterns, barrels or old tyres etc. Wherever or whenever it is not possible to remove water, a thin film of oil can be sprayed on the water surface. The insect larvae could also be destroyed by chemical treatment or by biological methods using larvicide fishes like Gambusia. The adult mosquito could be killed by fumigation using sulphur, pyrethrum, cresol, tercamphor etc or by spraying insecticides including DDT, gammexane, pyrethrum, malathion etc.

Prophylaxis or prevention of infection can be achieved by putting screens on all the doors, windows and ventilators of the houses. One can use mosquito-nets to prevent mosquito-biting during night. Use of mosquito repellent creams as well as repellent mats, coils etc help in protection against mosquito bites. One should maintain good hygienic surroundings as well as eat healthy food to maintain a healthy body which minimizes chances of infections.

Treatment of Malaria is by synthetic drugs like Quinine, Camoquin, Chloroquin, Pentaquine etc. Quinine is a natural alkaloid extracted from the bark of the cinchona tree grown in Java, Peru, Sri Lanka and India. It had been used effectively to combat malaria for the last 300 years. Several synthetic derivatives of the drug are currently in
use and have been successful in combating malaria to an extent. Therapy with a particular drug is generally done, keeping certain aims in mind. In order to alleviate symptoms, chloroquine, quinine, pyrimethamine etc. are given; to prevent relapses, primaquine is given; to prevent the gametocyte’s spread, primaquine is given for *P. falciparum* and chloroquine for all other species.

**Trypanosoma**

This group of flagellates consists of mostly symbiotic (commensal, parasitic or mutualistic) while some are free living as well. The group is a large and varied assemblage of flagellates.

Of all the parasitic Kinetoplastids, the most notorious belong to the genus *Trypanosoma*. These are blood parasites of vertebrates, but most of them are transmitted by invertebrate vectors. Multiplication of the flagellates takes place in the digestive tract of the vectors. Man has three species of trypanosomas as parasites- *Trypanosoma gambiense*, *T. rhodesiense* and *T. cruzi*. In case of *T. rhodesiense* and *T. gambiense* causing African sleeping sickness, the Tsetse flies, *Glossina palpalis*, serve as vectors injecting the infective stage when they bite (Fig. 15). *T. cruzi* causes Chagas’ disease in tropical America, bugs transmitting the disease by leaving the flagellates with fecal material near the punctures they make. If the flagellates get into the wound or penetrate a mucous membrane of the eye, a new infection may get established.

*Trypanosoma gambiense* is unicellular, microscopic, slender, leaf-like, flattened, colorless and actively wriggling flagellate (Fig. 16). It measures 10-40µ in length and 2.5-10µ in width. The spindle-shaped body remains spirally twisted and pointed at both the ends. The parasite migrates through the body by way of the blood. Normal habitats are the blood plasma, cerebrospinal fluid, lymph nodes and spleen.

Mouth is lacking in *Trypanosoma* which obtains its nourishment by osmosis from blood plasma. Gaseous exchange in respiration and elimination of excretory products also occur by diffusion through the body surface. Sexual reproduction is totally absent.

**LIFE CYCLE AND REPRODUCTION:**

*T. gambiense* is digenetic i.e. life cycle gets completed in two hosts; primary or principal host is the man in which the parasite feeds and multiplies asexually (Fig. 17). The secondary or intermediate host is a blood sucking Tsetse fly where further multiplication occurs and which transmits it from one principal host to another so it is also called carrier or vector host. Mammals like pigs, buffalo etc. act as reservoir of the parasite.

Life cycle in man: An infected fly on biting a healthy person, transmits the parasites into his blood. The parasite is found in blood plasma and never inside the blood cells.
The trypanosomes, which initiate infection in man, are devoid of free flagellum (metacyclic form) and soon they get transformed into long slender forms which are free swimmers. Parasite multiplies by longitudinal splitting. Following multiplication, it undergoes metamorphosis and turns into a short stumpy form which lacks a flagellum and is non-feeding. As the host develops sufficient antibodies, they eventually die unless ingested by a Tsetse fly with the blood meal.

Life cycle in Tsetse fly: When the blood of an infected person is sucked by the Tsetse fly, the short, stumpy forms go into the intestine of the insect where they change into long, slender form. In the intestine of the fly, the parasite reproduces and forms both epimastigotes and trypomastigotes. After two weeks or more in the gut of the fly, the flagellates migrate to the salivary glands, where they become attached to the epithelium and develop into the infective stage. When the fly bites a person to feed, it transfers the metacyclic forms, along with saliva, into its blood, where they initiate another infection. The cycle in Tsetse fly requires 20 to 30 days and a temperature between 75ºF to 85ºF for completion.

PATHOGENICITY:

The Gambian or chronic form of sleeping sickness in man primarily involves the nervous and lymphatic systems. There may also be invasion of dermis. A dark red button-like or larger lesion forms around the wound caused by the bite of an infected Tsetse, followed by local itching and irritation. After an incubation period of one or two weeks, fever, chills, headache, loss of appetite usually occurs, especially in non-natives. As time goes on, enlargement of spleen, liver and lymph nodes occurs, accompanied by weakness, skin eruptions, disturbed vision and a reduced pulse rate. The infection leads to meningoencephalomyelitis and hemolysis. As the nervous system is invaded by the parasites, the symptoms include definite signs of “sleeping sickness”. A patient readily falls asleep. Coma, emaciation and often death complete the course of disease, which may last for several years. The mortality rate is high.

CONTROL:

The control could be by treatment of the disease or by following prophylactic measures. If the disease is diagnosed early, the chances of cure are high. The type of treatment depends on the phase of the disease: initial or neurological. Success in the latter phase depends on having a drug that can cross the blood-brain barrier to reach the parasite. Bayer 205 (also available as Antrypol, Germanin, Suramin) and Pentamidine or closely related medicine lomidine are used in early stages of infection (before the parasite invades the nervous system). Once the parasite has reached the nervous tissue, an arsenic compound called Tryparsamide is used. Malarsoprol or Melarsen oxides are also commonly used. Each of these drugs, however, requires careful monitoring to ensure that the drugs themselves do not cause serious complications such as fatal hypersensitivity (allergic) reaction, kidney or liver damage, or inflammation of the brain. Nitrofurazone is also recommended when the person has arsenic resistance.
Prophylactic measures include killing of the fly by using insecticides like DDT and also removing its habitats in bushes and low trees along the rivers. A single intramuscular injection of 4mg/kg of Pentamidine remains effective for about 6 months against the disease.

**Leishmania**

An important pathogenic Kinetoplastid genus, closely related to *Trypanosoma* is *Leishmania*. It is responsible for serious diseases of man, cattle, dog, sheep, horse etc., collectively called Leishmaniasis. These are rounded or oval parasites (1.5 to 3.0 µm) of invertebrates and vertebrates with a morphologically complex life cycle. Body forms include a promastigote (leptomonad) form with a free flagellum and the characteristic amastigote (leishmanial) form with no flagellum or where the flagellum is never fully emerged (Fig. 18).

**LIFE CYCLE:**

The genus *Leishmania* is characterized by two different stages in its life cycle, each of which occurs in a distinct host. The primary host is the vertebrate (man) while secondary or intermediate host is an invertebrate (sandfly of the genus *Phlebotomus*). The amastigote form is often called Leishman-Donovan body or L-D body, is found in the cytoplasm of reticuloendothelial cells, monocytes and other phagocytic cells of the vertebrate host (so far found in mammals and lizards). In this stage, the parasite measures 2-5µm in diameter and may be rounded or oval in shape. Its cytoplasm is often vacuolated. A few to 100 may occupy one cell and their reproduction is by binary fission. Promastigotes are very similar to each other in almost all species.

Parasitized host cells rupture, liberating amastigotes that are engulfed by other phagocytic cells. Biting sand flies pick up both free amastigotes and free parasitized cells. In the midgut of the insect, the parasite becomes elongated with a large nucleus and acquires a short free flagellum arising from a blephroplast located near the anterior end of the body. It undergoes active reproduction and the infection, hence gets established in the sandfly gut. This is the promastigote or leptomonad form. When the infected sand fly bites again, promastigotes eventually reach the blood or other tissues of the vertebrate host and are engulfed by phagocytic cells.

**PATHOGENICITY:**

All mammalian leishmania can infect man. *Leishmania tropica*, *L. mexicana*, and *L. braziliensis*, predominantly leads to cutaneous leishmaniasis, an infection of reticuloendothelial cells of the skin or of mucosae of mouth and nose, while *L. donovani* causes visceral leishmaniasis, a killing disease. Infection occurs primarily in spleen and liver and secondarily in bone marrow, intestinal villi and other areas. The disease is called Kala-azar or dum dum fever.
*L. tropica* mainly attacks adults in North Africa, Asia including India, Russia, Europe and Australia. It causes long running superficial cutaneous ulcers called “Oriental Sores”.

*L. braziliensis* is present in most parts of tropic and subtropics regions of the New World, ranging at least from Panama to Argentina. The most severe form of this infection called “espundia” is endemic in the jungles of Brazil, Bolivia, and Peru etc. The clinical form frequently involves mucous membranes of mouth, nose and pharynx and may result in complete destruction of these tissues and associated cartilage. The lesions are resistant to treatment.

*L. mexicana* occurs in some countries of Central and South America, principally Mexico and Guyana. It causes a cutaneous lesion and does not spread to mucous areas. Ear lesions are known as chiclero ulcers.

*L. donovani* lives as an intracellular parasite in leucocytes or cells of liver, spleen, bone marrow, lymphatic glands etc. of men in east India, Assam, the Mediterranean areas, southern Russia, north Africa, central Asia, northeast Brazil, Colombia, Argentina, Paraguay, El Salvador, Guatemala and Mexico. It causes kala-azar or dum dum fever, which is a rural disease with reservoirs of infection in dogs, foxes, rodents and other mammals. The disease is characterized by a lengthy incubation period, an insidious onset and a chronic course attended by irregular fever, increasing enlargement of the spleen and of the liver, leucopenia, anemia and progressive wasting. The mortality is high; death occurs in 2 months to 2 years. The most obvious physical signs are progressive enlargement of the spleen and to some extent of liver. About two years after the acute stage of Kala-azar occurs in the viscera, post kala-azar leishmaniasis may appear, which are in the form of dis pigmented areas of skin (so the name Kala-black or fatal, azar-sickness) or modular lesions. Vector in this case is the sand fly, *Phlebotomus argentipes*. The strain in children is sometimes called *L. infantum*.

**CONTROL:**

The control revolves around treatment of disease along with prophylactic measures. Positive diagnosis relies on discovery of the parasite in infected tissues. For the treatment of Leishmaniasis the currently used drugs are limited to four. The first line compounds are the two pentavalent antimonials, sodium stibogluconate (Pentostam) and meglumine antimoniate (Glucantime). If these drugs are not effective, the second line compounds of pentamidine (Lomidine) and amphotericine B (Fungizone) are used.

Prophylaxis includes elimination of reservoir hosts. Stray dogs should be eliminated. Insecticides should be used to control the sand flies.

**Glossary**

Autotrophic: Type of nutrition in which organic compounds used in metabolism are obtained by synthesis from inorganic compounds.
Axopodium: Fine, needle-like pseudopodium that has a central bundle of microtubules.

Axoneme: Microtubules and other proteins that compose the inner core of flagella and cilia.

Basal body: An organelle equivalent to a centriole at the base of flagellum and cilia.

Binary fission: Asexual division that produces two similar individuals.

Body ciliature: Cilia distributed over the general body surface of ciliates.

Calcereous: Composed of calcium carbonate.

Centriole: Microscopic cylindrical structure, composed of microtubules, which is situated at each pole of the mitotic spindle and is distributed during mitosis. There it may function as a basal body and give rise to a flagellum or cilium.

Centrosome: Structure from which bundles of microtubules radiate outwards.

Cilium: Characteristic of many protozoan and metazoan cells, a motile outgrowth of the cell surface that is typically short and its effective stroke is stiff and oar-like.

Conjugant: One of a pair of fused ciliates in the process of exchanging genetic material.

Contractile vacuole: Large spherical vesicle responsible for osmoregulation in protozoans and some sponge cells.

Cytostome: Cell mouth

Cyst: A parasite surrounded by a resistant wall or membrane (the wall or membrane constitutes the cyst)

Disease: A specific morbid process that has a characteristic set of symptoms, and that may affect either the entire body or any part of the body.

Ectoparasite: A parasite that lives on the outside of its host.

Encystment: Forming resistant cysts in response to unfavorable conditions such as lack of food or desiccation.

Endoparasite: A parasite that lives within its host.

Endoral membrane: Ciliate undulating membrane that runs transversely along the right wall and marks the junction of the vestibule and buccal cavity.

Exconjugant: Ciliates that have separated after sexual reproduction.

Filopodium: Pseudopodium that is slender, clear and sometimes branched.

Filter feeding: A type of suspension feeding in which particles (plankton and detritus) are removed from a water current by a filter.

Flagellum: A characteristic of many protozoan and metazoan cells; it is typically long and its motion is a complex whip-like undulation.
Heterotrophic: Refers to the type of nutrition in which organic compounds used in metabolism are obtained by consuming the bodies or products of other organisms.

Host: Living animal or plant harboring or affording subsistence to a parasite; also a cell in which a parasite lodges.

Infraciliary system: The entire assemblage of ciliary basal bodies, or kinetosomes, and the fibres that link them together in the cell cortex of ciliates.

Kinetosome: A ciliary or flagellar basal body.

Kinety: One row of cilia, kinetosomes, and kinetodesmata of ciliates.

Lobopodium: A pseudopodium that is rather wide with rounded or blunt tips, is commonly tubular, and is composed of both ectoplasm and endoplasm.

Lorica: A girdle-like skeleton.

Macronucleus: Large, usually polyploidy, ciliate nucleus concerned with the synthesis of RNA, as well as DNA, and therefore directly responsible for the phenotype of the cell.

Membranelle: Type of ciliary organelle derived from two or three short rows of cilia, all of which adhere to form a more or less triangular or fan-shaped plate.

Merozoites: Individuals produced by multiple fission of sporozoan trophozoites.

Metachrony: Wave pattern that results from the sequential coordinated action of cilia or flagella over the surface of a cell or organism.

Micronucleus: Small, usually diploid, ciliate nucleus concerned primarily with the synthesis of DNA. It undergoes meiosis before functioning in sexual reproduction.

Mutualism: An association whereby two species live together in such a manner that their activities benefit each other.

Osmoregulation: The maintenance of internal body fluids at a different osmotic pressure (usually higher) than that of the external aqueous environment.

Parapodium: Lateral, fleshy, paddle-like appendage on polychaete annelids.

Parasitism: An association between two specifically distinct organisms in which the dependence of the parasite on its host is metabolic and involves mutual exchange of substances; this dependence is the result of a loss of genetic information by the parasite.

Pellicle: Protozoan “body wall” composed of cell membrane, cytoskeleton, and other organelles.

Primary host: The host for the adult stage of a parasite. Definitive host.

Proboscis: Any tubular process of the head or anterior part of the gut, usually used in feeding and often extensible.
Schizogony: Asexual reproduction by multiple or binary fission.
Siliceous: Composed of silica.
Sporogony: The production of sporoblasts by schizogony (in Sporozoa, Microspora, Myxozoa).
Symbiosis: The living together of different species of organisms.
Symmterogenic: Producing mirror-image daughter cells as a result of fission.
Synkaryon: Zygotic nucleus of ciliates.
Trophozoite: The motile stage of Protozoa.
Undulating membrane: Type of ciliary organelle that is a row of adhering cilia forming a sheet.
Vector: An essential intermediate host, usually an arthropod, in which the parasite undergoes a significant change.
Vegetative nucleus: Macronucleus.
Vestibules: Preoral chamber.

References:


Fig. 1 – Structure of *Euglena*
Fig. 2a

A. Base-to-tip undulation of flagellum leading to “Pushing force”

B. Tip-to-base undulation of flagellum leading to “Pulling force”

Fig. 2b – Movement of *Euglena*

Fig. 2c – Movement of flagellum
Fig. 2e – Euglenoid movement in *Euglena*

Fig. 2d – Paddle stroke movement of *Euglena*
**Fig. 3 – Binary Fission / Symmetrogenic division in *Euglena***

**Fig. 4 – Structure of *Paramecium caudatum***
Fig. 5 – Pellicular system in Paramecium

Fig. 6 – Structure of cilium and basal body (L.S.)
Fig. 7 – Ciliary beating and locomotion in *Paramecium caudatum*

A. Cycle of ciliary beating (side view)
B. Path taken by ciliary tip during beat cycle (surface view)
C. Series of adjacent cilia in a metachronal wave in various stages of beat cycle
   i. direction of effective stroke (solid arrow) is same as metachronal wave (dashed arrow)
   ii. direction of effective stroke (solid arrow) is opposite to metachronal wave (dashed arrow)
D. Metachronal waves during forward swimming
E. Course of progression during locomotion
Fig. 8 – Buccal Organelles of *Paramecium*

- endoral membrane
- dorsal peniculus
- ventral peniculus
- quadrulus
- cytostome
- food vacuole
- post buccal fibril

Fig. 9 – Asexual Reproduction / Binary fission in *Paramecium caudatum*

- anterior contractile vacuole
- macronucleus
- micronucleus
- posterior contractile vacuole
- Oral groove disappearing
- mitotic division of micronucleus
- Newly formed oral groove
- New contractile vacuole
- daughter paramecia
Fig. 10 – Sexual Reproduction / Conjugation in *Paramecium caudatum*

Fig. 11 – *Entamoeba histolytica* (A) Living trophozoite (B) Stained trophozoite
Fig. 12 – Life Cycle of *Entamoeba histolytica*

a) Trophozoite in lumen and mucosa of colon
b) Precystic stage
c) Cystic stage
d) Excystment in lower ileum

Fig. 13 – *Anopheles* mosquito (female)
Fig. 14 - Life Cycle of malarial parasite *Plasmodium vivax*

1-13 Asexual reproduction in man (primary host)
1-3 Pre-erythrocytic cycle in liver cells
4-10 Erythrocytic cycle in RBC
11-13 Beginning of gametocyte
14-26 Sexual reproduction in mosquito (secondary host)
21 Zygote
22 Ookinete
23-26 Development of sporozoites
Fig. 15 – Tsetse fly (*Glossina palpalis*)

Fig. 16 – Structure of *Trypanosoma gambiense*
Fig. 17 – Life Cycle of *Trypanosoma gambiense*
Fig. 18 – Life Cycle of *Leishmania donovani*