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وزارة التعليم العالي والبحث العلمي

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Departement of Biological Sciences

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Département des
Sciences
Biologiques

COURSE HANDOUT

Title:

Biodiversity of parasites

For Parasitology First Year Master's Degree Students

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Academic year 2024/2025

COURSE OUTLINE

Biodiversity of Parasites

- Faculty: Science and Technology
- Department: Biological Sciences
- Target Audience: Master 1 Parasitology
- Course Title: Biodiversity of Parasites
- Credits: 06
- Coefficient: 03
- Duration: 14 weeks
- Schedule: 1.5 hours

COURSE PRESENTATION

This course aims to highlight the position of parasites within their ecosystem. To achieve this, the course will be divided into several chapters. The content of the chapters generally focuses on: the various types of long-term interactions, parasitism in particular, its characteristics, parasite diversity and finally the role that parasites play in biodiversity.

At the end of this course, the student will master the concepts of ecology and parasitology. They will also explore the world of parasitism and the living organisms considered as parasites, understand the lifestyles of parasites, and recognize the relationships between parasites and their hosts.

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Chapter 1:

Introduction to the study of parasitism:

1 PARASITE AND SUSTAINABLE INTERACTIONS

Parasites are living beings that typically cannot survive without another living being, their host, which generally provides them with food and sometimes shelter as well.

Several groups of living organisms include parasites, such as viruses, bacteria, plants, protists, and metazoan animals. In this course, we will study parasites that belong to protists and metazoan animals.

Although the parasite most often causes varying degrees of damage, a gradual co-evolution between the host species and the parasitic species has established a sustainable interaction between them. Indeed, a pathogen that is too aggressive and kills its host risks no longer finding a suitable environment for its development.

Parasitism is a permanent or temporary association between two radically different beings. Here is some examples:

1.1 Temporary sustainable interactions

- Interactions between Leeches and Vertebrates

To feed on blood, leeches briefly cling to their host, such as fish, amphibians, or mammals. Following feeding, they separate from the host without causing death, enabling both species to carry on with their life cycles (Figure 1).

Figure 1 Limnotrachelobdella sinensis attaching on the inner surface of the gill opeculum

- Interactions between Mosquitoes and Humans

Mosquito females feed on human blood in order to obtain the nutrients they need to build their eggs. This encounter is brief and usually does not cause the host to die right away, even if it may spread infections (Figure 2).

Figure 2 A mosquito feeds on human blood

- Ticks and Mammals

Figure 3 Ticks nestle under the ears of cattle. (Photo credit: Rebecca Trout Fryxell, Ph.D.)

Ticks latch onto mammals for a short period to feed on their blood, then drop off. The host continues to live after the tick detaches, allowing the tick to survive and reproduce without fatally harming its host.

1.2 Permanent Sustainable Interactions

- Tapeworms in Mammals

Tapeworms can live inside the intestines of mammals (such as humans, dogs, or livestock) for extended periods, absorbing nutrients from the host's food. This interaction is sustained over a long time, as the parasite coexists within the host without killing it (Figure 5).

- *Plasmodium* (Malaria Parasite) in Humans and Mosquitoes

The Plasmodium parasite has a permanent sustainable interaction between two hosts: humans (where it infects red blood cells) and mosquitoes (where it reproduces). Both the human host and mosquito typically survive long enough for the parasite to complete its life cycle (Figure 4).

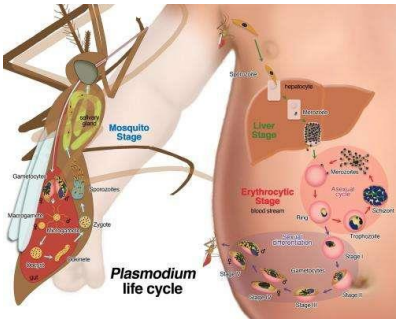


Figure 4 Life cycle of human malaria parasite in humans and mosquitoes.

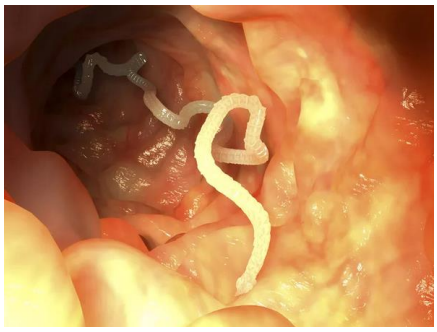


Figure 5 A tapeworm inside the intestines of a dog (JUAN GARTNER).

2 THE PLACE OF PARASITES IN BIODIVERSITY

Biodiversity, or biological diversity, is the variety and variability of all living organisms. This includes genetic variability within species and their populations, variability among species and their life forms, the diversity of associated species complexes and their interactions, and finally, the ecological processes that organisms influence or in which they are involved.

When beginning the study of animal ecology, the first step is to identify the specific animal species we want to study. To do that, we first need to understand what 'species' means.

2.1 What is a species?

We call a 'species' a group of living organisms that are:

- Able to cross breeding
- Share certain specific criteria:

2.2 Morphologic criteria

Members of the same species resemble each other, which means they share the same morphology. This similarity is found in the most detailed morphological features, commonly known as 'identification keys.

This resemblance in morphological criteria among members of a species must be heritable and should not be subject to any phylogenetic plasticity.

The resemblance criterion is operational since our perception allows us to implement it:

1- Physical Characteristics: resemblance in appearance, such as size, shape, color, and structure of organisms, can be used to differentiate species. This is often the first step in identification.

2- Anatomy: resemblance in internal structures, such as organs, skeletal features, or reproductive organs.

2.3 Biological criteria

The most important biological criteria to differentiate species is Reproductive Behavior: resemblance in mating rituals, courtship behavior.

The **Reproductive Behavior** refers to the condition where two different biological species cannot interbreed and produce fertile offspring. Even though the individuals of these species may look similar or live in the same area, they are considered distinct species because they cannot reproduce viable, fertile offspring when mating with each other. Inter-sterility acts as a reproductive barrier, contributing to the differentiation

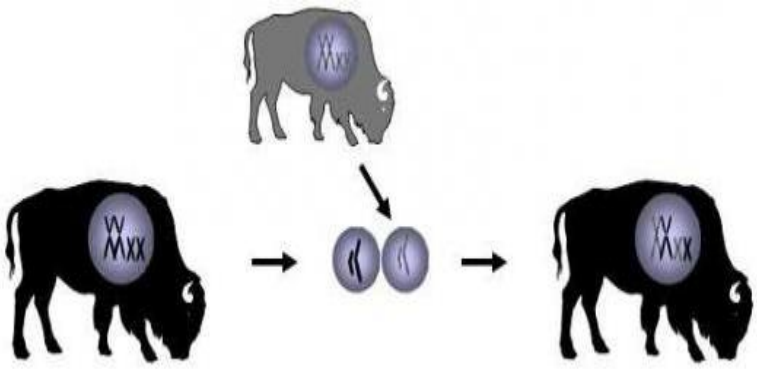


Figure 6 Inter-sterility

of species in biological classification. This barrier prevents gene flow between the distinct species, leading to their genetic isolation over time (Figure 6).

We should mention an exception: in nature, we can find offspring resulting from the crossbreeding of two different species; these are called ‘hybrids.’ Hybrids often exhibit a mix of traits from both parent species (Figure 7).

Communication is another biological criterion that we can use to distinguish members of a species. Individuals belonging to the same species use similar communication methods, such as calls, songs, or chemical signals.

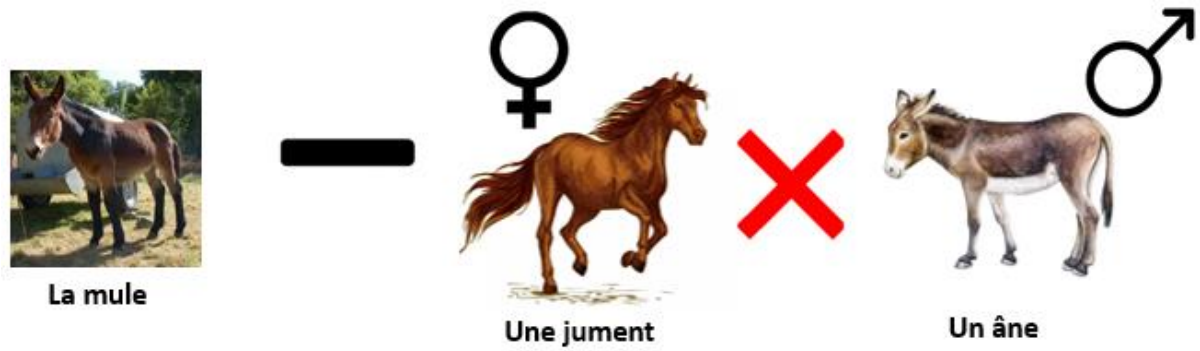
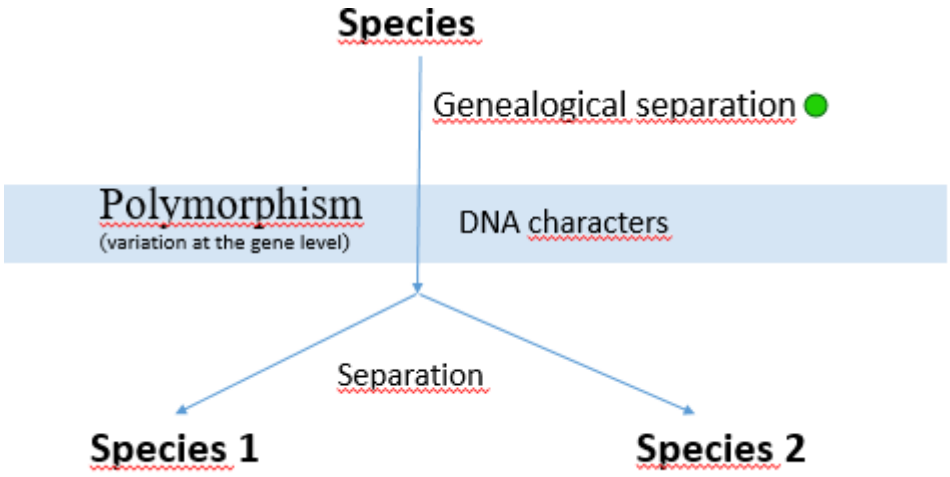


Figure 7 Example of hybrids

2.4 Phylogenetic criteria

Over generations, isolated populations develop genetic differences as a result of mutations, genetic drift, and natural selection. These differences can eventually become so pronounced that individuals from different populations can no longer interbreed and produce fertile offspring. This reproductive isolation marks the emergence of distinct species with separate genealogical histories.



1- **DNA Sequencing**: DNA barcoding is a technique used to identify and differentiate species based on a short, standardized region of genetic material, typically DNA. The method involves sequencing a specific segment of DNA from a sample and comparing it to a reference library of sequences from known species. If the sequence from the sample matches one in the library, the species can be identified. Comparing DNA sequences allows for the identification of genetic similarities among individuals within the same species. DNA barcoding, which involves sequencing a specific short region of DNA—often the COI barcode—is widely used to distinguish and identify different species.
2- **Genetic Markers:** Specific genetic markers or genes can be unique to certain species. PCR (Polymerase Chain Reaction) and DNA fingerprinting are used to amplify and analyze these markers.

2.5 Boundary issues

When determining whether two individuals belong to the same species, we must use one of the previously mentioned discrimination criteria. However, difficulties can arise. For instance, with microorganisms, morphological identification is challenging due to their small size. Additionally, when dealing with species that have long lifespans, it is difficult to test crossbreeding potential because these individuals reach sexual maturity late (ex: **Great white sharks** can live for about 70 years or more and typically reach sexual maturity around 20 to 30 years old.).

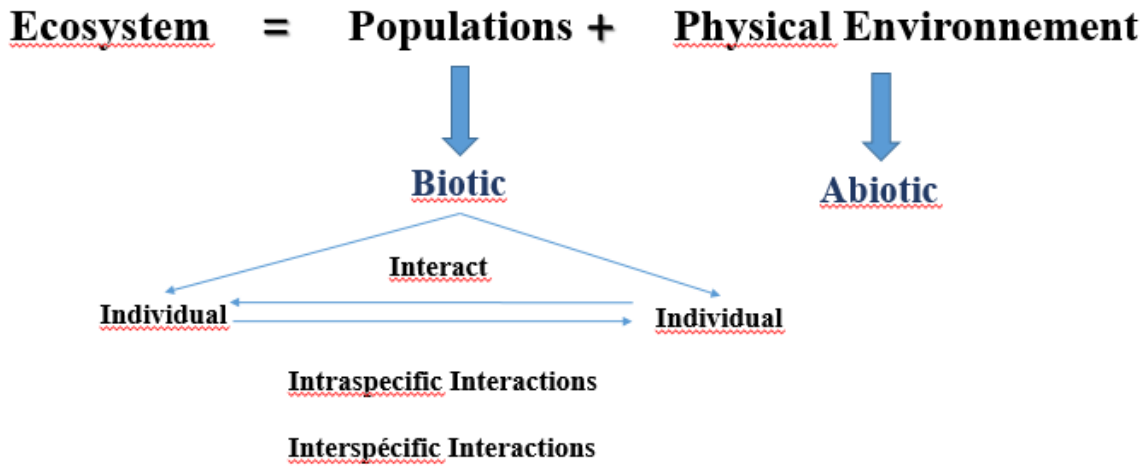
Sometimes it is even difficult to define the number of genes in the reconstruction of phylogenetic hypotheses.

Exemple:

Taxonomic description of two lice species, the body louse (*Pediculus vestimenti*) and the head louse (*Pediculus capitis*). The morphology of the individuals (here only the female is represented) made it possible to define two species. However, genetic data has confirmed that these two species are interfertile, and form a single species in the biological sense, called *Pediculus humanus*. The phylogenetic tree represents the evolutionary links in the genus *Pediculus*, with the sister species of *Pediculus humanus* which is associated with the *Pidiculus chimpanzé*, and which appears to have been isolated from it for 5.6 million years.

3 PARASITES AND ENVIRONNEMENT

The environment is the ecosystem where an individual lives. The ecosystem consists of populations and the physical environment. The population represents the biotic components, and the physical environment represents the abiotic components. The biotic components are characterized by interactions between individuals, where we can distinguish between intraspecific and interspecific interactions.



An ecosystem is an environment in which the physicochemical conditions are relatively uniform and allow for the development of a variety of living organisms.

What are these physicochemical comditions?

- ✓ The climatic conditions (such as temperature, solar radiation, humidity),
- ✓ Geological conditions (soil characteristics),
- ✓ Hydrological conditions (such as groundwater).

We can size several types of ecosystems:

- Terrestrial ecosystems.
- Aquatic ecosystems.
- Mixed ecosystems (water-land) and aerial-terrestrial ecosystems (air-land).
- Artificial or non-natural modified landscape ecosystems (created by humans).

3.1 Animal population dynamics

3.1.1 *Caracteristics of animal populations*

Individuals that belong to the same population live within a limited biotope. They must be of the same species and be able to interbreed with each other to produce offspring.

3.1.2 *Population dynamics*

Each individual in any population born, lives for a certain time, and dies. Therefore, a population is a dynamic system whose continuity results from compensatory phenomena:

- Individuals leave the system (mortality + emigration)
- Individuals enter the system (natality + immigration)

The dispersion of organisms or populations within a limited area can follow three typical models:

- ✓ Uniform dispersion:
- ✓ Random dispersion
- ✓ Clamped dispersion

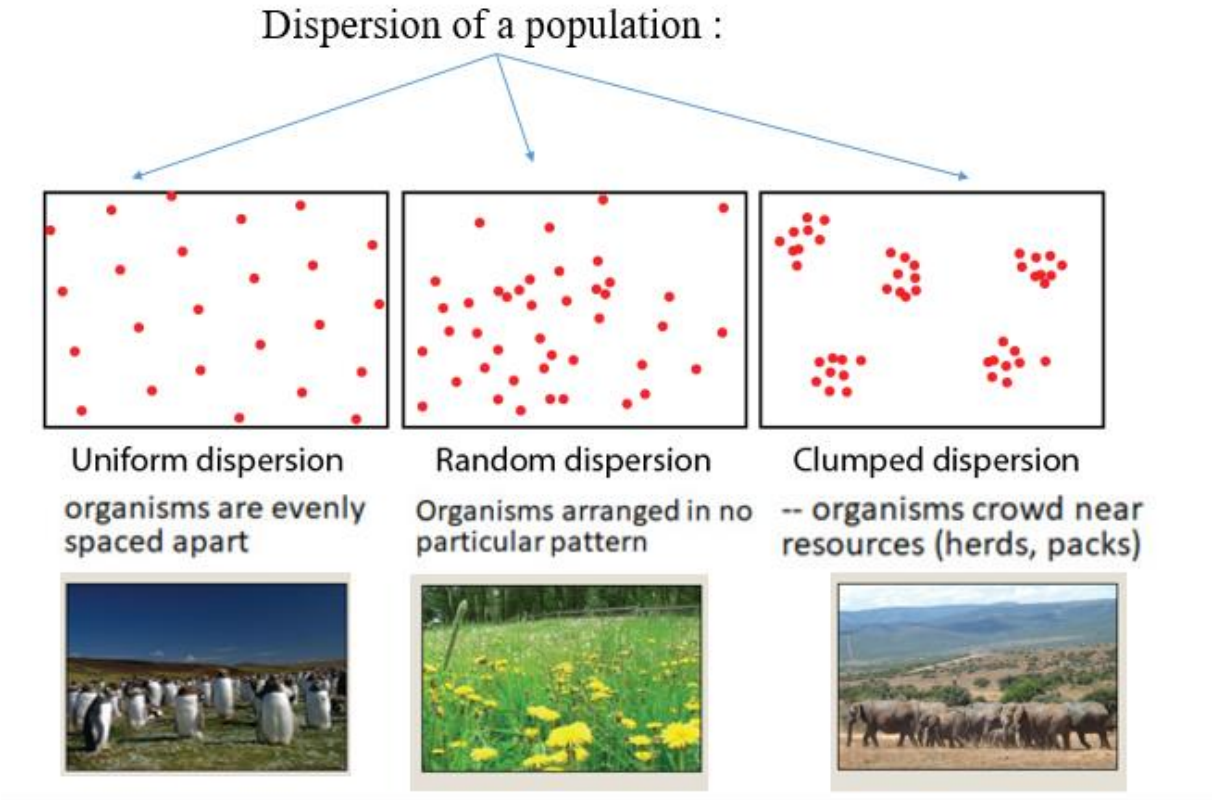


Figure 8 Population dispersion models

3.2 Competition and ecological niches

3.2.1 *What is an ecological niche*

In any ecosystem, it is common for many species to coexist in the same habitat. However, upon close observation, it is evident that each species occupies a distinct ecological niche.

The ecological niche can be defined as the role of the species (prey, predators) in the functioning of the ecosystem (the profession of a species/Habitat +role).

3.2.2 *Biotic regulation of populations*

Biotic regulations between populations are one of the most important aspects of the biology of many species, especially species that depend on other species for their survival (predators, parasites).

A limit to the growth of a population depends on:

1. Ressources (bottom-up control of the food chain)**.**
2. Predators or pathogene agents (parasites) (top-down control of the food chain**).**

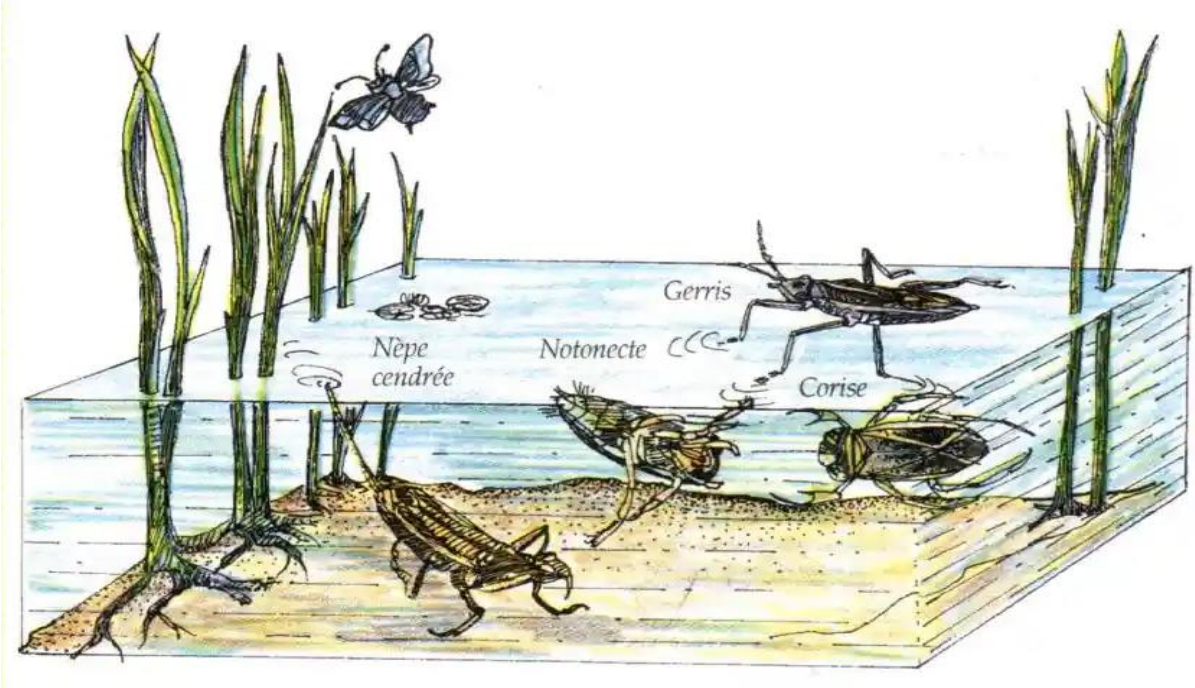


Figure 9 Example of ecological niche: The water scorpion, backswimmer, and water strider are predators of different prey

4 SUSTAINABLE INTERACTIONS

The concept, notably developed by Claude Combe and his colleagues since the 1980s-1990s, posits that there is no clear boundary in community life between strict parasitism and perfect mutualism. Sustainable interactions, which involve intimate relationships between organisms of different species, are termed heterotypic. However, when these interactions occur within the same species, they are called homotypic. Among heterotypic interactions, the following types can be identified:

1. Ecological associations
2. Trophic associations

4.1 Ecological associations

These are interspecific interactions that aim to ensure the transport and protection of one individual by another

There are two types of ecological associations:

A. The phoresis
B. The inquilinism

4.1.1 *The phoresis*

It is a type of association between two organisms, without obligatory parasitism, in which one individual (phoront) attaches itself to another individual (host) to migrate from one site to another.

It is a non-obligatory (both partners have independent food sources), non-destructive (The transport in question does not cause specific physiological damage), and temporary association. The transported species is called 'phoretic' (Figure 10).

However, in some cases, the boundary between phoresis and parasitism can be blurred. The phoront not only incurs an energy cost due to the additional movement on the host species, but the attachment mechanisms of the phoretic species can also cause lesions on the host, similar to those caused by the 'sucker' of a remora fish when it attaches itself to large fish such as rays or sharks.

Figure 10 Nymphs of mites (acariens) develop suckers (hypopes) to cling on the backs of beetles, allowing them to move from a dried area to a fresher one.

4.1.2 *The inquilinism*

It is a biological association grouping animals of different species based solely on spatial requirements, without any physiological necessity. One species (the inquiline) utilizes the body of another, larger species as a host; an inquiline species seeks shelter within its host (Figure 11).

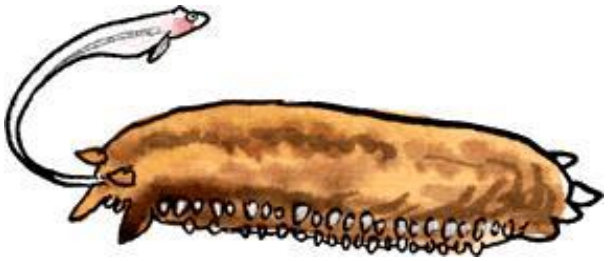


Figure 11 The fish Carapus (Fierasfer) takes shelter inside a sea cucumber by entering backward through the host's cloacal opening.

This relationship is more enduring than phoresis but still loose in nature.

4.2 Trophic associations

Most heterotypic associations are trophic. Trophic interactions arise from an association of living organisms, including microorganisms, interacting with each other for their nutrition and trophic mode. The relationships between each organism at a given trophic level form a complex web of interactions known as a trophic network

These interactions can be mutually beneficial for both partners or provide a benefit to only one of the partners.

1. Mutually beneficial interactions are:
    - The commensalism
    - The mutualisme
2. Non-mutually beneficial interactions are:
    - the competition
    - the predation
    - the parasitism

4.2.1 *The commensalism*

A sustainable interaction, relatively loose, non-obligatory interaction between individuals of different species where one partner (commensal) benefits from the association, while the other (host) neither gains an advantage nor experiences a significant disadvantage.

Example:

An example of commensalism is the interaction between barnacles and whales. Barnacles are small marine crustaceans that attach themselves to the skin of whales or the shells of turtles. Barnacles benefit from this relationship because they are elevated above the sea floor, providing them access to planktonic food in the

water column. The barnacles get a stable substrate for attachment and access to food particles carried by the passing whale.

The whales, on the other hand, are not significantly affected by the presence of barnacles. While the relationship may create some drag, it doesn't significantly hinder the whale's movement or health. In this case, barnacles benefit from the association, while whales are unaffected, demonstrating commensalism.

4.2.2 *The mutualism*

Mutualism is a mutually beneficial interaction for the both interacted individuals. It is a lasting and obligatory intimate association involving very specific physiological and morphological mechanisms.

Example:

A classic example of mutualistic interaction between two animals is the relationship between clownfish and sea anemones. The clownfish live among the tentacles of the sea anemone, gaining protection from predators due to the anemone's stinging cells, which the clownfish are immune to. In return, the clownfish provide the anemone with food by attracting prey and cleaning away debris. Additionally, the movement of the clownfish improves water circulation around the anemone, enhancing its respiration and nutrient absorption.

Another clear example of trophic mutualism is that of ruminant herbivores. These animals primarily feed on grass, which is extremely rich in cellulose, a type of polysaccharide that ruminants cannot degrade without the collaboration of microorganisms residing in the rumen. These microorganisms break down the cellulose walls of plants, obtaining nutrients and releasing other nutrients assimilable by the ruminant mammal

4.2.3 *The competition*

This refers to the interaction among living organisms for the acquisition of limited resources in a given environment, often resulting in the dominance of an individual or a group of individuals, a species, or a group of species.

Competition plays a significant role in the evolution and organization of populations by regulating the distribution and abundance of species.

NB: When the competition happens between individuals of the same species it is called dominance.

4.2.4 *The predation*

Predation refers to the act of an animal, a predator, feeding on another organism, the prey, the pray has to belong to a different species and is usually smaller than the predator. Predation plays a crucial role in regulating the populations of both prey and predators".

NB: When the predation happens between individuals of the same species it is called cannibalism.

4.2.5 *The parasitism*

Is a type of symbiosis, a close relationship in which one participant, the parasite, depends on the other, the host, and gains some benefit. In most cases of parasitism, the host incurs damage from the parasite at some point in the life cycle.

Chapter2:

Parasitism

As mentioned previously, parasitism is a symbiosis interaction between the parasite (which benefits) and the host (which is harmed).

1 PARASITES

- Dictionary definition:

An organism living in, on, or with another organism to obtain nutrients, grow, or multiply, often in a way that harms the host directly or indirectly.

- Biological definition:

A parasite is a living organism that cannot live without the help of another living being.

2 MODES OF PARASITISM

In general, parasitism is an interspecies interaction that occurs between two organisms of different species. However, in some cases, other types of parasitism are observed:

2.1 Intraspecific Parasitism

This occurs when an individual of a species attaches to another individual of the same species.

- Example: In deep-sea fish like *Haplophryne mollis*, one or more very small males live attached to the female and feed through the female's circulatory system (Figure 12).

Figure 12
Haplophryne mollis

2.2 Kleptoparasitism or Brood Parasitism

Brood parasitism, or egg parasitism, is the behavior of certain animals that do not raise their own eggs. Instead, they rely on substitute parents (hosts) who also take responsibility for feeding and raising a juvenile that is essentially foreign.

Brood parasitism is a type of kleptoparasitism found among birds, fish, insects, and freshwater turtles.

Most nesting parasites among birds are found in Africa, with 50 species that do not feed on their young. In Southeast Asia, this concerns 34 bird species.

- ✓ **Example:** *Cuculus canorus* (the common cuckoo) (Figure 13).

Figure 13 Cuculus canorus

3 TYPES OF PARASITES

According to their location on or within the host, there are two types of parasites:

- ✓ Ectoparasites
- ✓ Endoparasites

3.1 Ectoparasites

Parasites located on the external parts of the host or in cavities that open to the outside, such as the oral cavity or gill cavities (Figure 14).

3.2 Endoparasites

Also called Euparasites (Eu = true): parasites that invade and exit the host through infiltration. They may reach organs such as the brain, heart, or more generally, the circulatory system.

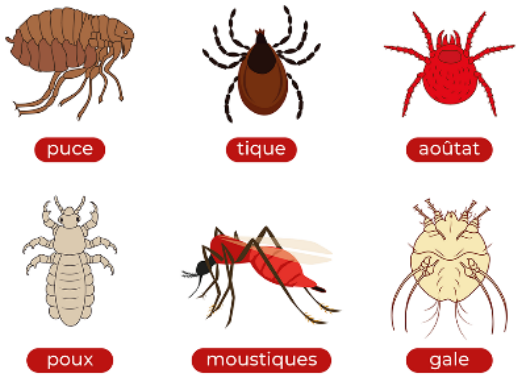


Figure 14 Ectoparasites

4 REPRODUCTION IN PARASITES

Most parasites reproduce asexually but can switch to sexual reproduction to encourage diversity and remain infectious. Some species of parasites can even reproduce sexually with other species through a process called hybridization. For example, some flatworm schistosomes can infect a broader range of hosts following the mating of a species infecting cattle with one infecting humans. This demonstrates how variation caused by hybridization can increase the spread of a disease.

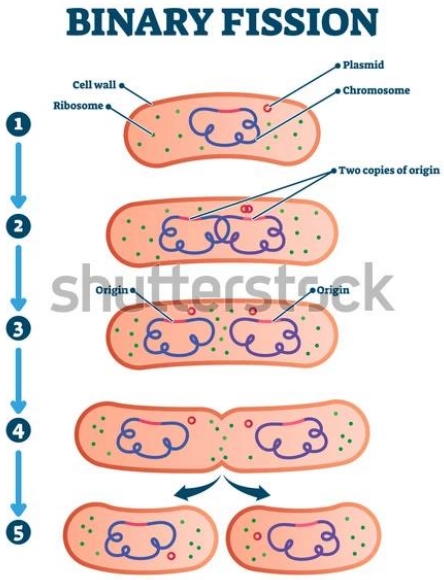
4.1 Reproduction in Protozoa

In parasitic protozoa, reproduction can be exclusively asexual or involve a succession of sexual and asexual reproduction:

4.1.1 *Asexual reproduction*

A mode of reproduction where no union of gametes occurs. In this case, a single individual can produce new individuals. This type of reproduction can occur through binary fission or multiple fission.

- ✓ Binary fission: The organism divides, producing two individuals from one (Figure 15):



Fiaure 15 Binarv fission

1. The micronucleus divides in two through a simplified form of mitosis.
2. The macronucleus divides in two by amitosis.
3. The cytoplasm divides into two equal halves by constriction.

- ✓ Multiple fission (sporulation): Many individuals are produced from a single individual at once (Figure 16):

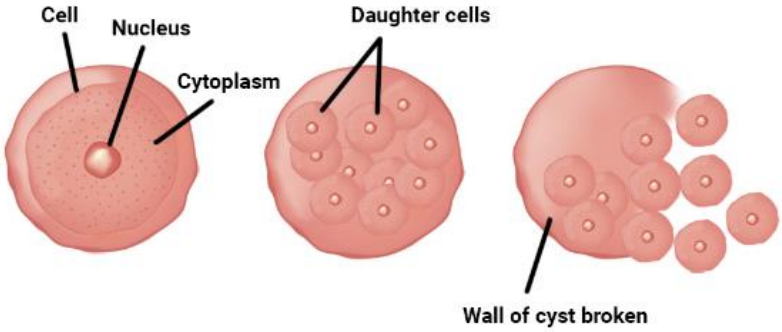


Figure 16 Multiple fission

1. The organism encysts, the nucleus divides several times, and a large number of tiny daughter nuclei are produced.
2. The cytoplasm fragments, and a small portion surrounds each daughter nucleus, forming many tiny organisms.
3. In favorable conditions, the cyst bursts, releasing these small organisms to grow into adults.

✓ Types of Multiple Fission in Protozoa (Figure 17):

1. Gamogony: The products are gametes.
2. Schizogony (or Merogony): The resulting individuals are called agametes or merozoites.
3. Sporogony: Occurs after sexual fusion, producing spores surrounded by a resistant coating. Mobile spores are known as swarmers or swarmospores.

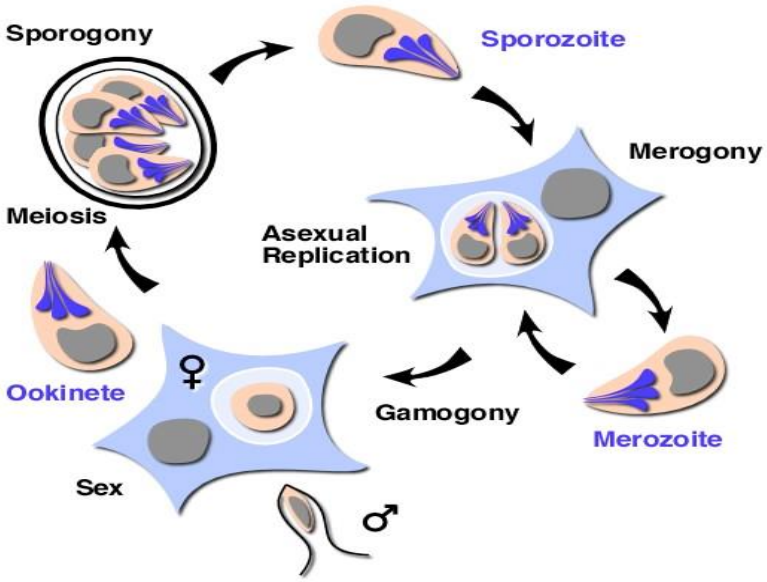


Figure 17 Multiple fission types

4.1.2 *Sexual reproduction in protozoa*

Sexual reproduction involves the union of two gametes to form a new individual. The two units (male and female gametes) from distinct individuals fuse by merging their cytoplasm, followed by the union of their nuclei. Most protozoa can continue to live and multiply asexually for extended periods but may undergo sexual reproduction at irregular intervals.

However, there are many protozoa where sexual reproduction occurs regularly. It involves meiotic division, reducing the chromosome number to haploid levels.

Two Main Forms of Sexual Reproduction in Protozoa:

a) Syngamy (sexual fusion):

Syngamy is the complete and permanent fusion of two specialized protozoan individuals or gametes, resulting in a fertilized cell, zygote, or ookinete.

Depending on the degree of differentiation between the fusing gametes, syngamy can take the following forms:

- Autogamy: Gametes derived from the same parent cell (same individual) fuse.
- Pedogamy: Fusion between two young individuals, or union between two sister cells.
- Hologamy: Two mature individuals behave as gametes and fuse.
- Merogamy: Fusion between two specialized cells, distinct from somatic cells.

- Isogamy: Union of gametes of similar size and shape (morphologically identical).
- Anisogamy (heterogamy): Fusion of two gametes that differ in size, shape, and behavior. These gametes are called heterogametes or anisogametes, and their fusion is known as anisogamy or heterogamy.

b) Conjugation:

Conjugation is the temporary union of two sexually differentiated individuals to facilitate the exchange of nuclear material. After the nuclear exchange, the individuals separate, retaining their distinct identities.

4.2 Reproduction in Metazoans

Parasitic metazoans include three groupes: **Platyhelminthes (flatworms), Nematodes (roundworms), Arthropods.**

4.2.1 *Flatworms (Platyhelminthes)*

Most flatworms are hermaphrodites (having both male and female reproductive organs Figure 18).

Flatworms can reproduce sexually and asexually (through fusion).

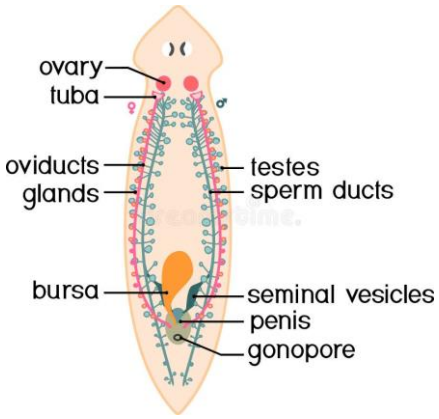


Figure 18 Reproductive system in flatworms

4.2.2 *Nematodes*

Nematodes can reproduce in three different ways:

1. **Amphimixis**: the union of sperm and egg.
2. **Hermaphroditism**: functional male and female sexual organs within the same individual.
3. **Parthenogenesis**: offspring production from unfertilized eggs.

4.2.3 *Arthropods*

Reproduction in arthropods is primarily sexual.

In some insect species, sexual reproduction can be accompanied by parthenogenesis.

5 NUTRITION IN PARASITES

5.1 Nutrition in protozoan parasites

Unicellular parasites, especially those from the phylum Apicomplexa, must invade a host cell to propagate, survive, and cause disease. During their intracellular development, parasites require large amounts of nutrients

and lipids to proliferate. These nutrients are obtained by recycling the host cell's resources and producing lipids from a plant-like compartment (apicoplast) unique to the parasite.

The apicoplast is a plastid-like organelle present in Apicomplexa cells, surrounded by four phospholipid bilayer membranes, containing circular DNA, and representing a vestigial chloroplast derived from an ancestral endosymbiotic microscopic algae that has lost its photosynthetic capabilities.

Trypanosoma, the protozoan parasite responsible for human trypanosomiasis, presents a complex life cycle alternating between mammalian hosts and an insect vector, encountering distinct environments that it adapts to by regulating its metabolism.

5.2 Nutrition in trematodes

Some trematode species inhabit the intestines and feed on the host's superficial epithelial tissues and associated mucoid secretions; while other species that live in the respiratory and circulatory systems exclusively feed on blood.

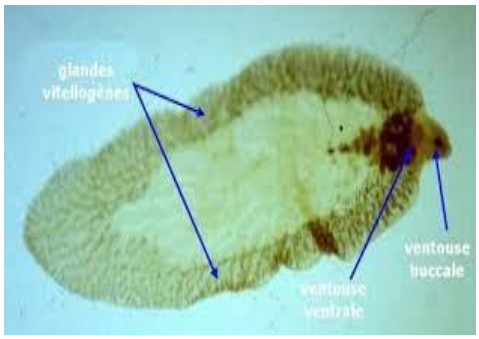


Figure 19 Morphology of trematodes

The feeding mode involves the muscular pharynx and normal attachment process of the oral sucker (Figure 19). This is purely a mechanical process, which can be complemented by enzymatic secretions produced by the trematode, which have a histolytic effect on the host's tissues.

Pharyngeal glands located in the pharynx secrete a powerful protease that erodes the host's epidermis, and the trematode subsequently sucks the lysed products.

5.3 Nutrition in cestodes

Cestodes have significant requirements for carbohydrates, proteins, lipids, minerals (especially phosphates), and vitamins. The bile salts play a role in the nutrition of cestodes; they lack a digestive tract, and they absorb soluble products and salts through osmosis. Proteins are acquired through a metabolic process on the surface of the cuticle. The tegument of cestodes consists of a syncytial epithelium covered by a glycocalyx. Their metabolism is anaerobic, and they absorb small organic molecules through the tegument. The microvilli located on the epithelium increase the surface area for absorption (Figure 20).

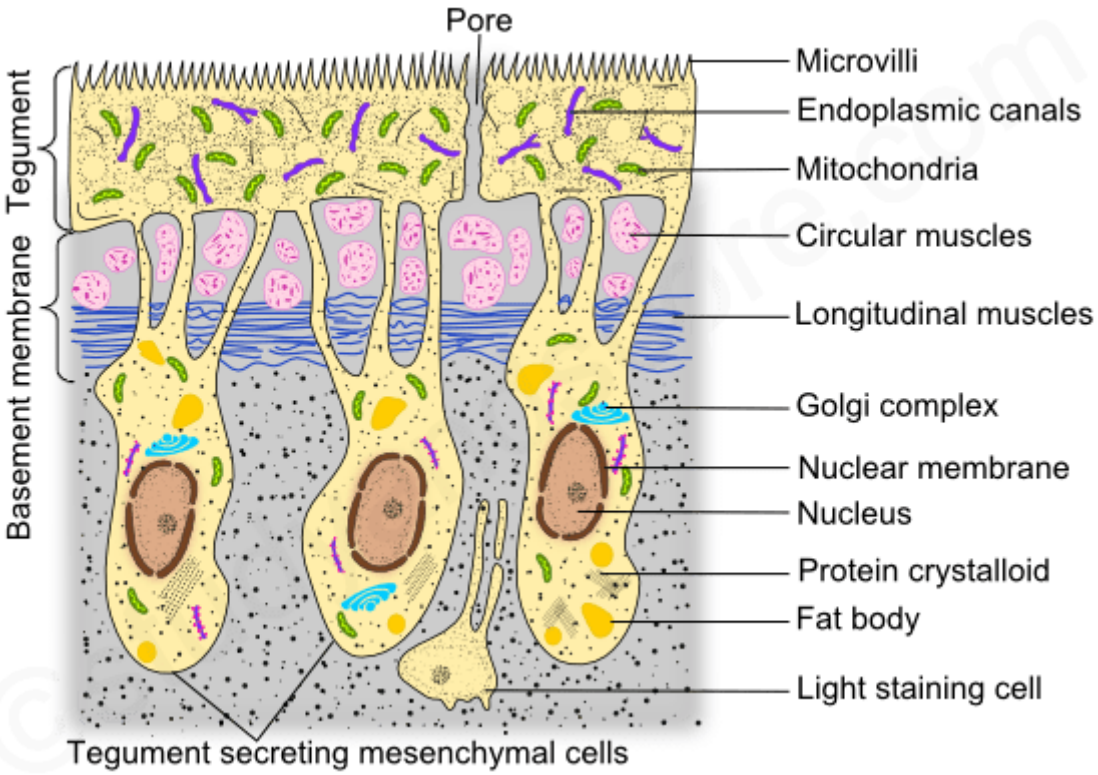


Figure 20 Tegument of taenia worms

5.4 Nutrition in nematodes

Phytoparasitic nematodes are obligate plant parasites, feeding on roots or aerial parts of a living plant.

Adult *Ascaris* develops in the intestine and feeds on digested liquids, contributing to protein-energy malnutrition in the host and poor carbohydrate absorption.

5.5 Nutrition in parasitic mites

Mites can colonize a wide range of environments, leading to different feeding habits across species.

- ✓ Some mites possess chelicerae shaped like pincers to grind solid food (animal and plant). Solid substances are digested externally by enzymes secreted by salivary glands located at the base of the mouthparts.
- ✓ Other ectoparasitic mites inject these secretions into their hosts, where it spreads in tissues to ensure pre-digestion (extra-intestinal digestion). They then suck up the liquefied tissues, which constitute a nutritional liquid. This nutritional liquid enters the midgut, which contains phagocytes, continuing digestion intracellularly.
- ✓ The tick group (Ixodida or Metastigmata) is exclusively hematophagous. Blood is sucked from hosts via a bite performed with the rostrum. During the blood meal, a pair of salivary glands

releases proteolytic enzymes into the host. After partial digestion inside the midgut, the soluble blood material is absorbed by intestinal cells through phagocytosis and pinocytosis. Digestion continues inside the cells through lysosomal action.

5.6 Nutrition in parasitic insects

Sucking lice have a very specific mode of nutrition due to their adaptation to host blood. They are hematophagous insects (feeding on the host's blood).

In contrast, chewing lice (Mallophaga) feed on the host's skin debris.

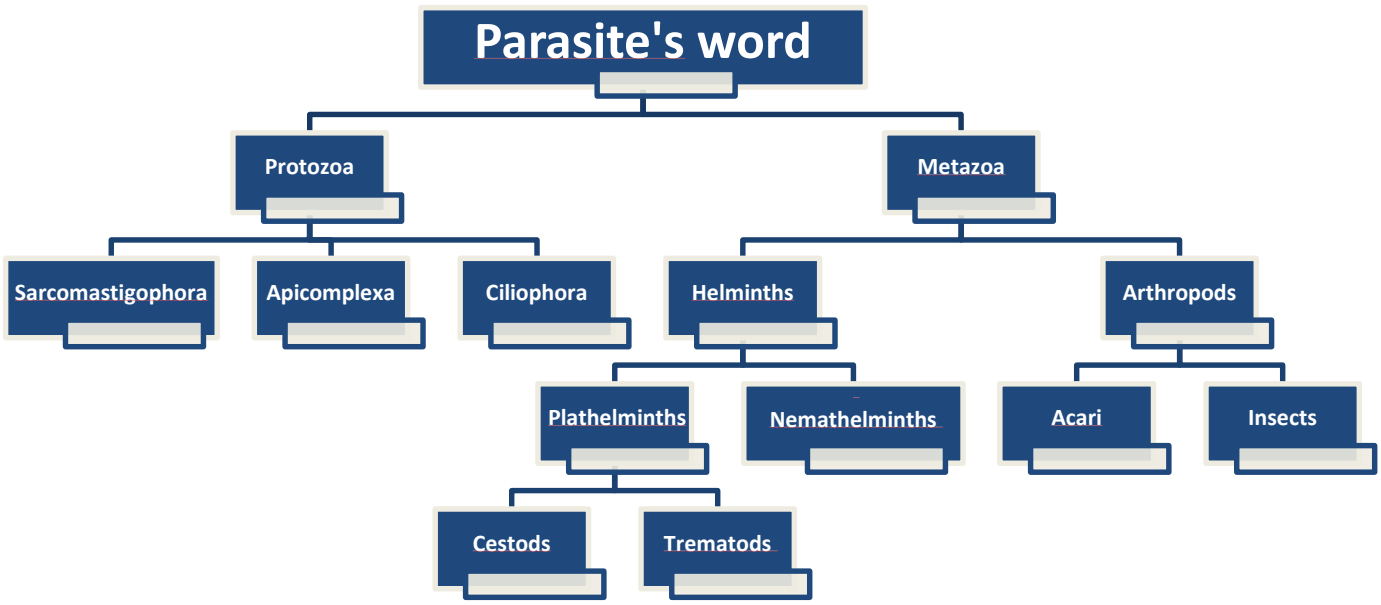
Bed bugs, which are parasitic insects, primarily feed on human blood, with a blood meal lasting from three to 15 minutes depending on their life cycle stage. The insect then hides for a digestion process that usually takes several days.

Parasitic insects like lice, fleas, and bedbugs are hematophagous regardless of sex (male or female).

In another group of parasitic insects, such as mosquitoes, females are hematophagous, biting homeothermic animals, and sometimes poikilotherms, absorbing blood to provide protein elements necessary for egg maturation. Males have reduced mouthparts, typically with atrophied mandibles, and feed exclusively on nectar from flowers.

6 PARASITE DIVERSITY

Parasite diversity refers to the variation in the species of parasites living on Earth. To study parasite diversity, we need to classify them based on various patterns such as taxonomy, life cycle, habitat, and host interactions, among others. In our course, we will focus on taxonomic classification to categorize the parasites.


Parasite's word
Protozoa
Metazoa
Sarcomastigophora
Apicomplexa
Ciliophora
Helminths
Arthropods
Plathelminths
Nemathelminths
Acari
Insects
Cestods
Trematods

Chapter3:

Protozoan parasites

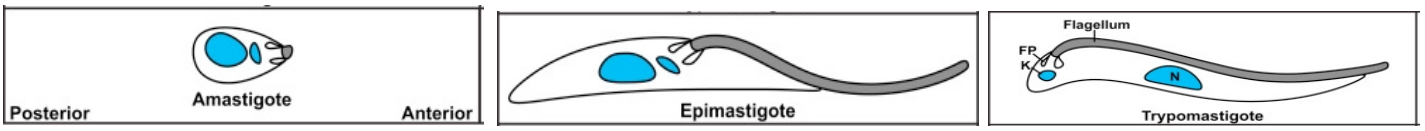
1 *SARCOMASTIGOPHORA* (FLAGELLATED UNICELLS)

1.1 Mastigophora

1.1.1 *Trypanosoma*

❖ Morphology :

- Very small flagellated protozoa.
- They have only one flagellum.
- Trypanosoma has three major morphological types: epimastigote, trypomastigote and amastigote.



1.1.1.1 *Trypanosoma brucei*

- **Causes:** Sleeping sickness in humans and Nagana (African animal trypanosomiasis) in ruminants.
- **Hosts:** A variety of mammals
- **Vectors:** Tsetse flies (blood-sucking insects of the family Glossinidae)
- **Subspecies** (complexes): (differ in host range and pathogenicity/ no morphological difference).

✓ *Trypanosoma brucei gambiense*,

✓ *T. brucei rhodesiense*

✓ *T. brucei brucei*

- **Forms:** The parasite occur only in trypomastigote form (metacyclic or procyclic).
- **Length:** 16-42 µm

Biology:

When a vertebrate host is infected, up to 20,000 metacyclic trypomastigote organisms are transmitted to the skin via the tsetse fly's saliva. The infective stages remain in the intercellular spaces around the bite site for 2 weeks, where they reproduce by binary fission, before entering the bloodstream. The bloodstream forms of trypomastigotes are initially long and slender, highly active and motile. The multiplication time is about 6 h; therefore, in a very short time they can build up a high population density (up to 100,000 parasites/ml of blood in humans and up to 100 million parasites/ml of blood in mice or rats).

Trypanosoma species have an antigenic variation that provides long-term protection against the immune response. Whenever parasite density reaches a certain level, the slender forms transform into intermediate forms and finally into short, stocky forms of trypomastigotes. These no longer divide actively, but are infectious to tsetse flies. After being ingested by the vector, the trypomastigots transform into procyclic trypomastigotes.

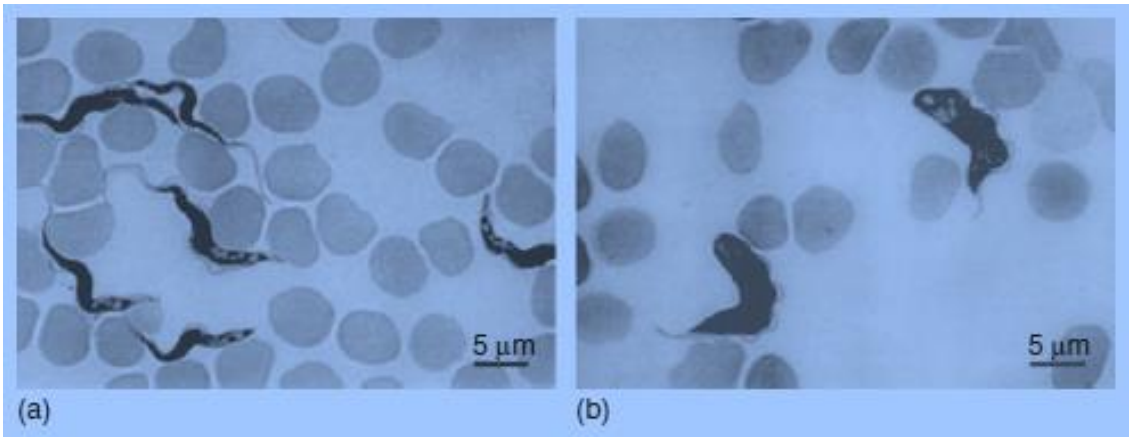


Figure 21: (a) Slender form and (b) stocky bloodstream form of Trypanosoma brucei.

1.1.1.2 *Trypanosoma cruzi*

- Causes Chagas disease or American trypanosomiasis (a potentially fatal disease).
- Hosts: More than 150 species of mammals, including humans
- Vectors: Mainly *Triatoma* (*Triatoma infestans*), but also *Panstrongylus* and *Rhodnius* (blood-sucking heteropteran insects -bedbugs)
- Subspecies: There is a wide variety of *T. cruzi* strains with different geographical variants and biological properties (*T. cruzi* lineage I and *T. cruzi* lineage II).
- Forms: The parasite can appear in three forms epimastigote (intermediate host), trypomastigote (definitive host + intermediate host) and amastigote (definitive host). The 20 µm blood stages of the parasite have a long free flagellum at their tip, often C-shaped
- Length: **12 to 30 µm**

Biology:

All stages of the bedbug development are susceptible and the parasite is transmitted via their faeces. Trypomastigote infective stages from bedbug faeces enter the mammalian host via a wound caused by the insect bite, facilitated by scratching by the host, or through a mucous membrane Food contaminated with insect faeces is a possible route of infection. Not all heteropteran insects are competent vectors, as only species that defecate while ingesting blood will allow infective stages to enter the bite ((Metacyclic trypomastigote forms are excreted by the vector via the faeces directly after a blood meal)

1.1.1.3 *Other Trypanosoma species*

Other less frequent *Trypanosoma* species are illustrated in table 1.

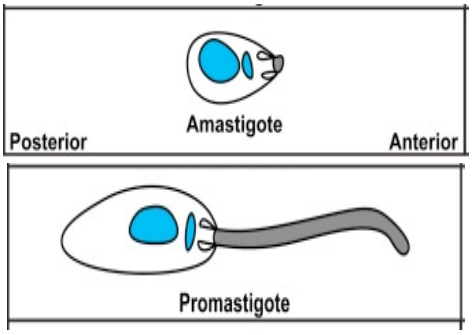
Table 1: Less frequent Trypanosoma species

Species	Disease	Forms	Length	Hosts	Vectors
Trypanosoma equiperdum	Dourine (infectious equine disease) in horses	Trypomastigote	from 15 to 31 µm.	Equins	By mating or by artificial insemination
Trypanosoma evansi	Surra (an infectious disease of mammals) in ungulates.	Trypomastigote	18-34µm	Mainly ungulates, but also rodents and carnivores	Mechanically transmitted by hematophagous insects
Trypanosoma vivax	Nagana	Epimastigote (intermediate host), trypomastigote (definitive host + intermediate host) and amastigote (definitive host).	14-27µm	Ruminants	Tsetse flies
Trypanosoma congolense	Nagana	Epimastigote (intermediate host), trypomastigote (definitive host + intermediate host)	9-18µm	Ruminants	Tsetse flies

1.1.2 *Leishmania*

Leishmania genus include species of high specificity to vectors, hosts and geographical localization (Table 2). Their general characteristics are:

- Very small flagellated protozoa,
- *Leishmania* have two major morphological types: promastigote (measure 15 to 25 µm long and have a long flagellum) and amastigote (are round or oval and measure 2 to 4 µm long and do not have an internal flagellum).



Biology:

Leishmania species are:

- Responsible for leishmaniasis.
- Require two hosts, an insect host or a biological vector (sandflies) and a vertebrate host.
- The vector in the old world is the genus *phlobotomus*
- In the New World, species of the genus *Lutzomyia* is responsible for the transmission of leishmaniasis
- Leishmaniasis are often zoonotic.

1.1.2.1 *Leishmania tropica*

- Causes: Cutaneous leishmaniasis in humans
- Hosts: Mainly humans, dogs, cats, occasionally rats
- Vectors: *Phlebotomus sergenti*
- Forms: promastigote (in the vector), promastigote and amastigote (in the definitive host)

Biology:

The reservoirs of the parasite can be dogs, sandflies, rats or humans. The geographical distribution of this species of parasite extends from India to Central Asia, the Middle East and south-eastern Europe to North and Equatorial Africa.

1.1.2.2 *Leishmania donovani*

- Causes: Visceral leishmaniasis (Kala Azar) in humans
- Hosts: Mainly humans, dogs, occasionally rats
- Vectors: *Phlebotomus martini* in Africa, *P. argentipes* in Asia.
- Forms: promastigote, amastigote

Table 2 Geographical Distribution of Leishmania Species by Clinical Form

Type	***Region***	***Leishmania species***
Localized cutaneous leishmaniasis	Old World:	- *L. major:* Asia, Middle East, Africa
		- *L. tropica*: Mediterranean basin
	New World (Central and South America):	*L. amazonensis, L. guyanensis, L. mexicana, L. panamensis…*
Diffuse cutaneous leishmaniasis	Old World:	*L. aethiopica*
	New World:	*L. amazonensis*
Cutaneo-mucosal leishmaniasis (extension to the organs of the RES: liver, spleen, lymph nodes, bone marrow):		*L. braziliensis*
Visceral leishmaniasis		*L. infantum* (Mediterranean basin, South America, China), *L. donovani*

Biology:

This parasite prefers macrophages in visceral organs, particularly the spleen, liver and bone marrow. Most human infections go unnoticed and the disease only really manifests in a fraction of infected people (<10%). The incubation period of the parasite lasts 3 to 6 months. The geographical distribution of this parasite species extends from East Africa (Sudan, South-West Ethiopia, Northern Kenya), to the Indian subcontinent (North-East India, Nepal, Bangladesh). The parasite causes an anthroponotic disease.

1.1.2.3 *Leishmania braziliensis*

- Causes: American cutaneous leishmaniasis in humans
- Hosts: humans
- Vectors: *Lutzomyia* species
- Subspecies: *Leishmania braziliensis guyanensis*, *L. b. panamensis*, *L. b. peruviana*
- Forms: promastigote (in vector), promastigote and amastigote (in human host)

Biology:

Geographic distribution: Central and South America

1.2 Order *Retortamonadida* (intestinal *Sarcomastigophora*)

1.2.1 *Chilomastix mesnili*

It is a nonpathogenic, cosmopolitan flagellate that is often described as a commensal organism in the human gastrointestinal tract.

- The cyst stage is resistant to environmental pressures and is responsible for the transmission of *Chilomastix*.
- Cysts and trophozoites can be found in the diagnostic of feces.
- Infection occurs by ingestion of cysts in contaminated water or food or by the fecal-oral route.
- Trophozoites are released into the large intestine and possibly the small intestine.
- It is considered a commensal agent whose contribution to pathogenesis is uncertain.

1. Morphology of the cyst (Figure 22)

- The cyst is of 6-9 µm
- It has a large single nucleus with a large karyosome.
- It has a prominent side knob which gives it a characteristic lemon shape.

***Figure 22 Chilomastix mesnili* cyct**

2. Morphology of the trophozoite (Figure 23)

- It is pear shaped and measure 10-20 µm in length.
- It has one large nucleus with a small karyosome and 3 flagella which are extend at the anterior end of the cel.
- It moves in a directional manner.
- A distinct cytosome can be seen near the nucleus

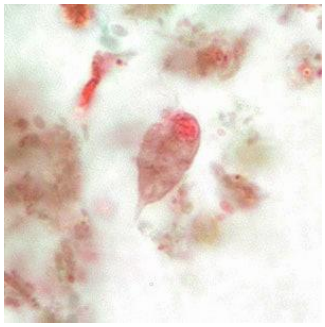


***Figure 23 Chilomastix mesnili* trophozoite**

1.2.2 *Retortamonas intestinalis*

- Parasite of the caecum in humans
- It is a cosmopolitan parasite of Old World monkeys (including the rhesus macaque) and Great Apes (including the chimpanzee).
- A ferric hematoxylin stain can be useful to visualize the cytoplasmic details.

1. Morphology of the cyst (Figure 24)
    - This is the infective stage.
    - Mesures about 4-7 µm long, 3-4 µm wide
    - The cyst is pear-shaped to ovoid, measures 4-9 µm in length and has one to two nuclei.
    - The shell is thin and poorly refractil.
    - It is possible to see an elongated nucleus wrapped in a U-shaped flagellum.
    - They are similar to cysts of *Chilomastix mesnili*, the distinction is made on the morphology of the nuclei, their number, and the size of the cyst.

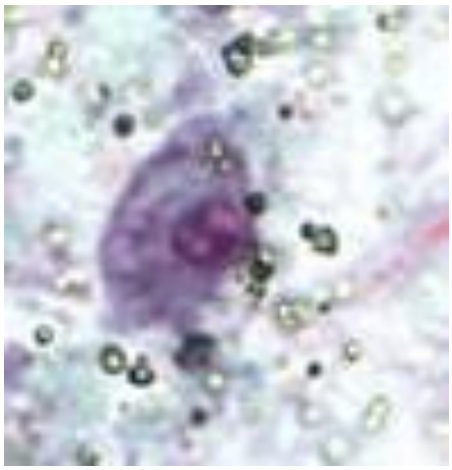


Figure 24 Retortamonas intestinalis cyct

2. Morphology of trophozoites (Figure 25)

- The trophozoites can be evolved by a stool culture.
- It has two flagella, one being shorter and thicker
- The nucleus is located at the anterior end but is often not visible

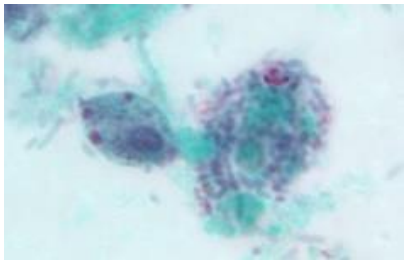


Figure 25 Retortamonas intestinalis trophozoite

1.3 Order *Diplomonadida* (intestinal *Sarcomastigophora*, two nuclei)

1.3.1 *Giardia*

These are parasitic organisms that are commonly found in humans, livestock, and wildlife. There are currently six confirmed species (*Giardia agilis*, *Giardia ardeae*, *Giardia psittaci*, *Giardia microti*, *Giardia muris*, and *Giardia lamblia*; synonymous with *Giardia intestinalis* and *Giardia duodenalis*), none of which appear to be highly host-specific:

- *G. lamblia* has a worldwide distribution and is the only species responsible for disease in humans, but can also be found in other mammals.
- *G. lamblia* has been subdivided into eight assemblages designated A–H based on DNA polymorphisms.
- It can causes an intestinal protozoan disease causing significant morbidity.

1. Morphology of cycts (Figure 26):
    - They represents the infective, non-motile and egg-shaped
    - They measure 8–14 µm by 7–10 µm.
    - The cysts are surrounded by a smooth and colorless, thick and refractile wall.
    - Newly formed cysts contain two genetically identical nuclei
    - Mature contain four prominent nuclei and four median bodies

2. Morphology of trophozoites (Figure 26):
   - Pear shaped
   - They have broad anterior end
   - They have narrow posterior end
   - They measure about 9–21 µm of long and 5–15 µm of wide
   - Bilaterally symmetrical
   - They have a large sucking or adhesive disk allows the *Giardia* to adhere to surfaces
   - Two median bodies
   - Four pairs of flagella located anterior, lateral, ventral, and posterior on the body
   - The pair of anterior flagella, known as axoneme or axostyle dividing the body into two parts longitudinally.

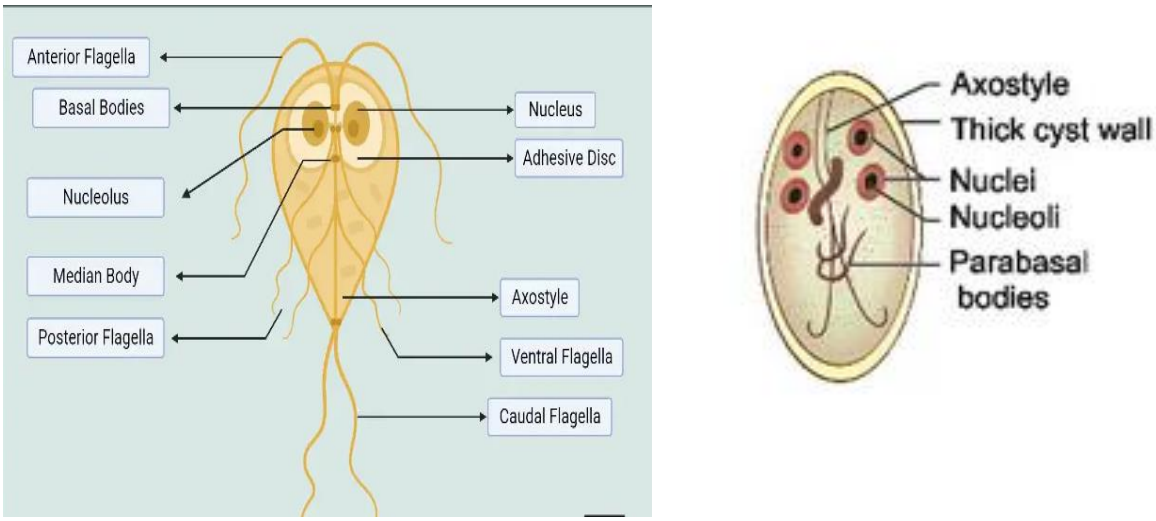


Figure 26 The morphology of giardia

1.3.2 *Enteromonas hominis*

1. Morphology of cycts (Figure 27):
   - Size: 4-10 µm,
   - Very little refractile,
   - Difficult to identify in feces,
   - They can have one, two or four nucleus arranged 2/2, one cyst gives four trophosoites maximum
   - Nucleus are located on each end of the cell.
2. Morphology of trophozoites (Figure 27):
   - Cosmopolitan flagellate.
   - Size of 4-10 µm, identified by its mobility;

- Oval or rounded slightly pear-shaped,
- Narrow posterior end
- One small and anterior nucleus
- Three anterior flagella, and a recurrent flagellum along a longitudinal groove in the posterior part.
- Almost never accompanied by cysts

(A) Schema of a trophozoite. (B) Hematoxylin-iron image of a trophozoite. Courtesy of DPDx, Centers for Disease Control and Prevention

(C) Schema of cysts. Abbreviations: fa, anterior flagellum; fr, recurrent flagellum; n, nucleus; rf, flagellar remnants; va, food vacuole.

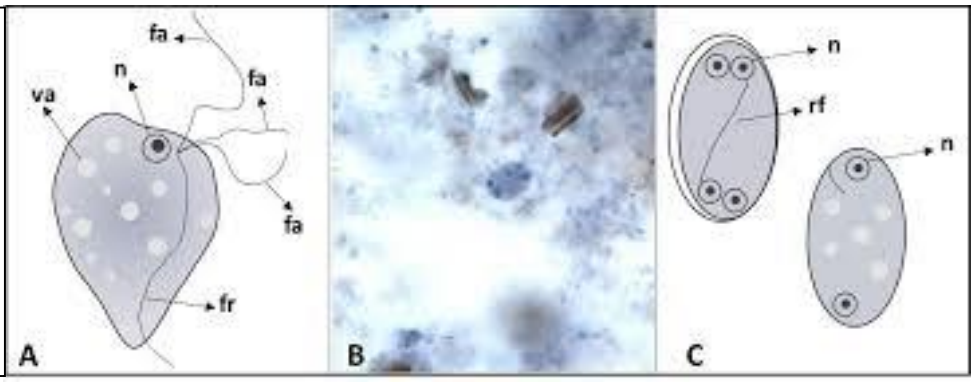


Figure 27 Enteromonas hominis.

3. Biology:

It lives in the large intestine, especially in the caecum, and is found in the feces where, it quickly loses its vitality, it becomes rounded and difficult to recognize. The cystic form is sometimes confused, despite its size being half the size of Giardia.

1.4 Order *Trichomonadida* (intestinal *Sarcomastigophora*, undulating membrane)

1.4.1 *Trichomonas vaginalis*

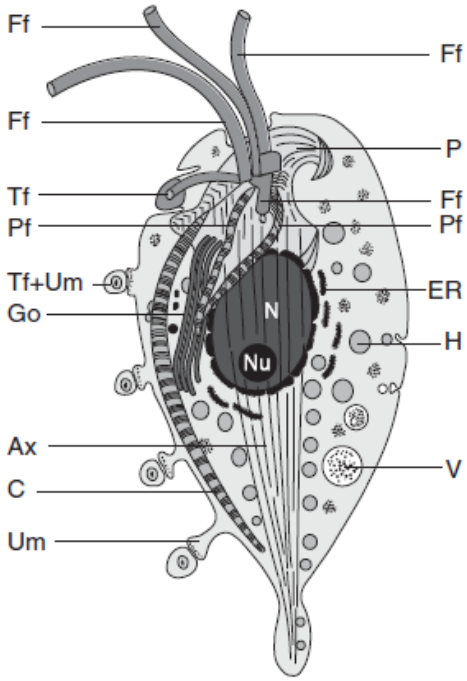
T. vaginalis, is a parasite specific to human, it is found in the human genitals (vagina, urethra or prostate). It colonizes the surface of the mucous membranes. (Figure 28):

When this parasite moves in a fluid medium, the flagellated trophozoites are pear-shaped. However, the parasite takes an amoeboid shape when they come into contact with an epithelial surface.

Other features:

- The infection is transmitted by direct contact,
- The disease caused is trichomoniasis a sexually contagious disease.
- It is very unlikely that trichomonasis will be spread via towels or toilet seats.
- *T. vaginalis* multiplies by binary fission.
- *Trichomonas* do not form cysts and are therefore susceptible to desiccation.

- *T. vaginalis* can alternate between oval and pear-shaped, measuring 10–25 in length and 8–15 µm. In weigh
- The pseudopod-like extensions in its posterior region ingest bacteria, epithelial cells, and red blood cells by phagocytosis.
- Of the five flagella that originate at the apical pole, four are free major flagella, while the fifth is a trailing flagellum that runs along the cell surface and is attached by an undulating membrane.
- A supporting structure called the costa runs beneath the undulating membrane.



Ax, axostyle; C, costa; ER, endoplasmic reticulum; EF, free flagella; Go, Golgi apparatus; H, hydrogenosomes; N, nucleus; Nu, nucleolus; P, pelta; Pf, parabasal filament; Tf, rear flagellum; UM, corrugated membrane; V, vacuole.

Figure 28 Ultrastructure of Trichomonas vaginalis.

1.4.2 *Tritrichomonas foetus*

T. fetus causes disease in cattle, it uses to be found in many countries and has many similarities with other *Trichomonadida*. (Figure 29):

Other features:"

- The parasite is pear-shaped (14 × 8 μm) with three free flagella and a trailing flagellum that is attached to the cell via a wavy membrane.
- It lives as a parasite in the vagina, uterus and ovarian tubes of cows and under the foreskin and in the urethra of bulls.
- While this parasite is highly pathogenic in females, bulls are almost asymptomatic.
- The disease is now rare in Europe (the introduction of artificial insemination), while in other parts of the world it remains a major problem.

A: Giemsa-stain. B: scanning electron microscopy. AF: anterior flagella; Ax: axostyle; N: nucleus; PF: posterior flagellum; UM: undulating membrane. A and B: reproduced from of Doi et al. (80) and b of Midlej et al.

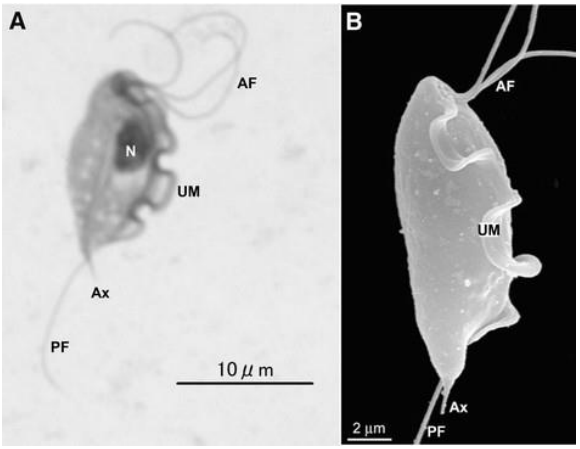


Figure 29 Tritrichomonas foetus trophozoites.

1.4.3 *Other Trichomonas species*

- ***Trichomonas hominis*** lives as a harmless commensal in the human colon, but is sometimes associated with diarrhea.
- ***Trichomonas tenax*** can infect the human oral cavity, where it feeds on bacterial flora.
- ***Trichomonas gallinae*** is a bird pathogen that causes pigeon canker. Yellow membranous lesions form between the esophagus and the crop. The pathogens can penetrate internal organs such as the liver, causing significant damage. Juvenile pigeons become infected by being fed by latently infected older birds or by contaminated food and water containers.

1.5 Superclass *Rhizopoda* (movement using pseudopodia)

1.5.1 *Ordre Amoebida*

1.5.1.1 *Entamoeba histolytica*

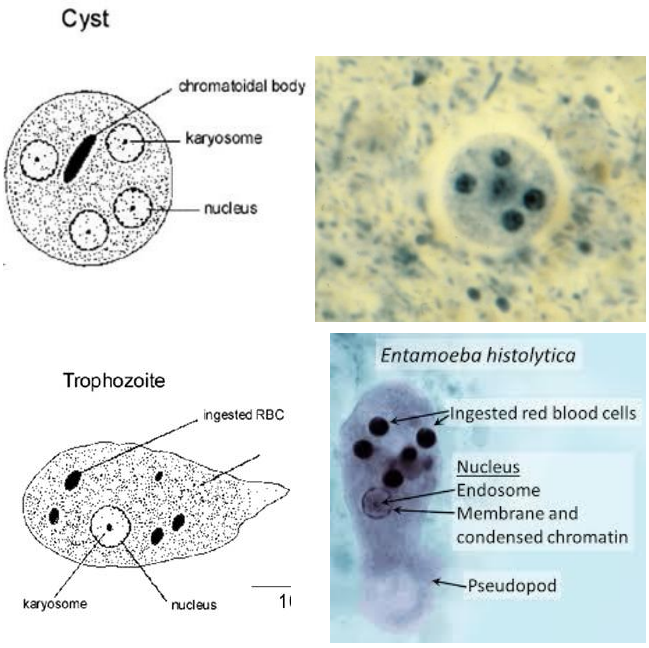


Figure 30 Cyst and trophozoite of Entamoeba histolytica

1. Morphology of cycts (Figure 30):
   - This is the infective stage.
   - Cysts containing four nuclei
   - Measure 10-15 µm
   - Usually spherical
   - **Chromatoid bodies with** rounded ends
2. Morphology of trophozoites (Figure 30):
   - Measure12-30 µm
   - The motility is progressive with fingerlike pseudopodia
   - One nucleus difficult to visualize in uncolored smear
   - Cytoplasmic inclusions : Red blood cells, leukocytes and tissue debris but no bacteria
3. Biology:

Entamoeba histolytica is the causative agent of amoebic dysentery (amoebiasis), one of the major tropical diseases, with an annual mortality of between 50,000 to 100,000. Despite, *E. histolytica* is generally a commensal agent; according to research studies, only 10% of individuals infected with *E. histolytica* cysts show symptoms of amoebiasis.

Humans are the major host of *E. histolytica*, although cats and dogs can be experimentally infected. *E. histolytica* is found worldwide. Its sister species, *Entamoeba dispar*, which is much more common worldwide, is nonpathogenic, but morphologically identical.

1.5.1.2 *Other species of Entamoeba*

1.5.1.2.1 *Entamoeba coli*:

1. Morphology of cycts (Figure 31):
   - This is the infective stage.
   - Cysts containing eight nuclei
   - Measure 15-25 µm
   - Usually spherical, may be oval, triangular or other shaped
   - **Chromatoid bodies are** filamentous with pointed ends
2. Morphology of trophozoites (Figure 31):
   - Measure 20-40 µm
   - The motility is slow and nondirectional with granular pseudopodia
   - One nucleus usually visible in non-colored smear
   - Cytoplasmic inclusions: Bacteria and other material but never red blood cells.
3. Biology:

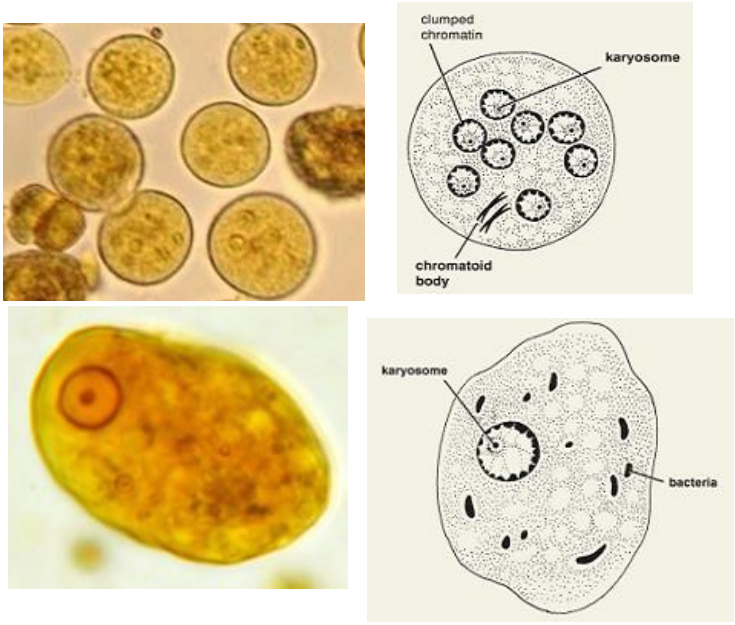


Figure 31 Cyst and trophozoite of Entamoeba coli

Is a non-pathogenic amoeba that occurs worldwide. Its trophozoites can be distinguished from those of E. histolytica and E. dispar, notably by their slower movements and more granulated plasma. A mature E. coli cyst contains eight nuclei.

1.5.1.2.2 *Entamoeba dispar*

Lives as a commensal in humans and is morphologically indistinguishable from trophozoites of *E. histolytica*

1.5.1.2.3 *Entamoeba hartmanni and Entamoeba moshkovskii*

They are relatively rare inhabitants of the human colon and are slightly smaller than *E. histolytica/E. dispar*.

1.5.1.2.4 *Entamoeba polecki*

Its cysts have a single nucleus.

1.5.1.2.5 *Entamoeba gingivalis*

It inhabits the oral cavity in humans, particularly the spaces between teeth and periodontal pockets. It is a very common amoeba that thrives with poor oral hygiene and dental caries.

1.5.1.2.6 *Endolimax nana*

It is a relatively small non-pathogenic amoeba species found in the human intestine. Its trophozoites are 6–15 μm in diameter and move slowly. They are found in 15–30% of the world population.

1.5.1.2.7 *Iodamoeba bütschlii*

It is mainly found in pigs, but also in the intestines of monkeys and humans. The cysts usually have one, but sometimes two or three nuclei and a clearly defined glycogen vacuole.

1.5.2 Ordre *Acanthopodida*

1.5.2.1 *Acanthamoeba spp*

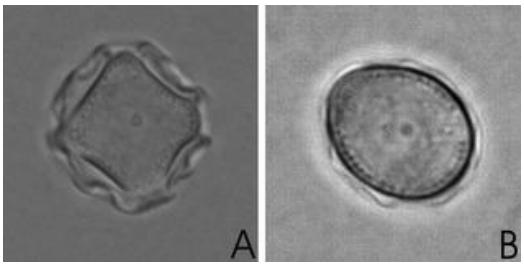


Figure 32 Acanthamoeba spp. cysts. A. polygonal cyst, B. rounded cyst

1. Morphology of cycts (Figure 32):
   - This is the infective stage.
   - Measure 13–20 μm
   - Multiple shapes but mostly rounded
   - Double-layer cell wall
   - The outer layer consists of a laminar fibrous layer
   - One small nucleus
2. Morphology of trophozoites (Figure 33):
   - Measure 25–40 μm long
   - They have numerous thorn- or th read-like pseudopodia (acanthopoda).
   - they have long oval or irregular shape
   - Granulated endoplasm
   - One small nucleus
   - It contains various cell organelles such as mitochondria, ribosomes, centrosome, Golgi apparatus, and vacuoles

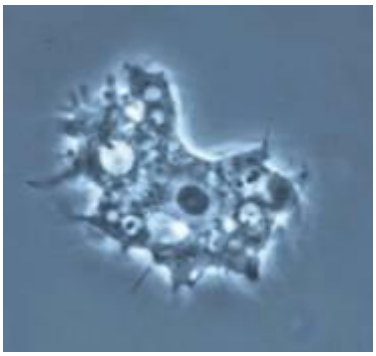


Figure 33 Acanthamoeba spp. cysts

3. Biology:

Acanthamoeba are normally free-living, but are also facultative pathogens capable of infecting humans (corneal inflammation). *Acanthamoeba* can also be an opportunistic pathogen, which can cause skin disease or granulomatous amoebic encephalitis (GAE).

The pseudopods give the trophozoite of *Acanthamoeba* a characteristic appearance and participate in the feeding, adhesion and movement.

1.5.3 Order *Blastocystida*

1.5.3.1 *Blastocystis hominis*

Morphology of cysts:

- This is the infective stage.
- Measure 3–5 µm
- Spherical to ovoid shape
- Multilayered cyst wall
- One to four nuclei
- Multiple vacuoles and glycogen and lipid deposits

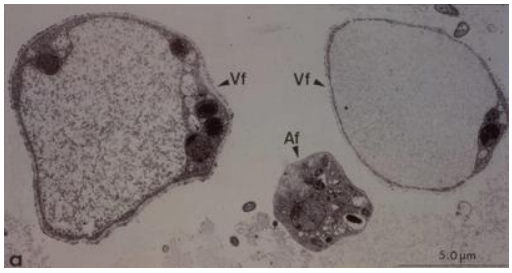


Figure 34 Blastocystis hominis - vacuolar forms, Vf and amoeboid form, Af

Morphology of the other forms (Figure 34):

- *Blastocystis hominis* is a polymorphic organism and the four forms commonly mentioned in the literature are the vacuolar, granular, amoeboid and cystic forms.
- The vacuolar form, also called the central vacuole form, varies considerably in size, ranging from 2 to 200 µm in diameter, with average dimensions of 4 to 15 µm.
- A surface layer of varying thickness is observed around most cells.
- Vacuolar forms are spherical in shape and are distinguished by a sizable central vacuole that can take up to 90% of the cell's volume.
- Granular form is almost similar to the vacuole form
- Amoeboid form is oval, with one or two large pseudopods but without a cell membrane.
- The amoeboid forms are smaller than vacuolar forms (2.6–7.8 µm)

Biology:

Blastocystis are anaerobic eukaryotic parasites of the digestive tract of humans and many animals. This genus was previously considered the cystic form of *Trichomonas intestinalis*, but was later separated by PCR.

Molecular tools have shown great genetic diversity within the genus *Blastocystis*, distinguishing different morphologically identical species. This species classification was based on the host from which the strains were isolated. Thus, *Blastocystis* isolated from humans was called *B. hominis*, in rats, *B. ratti*... however, these species are not confined to a single host.

2 *APICOMLEXA*

2.1 Family *Eimeriidae* (intestinal or tissue coccidia)

2.1.1 *Cryptosporidium parvum*

Cryptosporidium parvum is a cosmopolitan species known as a major cause of severe diarrhea in calves, children, and immunocompromised adults.

Other features:

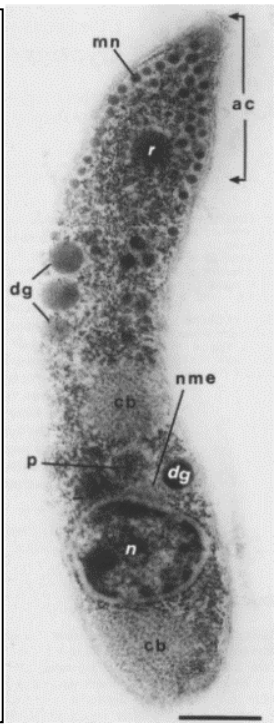
- Host specificity is low, therefore *C. parvum* is found in more than 40 vertebrate species.
- They could be found as: thick-walled oocysts, thin-walled oocysts, sporozoites, trophozoites, meronts I, meronts II, merozoites, microgamonts, macrogaments and zygots
- It is transmitted over infected water, infected food, direct infection through infected individuals

1- Oocysts:

- Spherical oocysts are about 5 × 4.5 µm,
- One oocyct contains four sporozoites
- In the case of thick-walled oocysts, the wall consists of three layers of membrane and two layers of chitin. They have a "seam", through which the sporozoites are released.
- Thin-walled oocysts are surrounded by only one membrane.

2- Sporozoites (Figure 35):

- The sporozoites are conical-shaped, very small, measuring only about 5 × 1 µm.
- They have one single rhoptry apically located
- They contain spherical, numerous and apically located micronemes
- One big nucleus in the posterior side



The apical complex containing the rnicronemes (rnn) and rhoptry (r) was a t the tapering anterior of the cell (labelled ac) with the nucleus (n) and adjacent crystalloid bodies (cb) a t the posterior, more rounded end. Dense granules (dg) occurred predominantly in the centre portion of the cell. The putative plastid-like organelle (p) and extended nuclear membrane region (nme) are also indicated. Bar, 0.5 pm

Figure 35 Longitudinal section (0.1 5 pm) through a sporozoite showing the distribution of internal organelles of Cryptosporidium parvum.

2.1.2 *Eimeria*

Parasites of the genus *Eimeria* can cause diseases known as coccidiosis. They have monoxenous life cycles occurring exclusively in the epithelial cells of the intestinal tract of vertebrates and some invertebrates.

The genus contains over 1200 species, including the most important parasites of poultry and other farm animals, but not humans. Under natural conditions, young animals tend to be infected with small numbers of oocysts or they develop immunity after a self-limiting disease. However, young animals raised on farms or even in factory farms can be infected with high doses of oocysts before they develop immunity, which can cause severe diarrhea and bleeding.

These parasites are generally strictly host-specific, and many are further adapted to a very specific habitat within their hosts.

1- Oocysts:

- An oocysts contains four sporocysts, and each sporocyst contains two sporozoites
- According to the specie, they have an ovoid, spherical or egg-shape
- According to the specie, oocysts are single or double-layered
- Sporulated oocysts measure 18–29 μm in length and 14–24 μm in width
- Sporulation of oocysts occurs after release into an environment with appropriate temperature, humidity, and oxygen levels.

- Sporulated oocysts are extremely resistant and can survive for several months.

2- Other forms (Figure 36):

- *Eimeria* sporozoites are worm-like and measure about 15 µm.
- The size of the schizonts varies in most species between 10 and 50 µm, but they can also reach 240 µm.
- The merozoites have the typical structure of Apicomplexa.

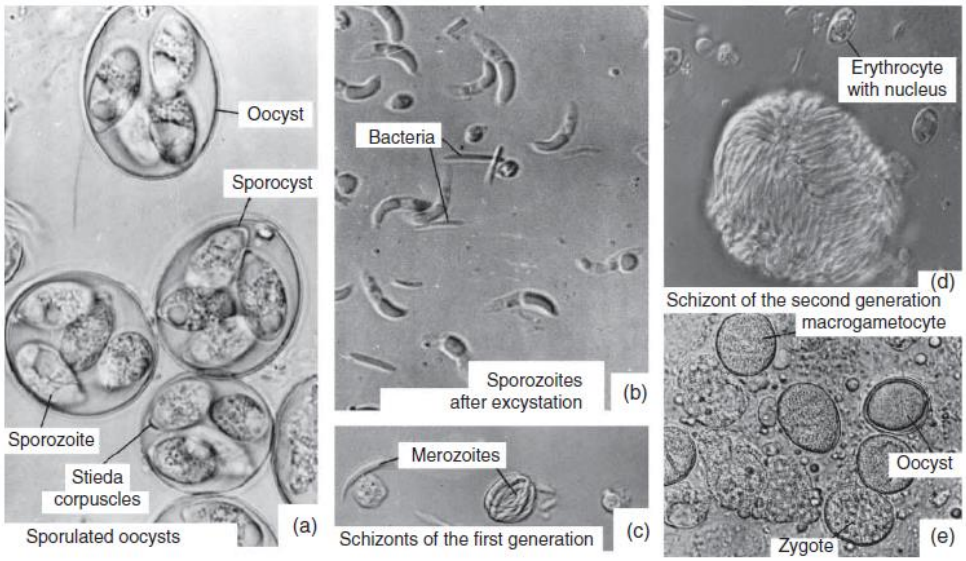


Figure 36 Different Eimeria forms and stages

Table 3 Emeiria species accordimg the host specificity, organ specificity, pathogenicity and parasite carachteristics.

Type	Host	Organ	No. of Schizont Generations	Pathogenicity	Average Oocyst Size (microns)
Eimeria bovis	Cattle	Hindgut, cecum, colon	2	++	23×20
Eimeria zuernii	Cattle	Hindgut, cecum, large intestine	2	++	20×15
Eimeria bakuen sis	Sheep	Small intestine	2	++	29×20
Eimeria arloingi	Goat	Small intestine	2	+	29×21
Eimeria debilecki	Pig	Small intestine	2	+	25×17
Eimeria stiedai	Rabbit	Bile ducts	6	+++	37×20
Eimeria tenella	Chicken	Ceca	3(2)	+++	25×19
Eimeria necatrix	Chicken	Midgut	3(4)	+++	20×17
Eimeria acervulina	Chicken	Midgut	4	++	17×14

Eimeria miwati	Chicken	Small intestine, large intestine	4	+	16×13
Eimeria truncata	Goose	Kidneys	?	+++	22×17
Isospora suis	Pig	Small intestine	3	+	21×19
Isospora belli	Humans	Small intestine	2	+	30×20

2.1.3 *Isospora*

The biology of the genus *Isospora* is broadly similar to that of *Eimeria*. However, each oocyst of this genus contains two sporocysts, each of which in turn has four sporozoites.

Isospora belli, the pathogen of coccidiosis in humans, is particularly prevalent in warm regions and can cause diarrhea. A prevalence of 3–4% has been observed in stool samples.

Isospora suis can cause severe diarrhea in pigs.

2.1.4 *Cyclospora*

Cyclospora cayetanensis is a diarrhoeic intracellular parasite specific to humans; it is widespread in tropical and subtropical countries and particularly in South America.

The life cycle of *C. cayetanensis* is monoxenous.

Agricultural products contaminated with oocysts can cause occasional infections.

Oocysts shed by an infected body are immature; therfore, direct transmission from one person to another is not possible.

Oocysts maturation is external (period of maturation of one to two weeks in a temperature between 23 and 27°C)

Free-living nematodes act as mechanical vectors in the contamination of food crops.

Figure 37 Cyclospora cayetanensis oocyst

1- Oocysts (Figure 37):

- Oocysts are spherical, measure about 7.5-10 µm in diameter
- Each oocyst contains two sporocysts each containing two infective sporozoites.

2.2 Family Sarcocystidae

2.2.1 *Toxoplasma gondii*

Toxoplasma gondii belongs to the "cystic coccidia" of the family *Sarcocystidae.* This parasite is of medical importance because toxoplasmosis of humans and domestic animals (especially sheep) is, unlike many other parasites, still prevalent in industrialized countries (Figure38).

Other features:

- The definitive hosts are felines, such as the domestic cat and the wildcat. Almost all mammals can serve as intermediate hosts.
- Many birds can be infected, including chickens.
- Development in the definitive and intermediate host occurs after ingestion of mature oocyst or bradyzoite froms.
- The first non-sporulated oocysts are passed in the feces about 3–9 days after infection.
- The sporulation process requires free access to oxygen and is completed within 2–4 days.
- Sporulated oocysts are highly resistant to environmental and other influences, including bleach, acid, and ultraviolet radiation. Under appropriate conditions, they can remain infectious for up to 5 years.

1- Oocysts:

- *T. gondii* oocysts are colorless and measure about 12.5 × 11 µm
- One oocyst contains two sporocysts and each contains four sporozoites and a granulated residual body.
- The transmission can be

2- Other forms:

- Tachyzoites are crescent-shaped and measure ~6 × 2 µm.
- Tissue cysts containing bradyaoites are round, measure up to 300 µm in diameter, and have a 2-3 µm thick wall.
- Bradyzoites are similar in size to tachyzoites.

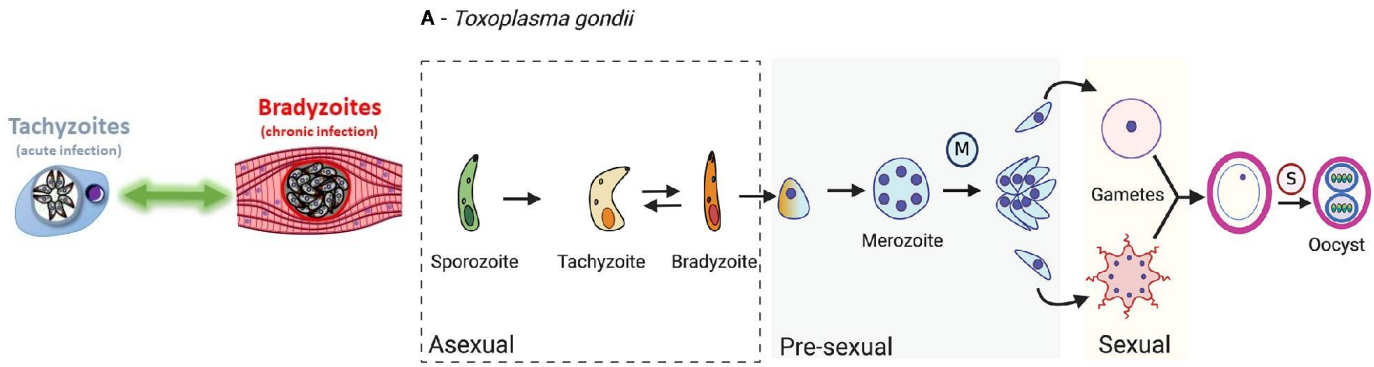


Figure 38 Toxoplasma gondii forms

2.3 Family *Haemosporidae*

2.3.1 *Plasmodium*

1- Biology :

- The genus *Plasmodium* (Greek: plasmatos, small entity) is divided into four subgenera with over 170 species.
- There are five human pathogenic species*: Plasmodium vivax, Plasmodium ovale, Plasmodium malariae, Plasmodium knowlesi, and Plasmodium falciparum*.
- They share a number of common characteristics, but also have distinctive features.
- The human-pathogenic Plasmodium species have very similar biology, but they cause different types of malaria (figure 39).

The following table outlines various *Plasmodium* species, the specific types of malaria they cause, and the frequency of fever attacks associated with each species.

Table 4 Plasmodium species according to the provoked disease and the fever frequency

Species	Disease	Fever Attacks – Interval
Plasmodium vivax	Malaria tertiana	48 h, Synchronous
Plasmodium ovale	Malaria tertiana	48 h, Synchronous
Plasmodium malariae	Malaria quartana	72 h, Synchronous
Plasmodium falciparum	Malaria tropica	48 h, Non-synchronous
Plasmodium knowlesi	Zoonotic Malaria	Fast replicating

- *Plasmodium* is transmitted by female Anopheles mosquitoes
- Approximately 10 to 100 sporozoites are injected into the host with the insect's saliva while it is feeding.

2- Morphology:

- The slender, elongated sporozoites of *Plasmodium* parasites are 10–15 μm long.
- Hepatic schizonts measure 30–70 μm.
- The merozoites resulting from the schizogonies of the liver and blood are about 1 μm long and oval in shape.
- After invasion of the erythrocytes, the parasite initially consists of a plasma bubble with a central food vacuole and an easily stained marginal nucleus.
- The developing blood stages have species-specific characteristics, on the basis of which they can be differentiated by experienced diagnosticians (Figure 39).

- Ookinetes reach a length of between 18 and 24 µm.
- Oocysts reach a size of 80 µm and are surrounded by a thin layer of fibrillar material.

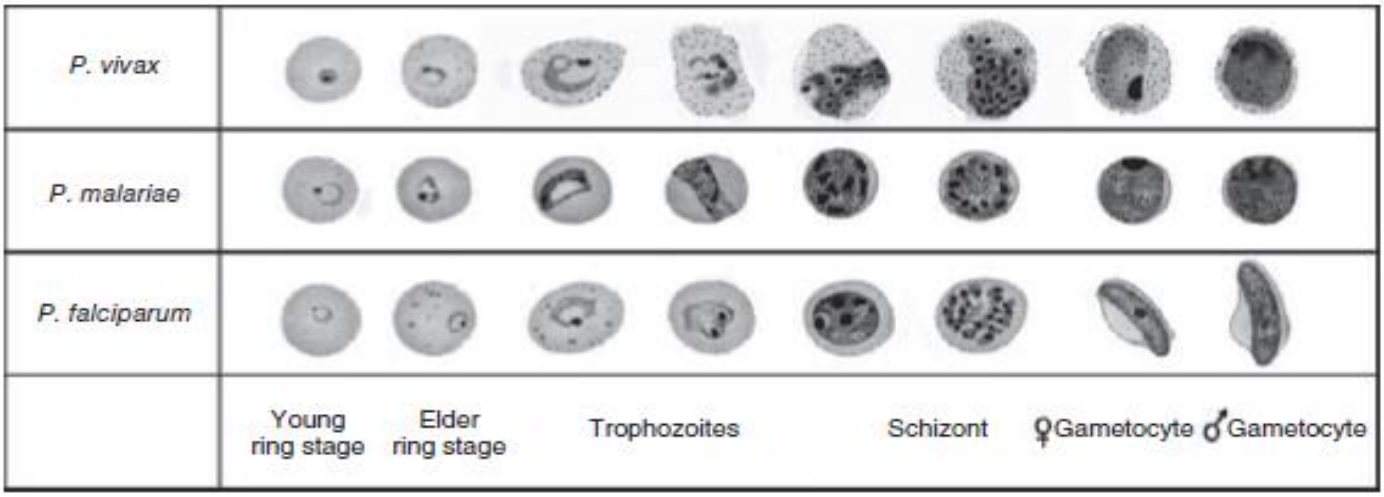


Figure 39 Blood stages forms according to species-specific characteristics

2.4 Family *Piroplasmidae*

2.4.1 *Babesia*

1- Biology:

- *Babesia* parasites are an heterogeneous group of piroplasms whose life cycle alternates between *ixodid* ticks and vertebrates
- The process of schizogony and gamogony occurs exclusively in the erythrocytes of the vertebrate host.
- In the tick, some species can be transmitted transovarially to subsequent generations.
- *Babesia* infections are of great economic importance for livestock farming in tropical and subtropical regions, but also in some temperate climates.
- Babesia parasites cause a disease called babesiosis or piroplasmosis, that affects mammals, and more rarely humans.
- *Babesia divergens* causes a common infection in European cattle, where it causes haemoglobinuria also known as "red water fever". The pathogen is transmitted by the castor bean tick *Ixodida ricinus*.
- *B. divergens* also causes severe babesiosis in humans, presenting as a fulminant infection.
- *Babesia bovis* is an important cosmopolitan pathogen that causes haemolytic anaemia in cattle. It is present in southern Europe, Asia, Africa, Australia and Central and South America. The main tick vectors are species of the genus *Boophilus*.
- Asexual reproduction of *Babesia* occurred through binary fission

2- Morphology:

- *Babesia* sporozoites infect only erythrocytes Pear-shaped

- Merozoites are of about 1 × 2 μm
- If infected blood is ingested by a tick, the gametocytes differentiate into gametes called "radiated bodies".
- The radiated (ray) bodies have several short, spine-like appendages.
- Each of the two bodies will fuse to form the zygote
- A single worm-shaped kinete develops within the zygote.

(a) A free merozoite invading a human erythrocyte. Panels b–j show different stages within the human erythrocyte. (b) Single round trophozoite. (c) Paired pyriforms, a stage formed by two attached pear-shaped sister cells. (d) Double round trophozoites, (e) Double paired pyriforms. (f) Tetrad (g). Quadruple round trophozoites. (h) Multiple parasites. (i) Double unattached pyriforms. (j) Quadruple unattached pyriforms. (k) Intact paired pyriform outside the erythrocyte. (l) Intact tetrad outside the erythrocyte. Slides were examined with a Primo Star microscope (Zeiss, Germany) at 100X magnification.

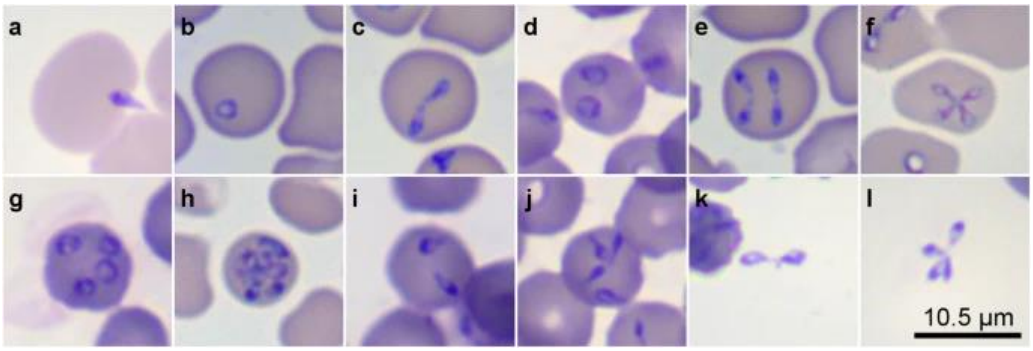


Figure 40 Babesia divergens forms inside and outside erythrocytes were identified in in vitro cultures by Giemsa staining.

3 PHYLUM *CILIOPHORA*

3.1 Balantidium coli

Balantidium coli (Greek: balantídion = small purse, because of its shape) usually lives as a commensal agent in the caecum and colon of pigs and other animals (including humans), its transmission occurs via round cysts, which are 40–60 μm in diameter (Figure 41).

Other features:

- The cysts are excreted in the feces and their strong wall helps them survive for several weeks in favorable environmental conditions.
- The emerging trophozoites are 50–200 µm long and irregularly oval.
- The surface of trophozoites is covered with rows of cilia that beat synchronously, allowing targeted movements.
- The cilia are thickest near the mouth of the cell, which lies at the bottom of a slit-like peristome, where they play a role in ingesting food.

Figure 41 Balantidium coli

- The macronucleus is elongated, but the micronucleus is very small.
- The trophozoites feed on bacteria and detritus.
- Humans in frequent contact with pigs, such as butchers and farmers, are at higher risk of infection.

Chapter 4:

Metazoan parasites

1 PHYLUM OF *PLATYHELMINTHES*

1.1 Class *Cestoda*

General characteristics:

- Adult worms are intestinal parasites of all vertebrates.
- Their body is consisted of a scolex (head) and numerous individual segments (proglottids).
- The surface of their body is covered with a tegument.
- They lack a mouth and digestif tract.
- They are hermaphrodites
- The first larval stage is six-hooked and called hexacanth or oncosphere.
- The second larval stage, metacestode, is characterized with a very variable morphology.
- The infection is contracted by ingestion of infected food.
- The subclass **Eucestoda**, the true cestodes or tapeworms, is the most important group of Cestoda.
- Due to morphological differences, the names of the larval stages are different between taxa, often even having species-specific designations.
- The life cycle of Eucestoda consists of three stages, all of which are directly related to each other:

1. The egg: Tapeworm eggs have different shapes according to species. Therfore, cestode eggs were classified into four types: pseudophyllidean, dipylidean, taenioid, and stilesian. Stilesian group is the only that do not infect humans (Figure 42 and 43).

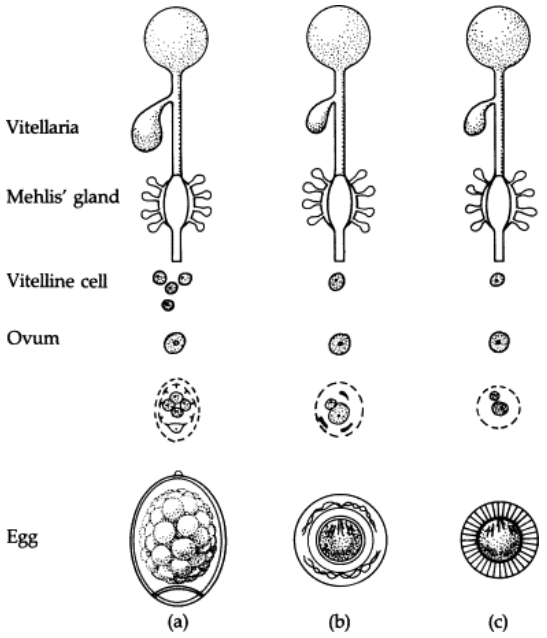


Figure 43 The three types of egg-forming tapeworms that infect humans. (a) Pseudophyllidean, (b) Dipylidean (c) Taenioid,

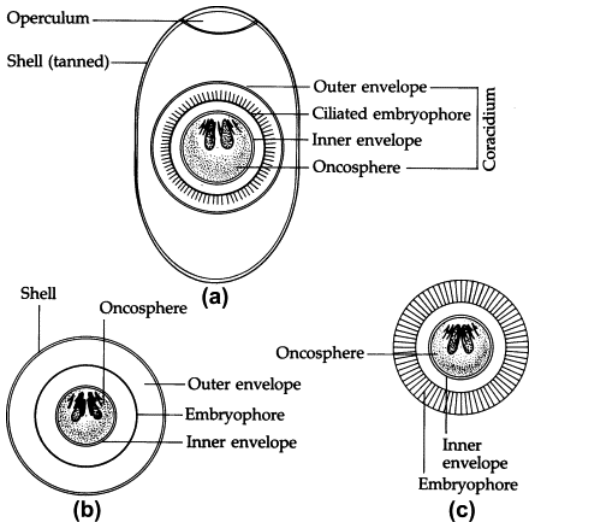


Figure 42 variation in cestodes eggs with the shape pf omcospheres inside their eggs . (a) Pseudophyllidean. (b) Dipylidean. (c) Taenioid.

2. The first larval stage (oncosphere or hexacanth): it is the first form of Eucestoda that appears after the emryogenesis, they develop after the release of the cestode egg in the environment; they stay inside the egg enveloped with a protective membrane until being ingested with the first intermediate host; the larva will be released out of the egg directly after ingestion. The Oncospheres are equipped with six hooks that help the larva to fix to their hosts (Figure 44).

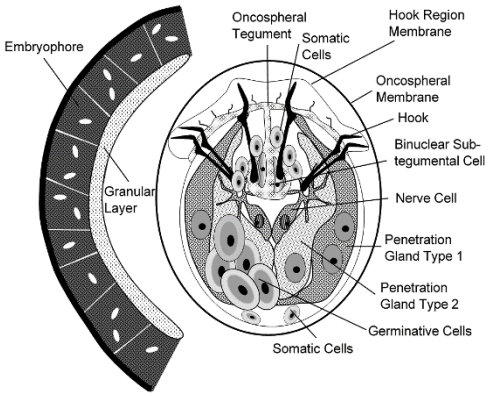


Figure 44 Oncospheral morphology

3. The second larval stage (metacestode): it is the second larval form of tapworms, it lives inside the intermediate host, usually the second one, and the can appear in different forms according to species: procercoid, plerocercoid, cysticercoid, cysticercus, hydatid, alveolar metacestode (Figure 45).

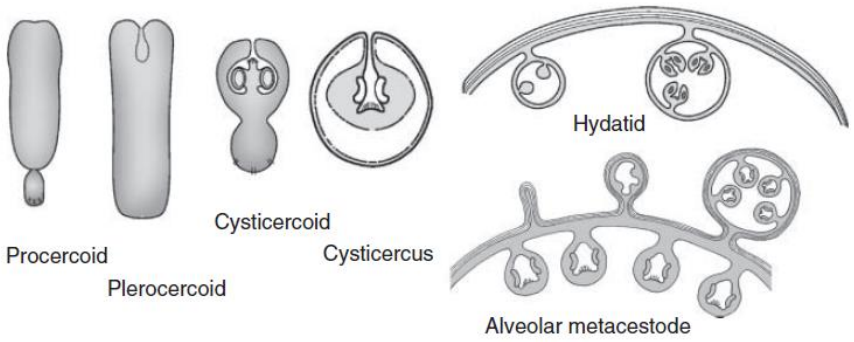


Figure 45 Different forms of metacestodes

4. The adult worm: The adult body consists of three distinct regions: scolex, neck, and strobila. **The strobila is a chain of segments called proglottids. Every new proglottid is formed next to the neck, differentiate and pooch older proglottids** progressively posteriad. The sexual reproductive system matures progressively as each proglottid is shifted posteriad; therfore, the most

posterior proglottid is the most sexually mature segment. The progressive sexual maturity divide the adulte's strobila into **immature**, **mature** and **gravid** (egg-filled) proglottids.

5. In apolytic species, the gravid proglottids are detached from the strobila to exit the body of the host with stools. While, in anapolytic species, the warm release the eggs directly into the host's intestine through a uterine or a genital pore; the eggs are, subsequently, discharged to the exterior with feces (Figure 45).

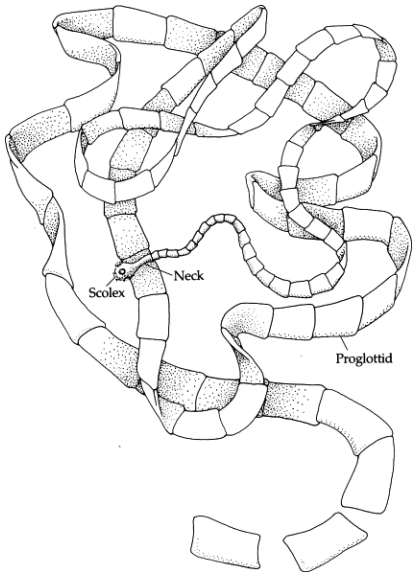


Figure 46 The morphology of tapworms

The adulte tapworms lack a digestif tube, they feed through their tegument

The scolex is equipped with suckers, we can categorize tapworms accordimg to the shape of suckers (Table 5): acetabulate (**Ordre Cyclophyllidea)** or bothriate (**Order of Pseudophyllidea) (Figure 47)**.

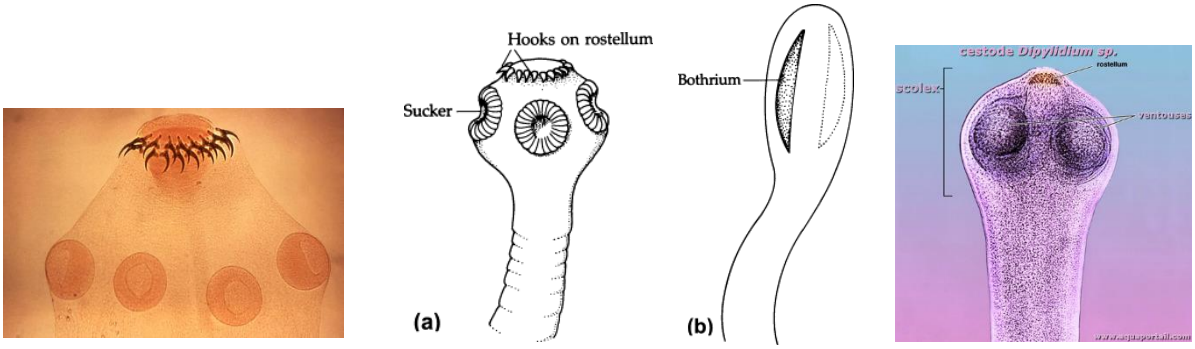


Figure 47 Types of scolices in tapeworms (a) Acetabulate, showing three of the four suckers and the hooks. (b) Bothriate, showing one of the two bothridiums.

Table 5 Differences between the two Cestode orders

	Cyclophyllidea	Pseudophyllidea
Genera of interest	*Moniezia* *Anoplocephala* *Taenia* *Dipylidium* *Mesocestoides** *Echinococcus*	*Diphyllobothrium* *Spirometra*
Scolex	Hooks* and suckers	Shallow longitudinally grooved bothria
Uterus	Lateral pore(s)	Ventral pore
	Gravid proglottids shed	Eggs shed
Eggs	Radially striated Hexacanth larva 5 lines = hooks	Operculate Ciliated embryophore – 'coracidium'
Lifecycle	1 intermediate host* – vertebrate or invertebrate	2 intermediate hosts– copepod then vertebrate

1.1.1 Order *Pseudophyllidea (ex: Diphyllobothrium latum)*

Diphyllobothrium latum known as the large fish tapeworm, it can reach 8 to 20 m, sometimes cause life-threatening anemia due to its absorption of vitamin B12.

Other features:

- Its development requires two intermediate hosts.
- The operculated eggs are excreted unembryonated.
- In 3 to 4 weeks, a coracidium develops, which is a ciliated oncosphere with a pair of protonephridia.
- The coracidium bursts out of the egg through the operculum and swims in the water.
- If eaten by a copepod (Diaptomus or Cyclops), it develops in the body cavity and becomes a 0.5 mm long **procercoid**. It is a solid oblong larva, which has an undeveloped scolex at the retracted anterior end and a rounded cercomer, which still bears the six hooks of the oncosphere at the posterior end.

- After ingestion of infected copepod by a fish, the larva loses its cercomere and becomes a **plerocercoid** about 5 mm long, which already has a scolex typical of the adult worm, but always in a retracted position.
- Although the plerocercoid is infective for the definitive hosts after 2 months, the infected fish is usually chased away by another fish (Figure 48).
- In this case, the plerocercoid also penetrates the intestinal wall of the predator and survives in the organs of the body cavity without alteration.
- These hosts in which no further development of the larva takes place are called paratenic hosts.
- Once the infected fish is consumed by a definitive host, the worm usually settles in the jejunum and begins to develop very quickly.
- The first eggs are excreted 18 days after infection.
- Humans are usually inhabited by a single worm, which can live for many years.

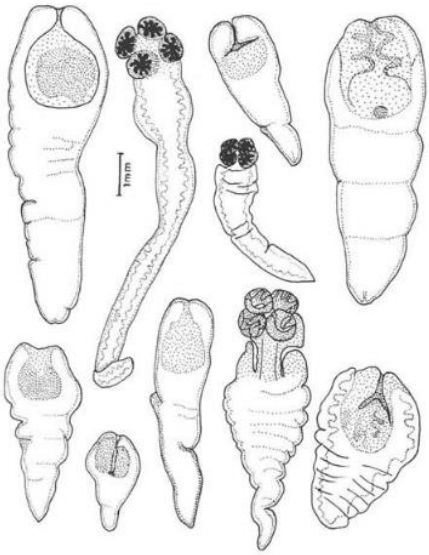


Figure 48 Plerocercoïdes in Phyllobothrium sp.

1.1.2 Order *Cyclophyllidea*

It is a highly developed and important order of *Eucestoda* that includes parasitic of vertebrates excluding fish equipped of four suckers.

Other features:

- Vitellarium posterior to the ovary.
- Genital openings almost always lateral.
- Eggs not operculated, containing an oncosphere when excreted.
- They need one intermediate host.
- Metacestode of **cysticercoid** or **cysticercus** type.

1.1.2.1 *Moniezia expansa*

- Sheep tapeworm (Figure 49)

- It can become pathogenic in lambs (digestive problems, diarrhea), but the worms end up being expelled after several months, immunizing the host.
- The parasite belongs to the family Anoplocephalidae, whose scolex does not have hooks, but prominent suckers. Anoplocephalidae are parasites of terrestrial mammals, especially lagomorphs and ungulates.
- The intermediate hosts are free-living mites, the Oribatidae, which live among bark, leaf litter and roots.

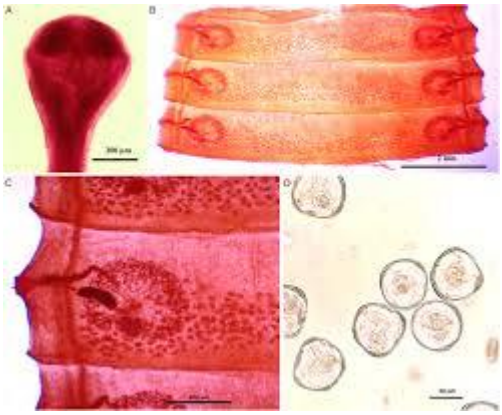


Figure 49 Moniezia expansa

- They are very long worms (up to 10 m), carrying very short and wide segments with two sets of lateral genitalia.
- The eggs are somewhat triangular and rather large. They contain an embryophore, which carries the very small oncosphere.
- The metacestode is of cysticercoïd type
- This larva bears oncospheric hooks at the end of a long tail and is not infective for sheep until 15 to 18 weeks.
- The prepatent time in the final host is 25 to 40 days.

1.1.2.2 *Rodentolepis nana (Hymenolepis nana)*

- The dwarf tapeworm of humans and other primates
- It is easily maintained in the laboratory in mice and grain beetles.
- They have a retractable rostrum bearing a ring of 18 very small equal hooks of 16 × 8 µm
- The eggs are broadly oval, 50 × 40 µm,
- The adult reaches a length of only 50–60 mm and a width of 0.5–1 mm. In the normal mode of infection, the eggs are ingested by grain beetles or other insects.
- If humans or mice ingest beetles with a contaminated meal, the larval wall is dissolved.
- The scolex settles in the duodenum of the final host and begins to form a strobilus.

Rodentolepis nana

- In mice, young worms migrate to the lower ileum after 3–4 days, where they become sexually mature and begin laying eggs on day 7.
- The second mode of infection, more common than the first, is autoinfection without insect intervention: if a definitive host (human or mouse) swallows eggs, they enter a villus and become thin-walled cysticercoids without cercomeres in the upper intestine.

- The cysticercoids return to the intestinal lumen, evaginate their scoleces, attach to the intestinal mucosa, and develop into adults that reside in the ileal portion of the small intestine (Figure 50).

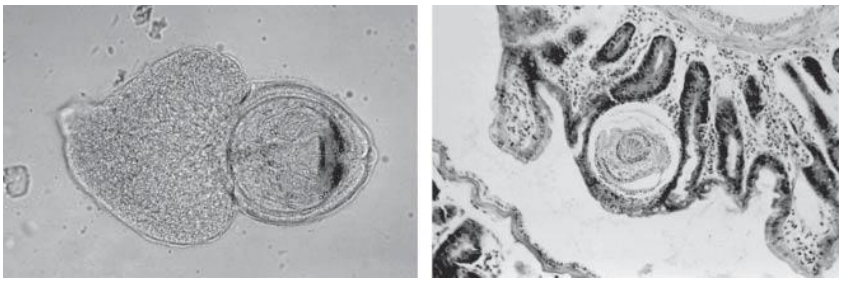


Figure 50 Rodentolepis nana cyeticercoid

1.1.2.3 *Taenia saginata*

- The beef tapeworm is one of three species of the family *Taeniidae* that infect humans but not carnivores.
- Only the larval tapeworm is found in beef.
- *T. saginata* has a cosmopolitan distribution.
- In cattle, it causes relatively few health problems but is a major concern for meat inspection.
- *T. saginata* is the only species of the genus *Taenia* that *lacks scolex hooks*.
- Although hooks are present in the young cysticercus, they disappear shortly thereafter.
- *T. saginata* is present in up to 0.5% of the human population, even in countries with strict sanitation policies.
- The prevalence in cattle is 0.7–15%
- Humans usually harbour only one tapeworm per individual
- After a prepatent period of 10 weeks, the tapeworm releases six proglottids per day, each containing 80,000 to 100,000 eggs. A single specimen can produce up to 1 million eggs/day.
- The proglottids are highly motile and gradually expel the eggs, which are loosely dispersed and are only ingested by livestock singly.
- The cysticercus become infective after 10 weeks and preferentially settle in the masseter muscle, tongue, diaphragm and heart of the intermediate host.
- They cause relatively few symptoms in terms of host response, even when dead or calcified.

1.1.2.4 *Taenia solium*

Taenia solium has common features with *T. saginata*, however, it exist differences between the two species illustrated in table 6.

Table 6 Differences between Taenia saginata and T. solium

Adule	Taenia saginata	Taenia solium
Name	*Taenia* of bovin	*Taenia* of porc
Scolex	Without hooks	With hooks
Length	>10m	3–4m
Size of gravide proglottids	18–20 × 4–7mm	9–12 × 6–7mm
Width of proglottids	6: 1	3 : 1
Morphology of ovairy	Bipartite	Bipartite with supplementary lobes
Nembre of uterus branches	2 × 20–30	2 × 7–12
Vagin	with sphincter	without sphincter
Size	7–9mm	6–15mm
Apparence	Yellow-white, firm	Whitish, transparent
Intermediate host	uniquely Bovins	Pig, experimentally other mammals too
Old termes	Cysticercus bovis, Cysticercus inermis	Cysticercus cellulosae, Cysticercus ocularis

1.1.2.5 *Echinococcus*

Adult worms of the genus *Echinococcus* are only a few millimeters long.

These parasites are of great importance because the metacestodes proliferate asexually and infect mammals, including humans, inducing severe disease, in the form of cystic Echinococcosis (also known as hydatid disease or hydatidosis), alveolar or polycystic Echinococcosis:

- The biology of *Echinococcus* is the same as that of most taeniids: the definitive hosts are carnivores and the intermediate hosts are herbivorous prey mammals.
- Asexual proliferation in the intermediate host is obligatory.
- The larvae can settle in: liver, lungs, kidney, bones, muscles, SN
- Exceptionally, adult worms are up to 7 mm long and have up to six proglottids.
- The number of species and strains has increased significantly since the introduction of molecular analysis methods (Table 7):

1. *Echinococcus granulosus* (Cystic Echinococcosis): adult 2-3 mm long and has three proglottids, only the last one is gravid (Figure 51)
2. *Echinococcus multilocularis* (Alveolar Echinococcosis): adult 3 mm long and has three to five proglottids (Figure 52)
3. *Echinococcus vogeli* and *Echinococcus oligarthrus* (Polycystic Echinococcosis): adult 4-6 mm long

Figure 51 Echinococcus granulosus adult

Figure 52 Echinococcus multilocularis adult

Table 7 The most important species in Echinococcus generia

Species (and strains)	Final Hosts	Intermediate Host(s)	Human Infections	Hydatid Features	Geographical Distribution
Echinococcus granulosus s. str., strains G1–G3	Dog	Sheep, goat, and cattle	Common	Unilocular	Worldwide in regions with extensive sheep breeding
Echinococcus canadensis strains G6/G7	Dog	Pig, camel, cattle, goat, sheep	Uncommon	Unilocular	Worldwide
Echinococcus canadensis strains G8, G10	Wolf	Moose, wapiti	Uncommon	Unilocular	Northern arctic and boreal
Echinococcus equinus	Dog	Horse	Unknown	Unilocular	Worldwide
Echinococcus ortleppi	Dog	Cattle	Uncommon	Unilocular	Worldwide
Echinococcus felidis	Lion	Unknown	Unknown	Unknown	Africa

Echinococcus oligarthrus	Wild felids	Agouti	Uncommon	Unilocular	Neotropical
Echinococcus vogeli	Bush dog	Paca	Uncommon	Polycystic	Neotropical
Echinococcus multilocularis	Red fox, arctic fox	Arvicoline rodents	Common	Alveolar	Holarctic

1.2 Class of Trematoda (Digenea)

General characteristics (Figure 53):

- The life cycle of most trematode genera consists of two intermediate hosts and one definitive host except the Schistosomoidea which need only one intermediate host.
- The first intermediate host is almost always a mollusk, usually a freshwater or marine snail, although in rare cases it may be a bivalve or even a polychaete.
- There is a strong host specificity regarding the first intermediate host.

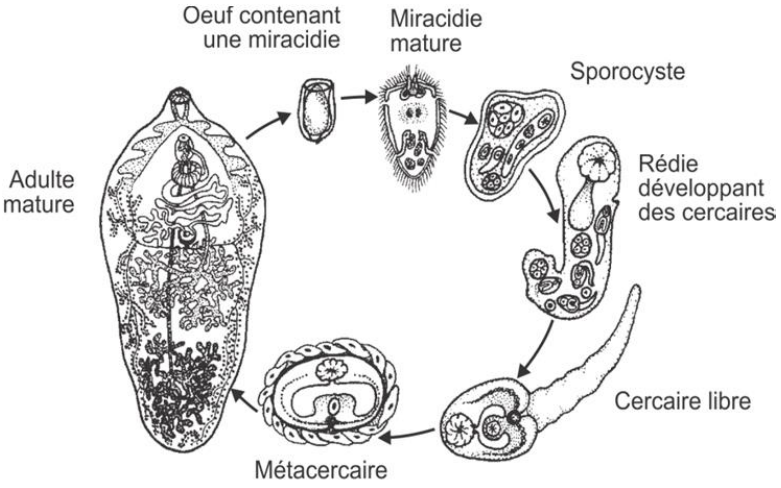


Figure 53 The development forms in Trematodes

- The number of offspring of adult trematode is often much smaller than the number of larvae produced asexually in the first intermediate host.
- Two types of free-swimming larvae develop: miracidia and cercariae.
- The second intermediate host is usually an animal from the food chain of the final host.
- The eggs are passed in the definitive host's faeces (or in its urine or sputum, depending on the locality of the adult worm).
- If the eggs are not embryonated when laid, the first larva, an actively swimming ciliated miracidium, develops in the water inside the eggshell, hatches, and invades the first intermediate host.
- If the excreted egg is already embryonated, containing the miracidium, it must be eaten by the first intermediate host.

- In both cases, the miracidium loses its cilia as it invades the host, pierces the skin or intestinal wall, settles in one of the organs, and becomes a mother sporocyst, containing numerous omnipotent germ balls. After maturation they migrate to the hepatopancreas ("liver") of the mollusc.
- Their germ balls develop into the final larval generation, the cercariae.
- The cercariae leave the first intermediate host and swim to find the second intermediate host (or in the case of schistosomes, the definitive host).
- The cercaria migrates to muscle tissue, the haemocoel, the liver or other organs of the body and settles there, but never ends up in the intestine. From the secretions of its cystogenic glandular cells, it produces an elastic hyaline envelope or cyst wall. This stage is the metacercaria (Greek: metá = after), which is again lacking in schistosomes.
- It does not develop further, but must wait to be ingested by a definitive host, a vertebrate.
- During passage through the stomach and duodenum of the vertebrate, the cystic wall of the metacercaria is dissolved. The preadult fluke migrates to its final location in the small intestine (but sometimes to other organs) and becomes an adult.

❖ The digenetic trematodes are separated into six morphological forms (Figure 54):

1. Amphistomes: are digenetic trematodes that are usually referred to as "stomach" or "rumen" flukes due to their location in ruminants' stomachs. They are identified by the presence of the ventral sucker or acetabulum at the posterior end of the body and the lack of an oral sucker. The body is distinguished by a big posterior sucker and a fleshy structure that resembles leaves and is either pink or red in color.
2. Echinostomes: are parasitic flatworms with medical and veterinary significance that infect humans, domestic animals, and wildlife. They also parasitize a variety of invertebrates and cold-blooded vertebrates in their larval stages. The life cycle of these intestinal flukes involves three hosts. There is a band around their oral sucker.
3. Schistosomes: are unisexual, dimorphic digeneans. The male's gynecophoric canal, carries the long, cylindrical female. The ventral sucker, that is present at the anterior end of both sexes, is situated behind the oral sucker, and serves to attach to blood vessel walls.
4. Monostomes: present only one oral sucker at the anterior end, with no ventral suckers.
5. Holostomes: their main body is separated into two sections. The anterior portion contains an extra adhesive (tribocytic) organ in addition to an oral and ventral sucker, while the main internal structures are carried by the posterior portion.

6. Distomes: This digenean have an oral and a ventral sucker, however, they lack the other characteristics displayed by the morphological forms previously discussed.

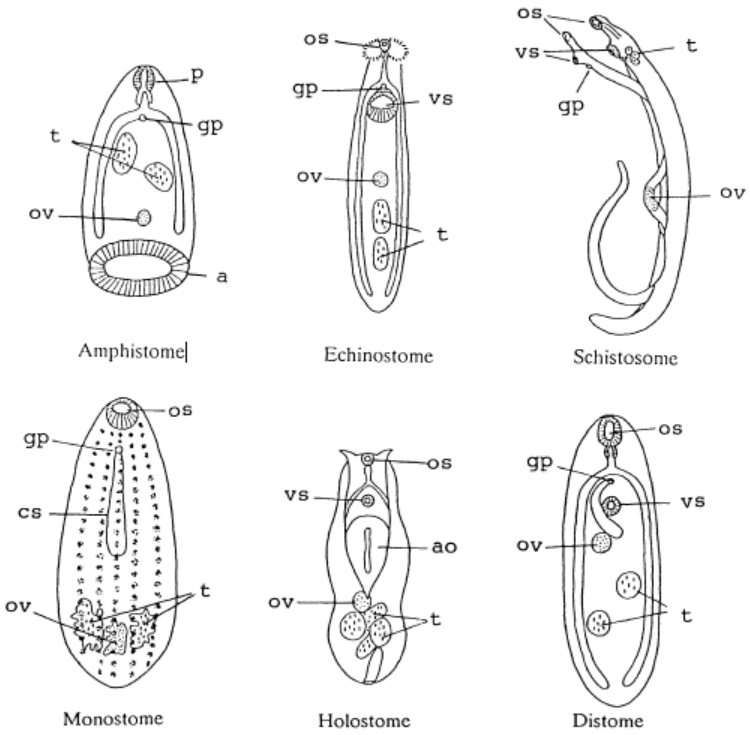


Figure 54 The six morphological forms of trematodes

1.2.1 *Schistosoma : Family Schistosomatidae (Schistosomes or bilharzia, separate sexes)*

The genus *Schistosoma* is the most important genus of trematodes in the world. This genus is answered in the tropics of Africa, East Asia and South America, more than 200 million people are infected.

The disease they cause is called bilharzia. *Schistosomatidae* contains 15 genera. Most of them are parasites of birds, five inhabit mammals and one occurs in an Australian freshwater crocodile (Table 8)

In the genus *Schistosoma*, there are seven species infecting humans and three infecting domestic animals, while they do not constitute a monophyletic group.

- *Schistosomatidae* differ from other digeneans by the following characteristics:

✓ Adults are dioecious and the sexes are separate.
✓ Males and females live in permanent copulation.
✓ They inhabit blood vessels, i.e. species-specific locations in veins.
✓ They have no second intermediate host and no metacercariae.
✓ The shape of eggs can help to identify *Schistosoma* species (Figure 56).

- ✓ The egg is the infective stage and not the adults, with eggs carried into certain tissues, where they cause pathology.
- ✓ Unlike other trematodes, they can live for decades.
- ✓ Cercariae are furcocercarious (forked tail).
- ✓ There is no proper oral sucker, but an apical or oral organ. No pharynx.
- ✓ Adults of both sexes are much longer than wide.
- ✓ The two suckers lie close together.
- ✓ The genital pore is posterior to the ventral sucker.
- ✓ Behind the esophagus, the intestine divides into two long ECCA, which unite again at a species-specific position to form a rod reaching the distal part of the body.
- ✓ The female is longer and thinner than the male.
- ✓ Since the male does not move alone in the blood vessel, but is always carried by the male, it has poorly developed

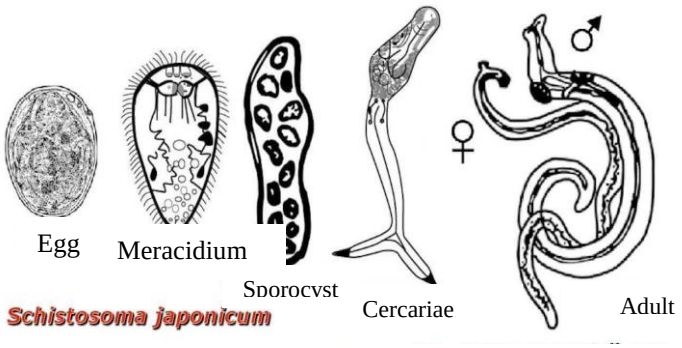


Figure 55 Development forms of Schistosoma jeponicum

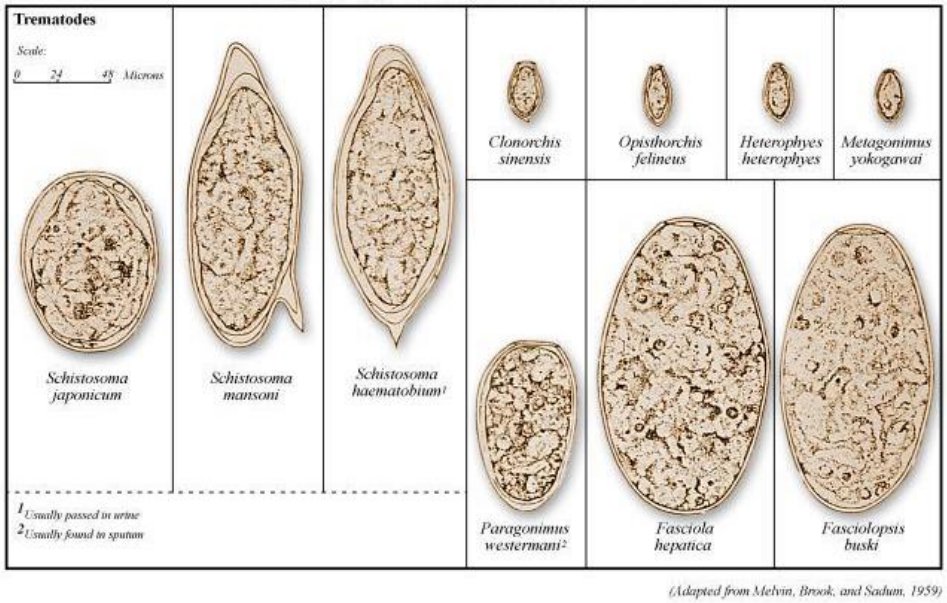


Figure 56 Trematode eggs found in stool specimens of humans

Table 8 Imoprtant human pathogenic Schistosoma species

Schistosoma species	Distribution	Intermediate host	Mammalian reservoir hosts	Localization of adults	Form of eggs	Eggs shed with
mansoni	Africa, Madagascar, west of South America, the Caribbean	*Biomphalaria* (Planorbidae, lung snails)	Primates, rodents	Mesenterial veins of colon	Oval with lateral spine	Feces
haematobium	Africa, Madagascar, Middle East	*Bulinus* (Planorbidae)	Primates	Veins of lesser pelvis, esp. bladder	Oval with terminal spine	Urine
intercalatum	Central Africa	Bulinus (Planorbidae)	Rodents	Veins of colon and colon sigmoideum	Spindle-shaped with terminal spine	Feces
japonicum	China, Indonesia, Philippines	*Oncomelania* (Pomatiopsidae)	>40 species of mammals	Mesenterial veins of small (and large) intestine	Rotund with rudimentary lateral spine	Feces
mekongi	Laos, Cambodia	*Neotricula* (Pomatiopsidae)	Dog	As japonicum	As japonicum	Feces

1.2.2 *Leucochloridium paradoxum*

- *L. paradoxum* inhabits the cloaca of various songbirds.
- Has only one intermediate host, in which the cercariae develop into metacercariae that are then eaten by the definitive host to continue their life cycle.
- Embryonated eggs are ingested by *Succinea putris*, a terrestrial pulmonate snail that lives in moist vegetation (Figure 59).
- Inside the snail, tailless cercariae develop into long, branched sporocysts.
- Hundreds of these cercariae move into the distal part of the sporocyst, which forms an inflated "brood sac" that extends into one of the snail's tentacles.
- The larvae then develop into metacercariae with thick, gelatin-like cyst walls (Figure 57).
- The brood sac has a pattern of shiny greenish-brown transverse rings.
- During the day, the colorful sporocyst inside the tentacle exhibits pulsating movements, mimicking a caterpillar or butterfly worm, which attracts birds.
- When the brood sac is removed from the tentacle and eaten, adults develop in the bird (Figure 58).

Figure 57 Metacercaria of Leucochloridium paradoxum

Figure 58 Adult of Leucochloridium paradoxum

Figure 59 Brood sac in *Succinea putris* snale

1.2.3 *Diplostomum spathaceum*

- They are intestinal parasites of birds
- Their body consists of two different sections, a flat or spoon-shaped part, and an elongated and round part.
- *D. spathaceum* is a parasite of gulls feeding on freshwater fish.
- It has some economic importance, since its metacercariae cause damage to the eyes of fish.
- The eggs are excreted unembryiated.
- The miracidia, developing in fresh water, invade the pulmonate snail *Radix peregra* (=*R. ovata=R. balthica*).
- The cercariae developing in the daughter sporocysts are furco-trichocercous
- They invade the second intermediate host, which can be various species of freshwater fish, mainly in the region around the gills.
- They then migrate via the subcutaneous connective tissue and musculature into the lens, where they become non-encysted metacercariae, called diplostomula (Figure 61).
- After 8 weeks, these are capable of infecting gulls when ingested. The adult worm is 4 mm long, with a flat oval forebody of 1.3 × 0.6 mm and an elongated posterior body of 2.3 × 0.6 mm (Figure 60).

- The anterior end of the body is trilobed, with small lateral protuberances (lappets) on each side of the oral sucker.

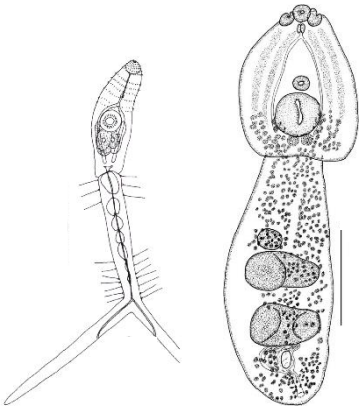


Figure 61 Diplostomum spathaceum adult

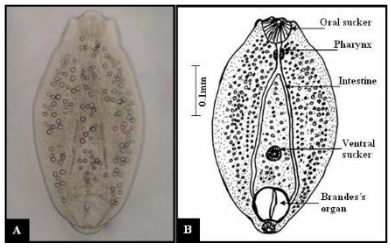


Figure 60 Metacercaria of Diplostomum spathaceum. A-Photomicrograph (150X). B-Camera lucida drawing.

1.2.4 *Fasciola hepatica (superfamille Echinostomatoidea)*

It is one of the most important parasites of ruminants in temperate climates and the most important representative of the family *Fasciolidae*.

Unfortunately, the common liver fluke is often considered a prime example for digenean trematodes. However, this is misleading because *Fasciola* is atypical of flukes.

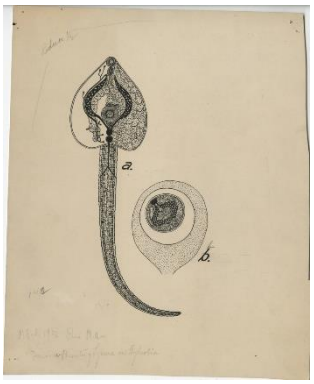


Figure 62 Fasciola hepatica (common liver fluke). a. Cercaria b. Encysted cercaria.

- First, ruminants are not typical hosts for Digenea (as they rarely ingest animals - normally the second intermediate hosts);
- Second, bile ducts are rarely inhabited by trematodes;
- Third, a metacercaria encysting on plants is a rarity in digeneans,
- And finally, the morphology of *Fasciola hepatica* adult is markedly altered from that of "typical" Digenea and does not provide a good model for comparing structures common to other trematodes.

The eggs are not embryonated when they are passed with the feces of the final host.

In water, the eggs mature in 2 to 3 weeks and release miracidia that invade the first intermediate host. It is an aquatic pulmonate gastropod of the family *Lymnaeidae*.

After 7 weeks, the cercariae leave the snail.

The cercariae encyst on submerged green leaves of aquatic plants preferentially on the underside (Figure 62).

There, they form a hemispherical metacercaria with a multilayered cyst wall.

In humid conditions, the metacercariae remain infective for up to several months and can survive temperatures below freezing. However, they are quite susceptible to desiccation.

Following ingestion by the final host, the young worms are released into the digestive tract and then penetrate the intestinal wall to enter the liver through the hepatic capsule.

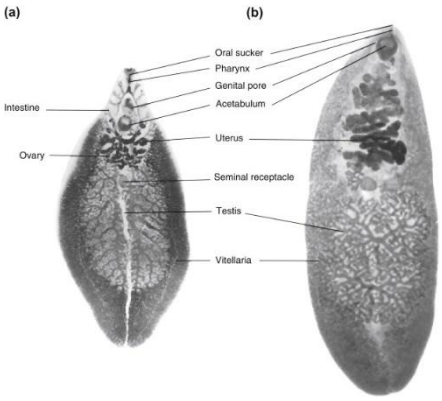


Figure 63 Two fasciolid flukes. (a) Fasciola hepatica, the sheep liver fluke. (b) Fasciolopsis buski.

Over the next 6–8 weeks, they migrate into the liver parenchyma and invade the biliary tract, where they become sexually mature.

The prepatent period (time until eggs are excreted) is 55–105 days.

Approximately 5,000–20,000 eggs are laid by an adult female worm per day.

The leaf-shaped adult worm (up to 300 × 139 mm in length) has a cone-shaped anterior projection containing the small oral sucker and the first part of the intestinal caeca with diverticula (Figure 63).

In the area of body enlargement, the large ventral sucker, a large cirrus pouch, and the genital opening are visible.

Eggs appear pale yellow and measure 130–140 × 70 μm. When observed in large numbers in the uterus, they appear as a dark brown mass.

1.2.5 *Opisthorchis felineus (family Opisthorchiidae)*

Opisthorchis felineus, the cat liver fluke, infects piscivorous (fish-eating) mammals such as cats, foxes, otters, as well as humans in Eastern Europe and Russia (Figure 64).

O. felineus inhabits the gallbladder and bile ducts of many vertebrate species except fish.

The name Opisthorchis indicates that the testes are located posteriorly on the body.

O. felineus produces embryonated eggs containing miracidia, which invade the freshwater snail *Bithynia leachi*.

The cercariae produced via the rediae are released by the snail and exhibit a characteristic floating position in the water with the curved body suspended from the perpendicular tail.

Upon contact with hard objects, the cercariae immediately start rotating upwards, increasing the chances of contact with a second intermediate host, which are fish such as minnows and barbels.

The cercariae invade the subcutaneous connective tissue or musculature of the fish, where they become very robust metacercariae that are resistant to refrigerator temperatures, drying, salting for a considerable time.

Once ingested by a definitive host, the young flukes migrate from the duodenum to the biliary tract and in severe infections also to the pancreatic duct.

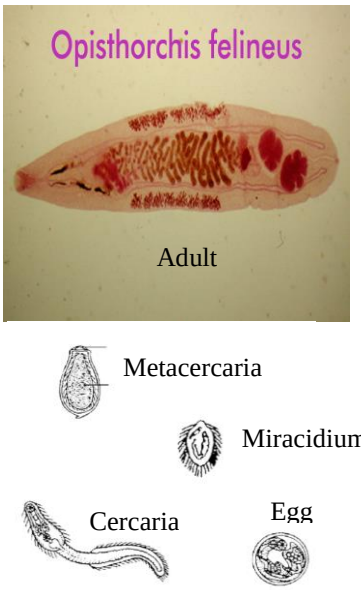
The prepatent period is 3 to 4 weeks.

Cases of infection lasting up to 25 years have been reported.

In the following table (Table 9) you find the comparision between the most commen species of *Opisthorchiidae*

Table 9 Comparison between the main species of Opisthorchiidae

Feature	*Opisthorchis felineus*	*Opisthorchis viverrini*	*Clonorchis sinensis*
Distribution	Russia, East Europe	Thailand, Laos, Vietnam, Cambodia, Malaysia	China, Japan, Korea, Taiwan, Thailand, Vietnam
Infected humans	Not known	10 million	35 million
Life span in humans	Not known	10 years	26 years (proven)
Adult worms, length (mm)	5–12	7–12	10–25
Width (mm)	Up to 3	2–3	Highly branched
Shape of testes	Clover-leaved with 4–5 lobes	As in *O. felineus*	Highly branched
Egg size (µm)	26–30 × 11–15	27 × 15	29 × 17
1st Intermediate host	*Bithynia leachi*	*Bithynia* spp. (*B. siamensis, B. goniomphalus, B. laevis, B. funiculata*)	*Parafossarulus striatulus, Alocinma longicornis* (Hydrobiidae), *Bithynia fuchsianus*
2nd Intermediate host	Mainly cyprinid fish	Fish	Fish



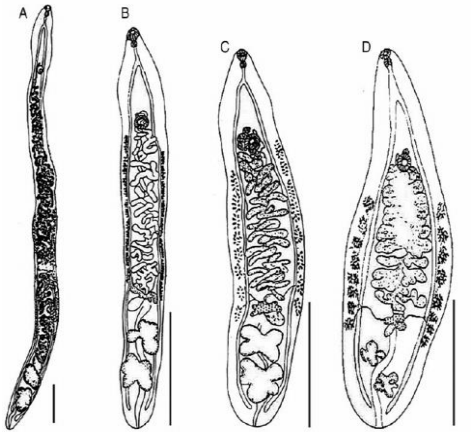


Figure 64 Opisthorchis felineus and its forms and Opisthorchis spp. Found in Vietnam. (A) Opisthorchis longsissimus; (B) Opisthorchis chelis; (C) Opisthorchis parageminus and (D) Opisthorchis viverrini.

1.2.6 *Paragonimus westermani (Family Paragonimidae)*

The oriental lung fluke inhabits mammals and humans in East and Southeast Asia.

More than 50 species occur worldwide, but not all become sexually mature in humans.

P. westermani occurs as a diploid, triploid, and occasionally tetraploid species.

In the diploid form (22 chromosomes), two adults are enclosed in a lung cyst and insemination is reciprocal.

The triploid form (33 chromosomes) found in East Asia is sympatric with the diploid species, has aberrant spermatogenesis, and therefore propagates through parthenogenetically developed eggs.

The single adult in a lung cyst is larger than the diploid worm and produces more eggs (Figure65).

The first intermediate hosts in Malaysia, Thailand and the Philippines are snails of the superfamily *Cerithoidea* with the family *Thiaridae* (Thiara, Melanoides) and the related *Semisulcospira libertina* in China, Japan, Korea and Taiwan.

Microcercal cercariae develop in the redia.

The cercariae, which are poor swimmers, because of their small tip-like tails, penetrate the crabs. Encysted metacercariae are found in the organs and muscles of the crabs.

The metacercariae have a very characteristic morphology.

The definitive hosts are mammals, which feed on freshwater crabs.

Humans become infected by eating infected crabs.

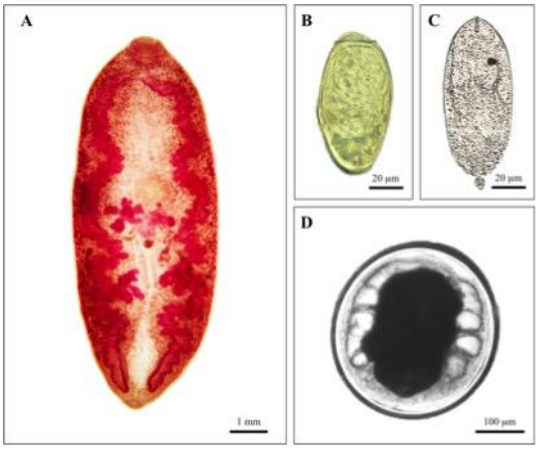


Figure 65 Paragonimus westermani A adult, B egg, C cercaria, D metacercaria

1.2.7 *Dicrocoelium dendriticum (family Dicrocoeliidae)*

The lesser liver fluke (in contrast to the greater liver fluke *F. hepatica*)

Dicrocoelium inhabit the bile duct, gallbladder and pancreatic duct of reptiles, birds and mammals.

Dicrocoelium almost all have terrestrial life cycles. Therefore their eggs are laid embryonated and must be eaten by the first intermediate host, which is a snail.

Arthropods always serve as second intermediate hosts.

D. dendriticum lives in the gallbladder of even-toed ungulates and occasionally other herbivorous mammals (Figure 66).

Humans can be infected, but very rarely.

The eggs are eaten by terrestrial and xerophilous snails

The cercariae migrate to the respiratory chamber of the snail forming a sphere of about 1 mm in diameter enveloped in solid mucus. These mucus balls are apparently very attractive to some ants of the genus *Formica*. The ants feed on the mucus balls.

The cercariae migrate to the subesophageal ganglion and transform into ametacercariae; then they migrate backwards and settle in the hemocoel of the abdomen, where they encyst to become true metacercariae.

The prepatent period is at least 8 weeks after the worm is ingested by the definitive host and settles in the bile ducts

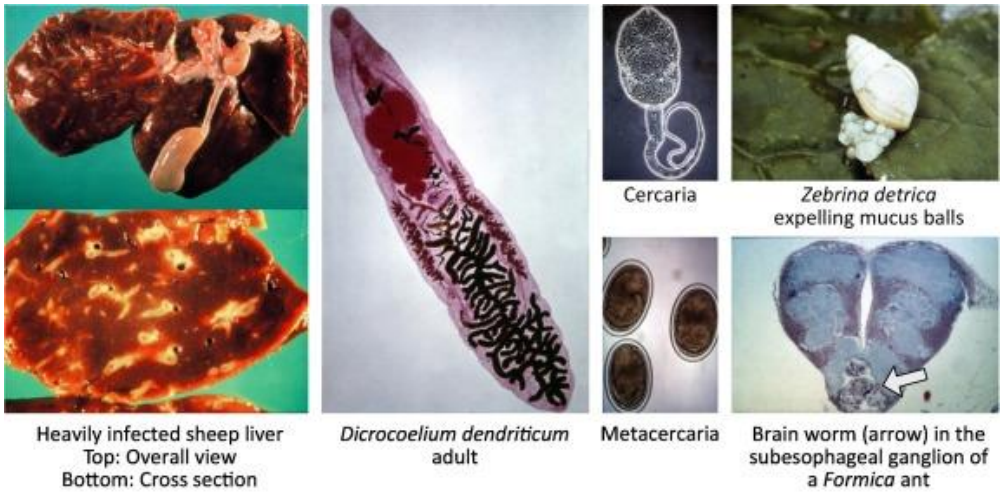


Figure 66 Dicrocoelium dendriticum

2 PHYLUM OF NEMATODA –ROUNDWORMS-

General characteristics:

- A complex three-layered cuticle
- The absence of circular muscles
- The absence of protonephridia
- Sperm without flagella
- About 50% of species live in marine environments and 25% live in soil.
- Some species are plant pests and others are parasites of animals.
- They do not present as ectoparasites. This is probably due to the absence of body appendages that would allow anchoring to the skin or fur.
- Nematodes have a round, spindle-shaped and uniform shape (Figure 67).
- Nematodes lay their eggs which contain the first juvenile stage called larva.
- The term larva is not accurate, because there is no fundamental difference between larva and an adult worm and no true metamorphosis takes place.
- Nematodes go through four larval stages, L1–L4. What is sometimes called the L5 stage is not a larval stage, but a juvenile adult.
- To progress from one larval stage to the next, worms go through a molting process called ecdysis.
- A larva that has not shed its cuticle by the time it progresses to the next stage is called a sheathed larva

- Nematode species that are considered as animal parasites are dispersed in different nematode families and genera:

  Following is the systematic position of most nematode species:

- *Dorylaimea (class)*
  - ➢ *Mermithida (order)*
  - ➢ *Trichocephalida (order)*
    - ❑ *Trichinelloidea (superfamily)*
- *Capillariidae (family)*
- *Trichinellidae (family): (vivipare) : **Trichinella spiralis** (trichine), T. pseudospiralis, T. nativa, T. britovi, T. nelsoni, T. papuae, T. murelli, T. zimbabwensis*
- *Trichuridae (family): **Trichuris trichiura** (trichocéphale), Capillaria philipinensis*
- *Chromadorea (class)*
  - ❖ *Rhabditica (superorder)*
  - ➢ *Panagrolaimida (order)*
  - ✓ *Strongyloidoidea (superfamily): **Strongyloides stercoralis***
  - ✓ *Strongyloidea (superfamily)*
- *Ancylostomatidae (family): Ancylostoma duodenale, Necator americanus*
- *Metastrongylidae (family): Angiostrongylus cantonensis*
- *Trichostongylidae (family): Haemonchus contortus, Dictyocaulus viviparus*
  - ➢ *Spirurida (order)*
  - o *Ascaridina (suborder)*
  - ✓ *Ascaridoidea (superfamily)*
- *Ascaridae (family): Ascaris lumbricoides, A. suum, Toxocara canis*
- *Anisakidae (family): Anisakis, Anisakis simplex*
  - o *Dracunculina (suborder)*
  - ✓ *Dracunculoidea (superfamily): Dracunculus medinensis*
  - o *Oxyurina (suborder)*
  - ✓ *Oxyuroidea (superfamily)*
- *Oxyuridae (family): **Enterobius vermicularis**, Oxyuris equi*
  - o *Sprirurina (suborder)*
  - ✓ *Filarioidea (superfamily)*
- *Filariidae (family): parasites of animals*

- *Onchocercidae (family): Onchocerca volvulus,* ***Wuchereria bancrofti****, Bugia malayi, Loa loa, Dirofilaria immitis*

In the class *Chromadorea*, L3 is the infective stage for the definitive host, while in the class *Dorylaimea*, parasites of vertebrates, L1 is the infective stage.

Most nematodes are oviparous. Only *Trichinella* and the filariae of the family *Onchocercidae* are viviparous.

- Hosts are invaded by several routes:
  - ✓ By ingestion of embryonated eggs (e.g., *Ascaris*), developed larvae (*Haemonchus*), or an intermediate host (e.g., *Dracunculus*)
  - ✓ By percutaneous larval invasion (e.g., *Ancylostoma*)
  - ✓ By larval injection via blood-sucking arthropods (e.g., *Wuchereria*)
  - ✓ Rarely by prenatal larval infection of the fetus (e.g., *Toxocara*)
  - ✓ By ingestion of nonobligate paratenic hosts, in which L3 stages remain unchanged and accumulate, facilitating infection of the definitive host (*Anisakis*).

Parasitic nematodes are usually colorless.

They measure from 1.5 mm (*Trichinella spiralis*) to 1 m (*Dioctophyme renale*) or even 9 m in length (*Placentonema gigantissima* in the placenta of sperm whales).

Nematodes are long, thin, round, unsegmented and bilaterally symmetrical.

The anterior mouth opening is connected to the posterior anus by a straight unbranched intestine.

The body cavity is a pseudocoelom filled with fluid under high hydrostatic pressure.

There is no circulatory system.

Two excretory ducts run along each side of the body, emptied by an excretory pore near the head.

Gender dimorphism is generally present: females are generally larger than males.

Eutelia (constant number of cells in the body) that no repair is possible after injury.

Nematode eggs are easily distinguished from eggs of other parasitic worms. Their shape is elliptical and the two poles are symmetrical (except in rare cases where an operculum is formed). The shell may be thick or thin. Usually, the eggs are very durable and resistant.

In *Trichuris* and *Capillaria*, the shell contains openings at both ends, which are blocked by a plug of chitinous microfibrils

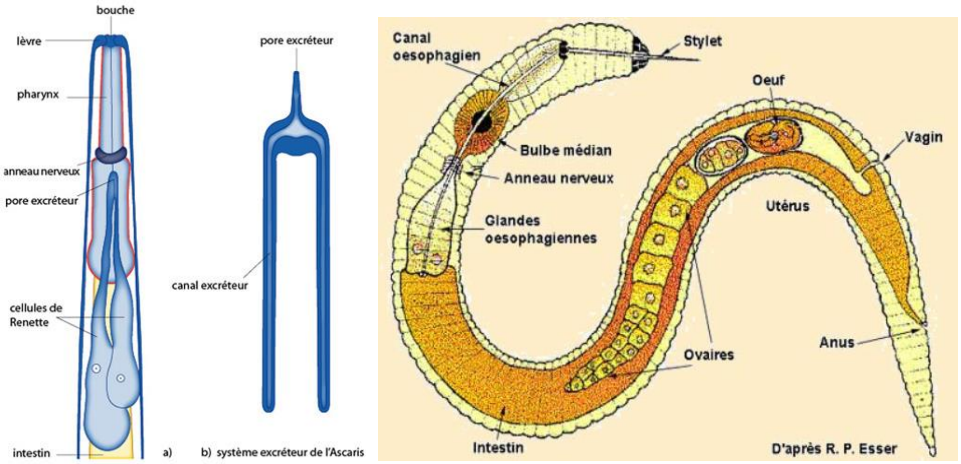


Figure 67 Structure of nematodes

2.1 Dorylaimea

- The class *Dorylaimea* (sometimes called *Dorylaimida*) contains the large order *Trichocephalida*, with its families *Capillariidae*, *Trichinellida*e, and *Trichuridae*.
- Characteristics of this order are:
  - ✓ L1 infects the vertebrate host.
  - ✓ A stylet in the wall of the esophagus, the odontostyle.
  - ✓ Presence of a secretory organ, the stichosome.
  - ✓ Presence of two testes and a single ovary.
  - ✓ Absence of special sensory organs, the phasmids.
  - ✓ Filiform tension receptors (metanemes).
- Capillariidae, sometimes called hairworms, are extremely long and slender nematodes, many of which are parasites of poultry with earthworms as intermediate hosts.
- *Calodium hepaticum*, formerly *Capillaria hepatica*, a parasite of rodents and other mammals, must first infect a host, where the worms mature into adults in the liver. They produce eggs that remain in the liver. The infective eggs are then passed in the feces, or in the other case, eaten by a predator when the host dies and decomposes.
- In humans, serious disease can occur by infection through eggs passed by urban rats.

2.1.1 *Trichinella spiralis*

- Agent of trichinellosis in humans
- The genus *Trichinella* is very unusual in that all infected host individuals are definitive hosts that harbor adult worms in their intestines and then become intermediate hosts carrying L1 stages in their muscles, ready to infect another definitive host.
- *Trichinella* is viviparous. The host is infected by injection of contaminated meat with encapsulated L1.
- Morphologically, *Trichinella* is characterized by the structure of the pharynx, the long posterior part of which is called the **stichosome**
- Females measure 4mm and males 1.5mm in length.

2.1.2 *Trichuris trichiura*

- The human whipworm that causes Trichuriasis
- Measures a few millimeters, lives embedded in the wall of the caecum (Figure 68)
- It can exist in the human body for many years without manifesting itself
- When more than 100 worms are present, hemorrhages, diarrhea and sometimes intestinal prolapse can develop
- The worms have a long, threadlike anterior end and a thick, short posterior end
- Other species of the genus are *Trichuris vulpis* in dogs, *Trichuris ovis* in sheep and *Trichuris suis* in pigs.
- Contamination occurs through ingestion of eggs.

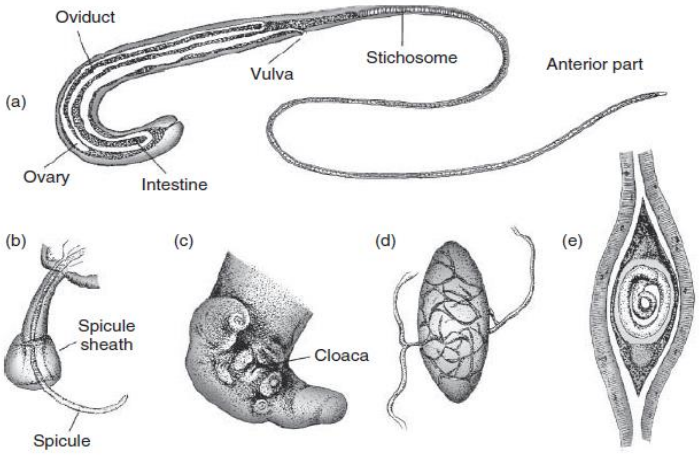


Figure 68 Trichinellidae: (a) Trichuris trichiura, femelle, (b) Trichuris trichiura, extrémité postérieure du mâle, (c) Trichinella spiralis, extrémité postérieure du mâle, (d) larve musculaire de Trichinella spiralis, complexe cellulaire nourricier entouré de vaisseaux sanguins, (e) Trichinella spiralis

The other *Trichinella* species are demonstrated in table 10 with their charcteristics.

Table 10 Species of the genus Trichinella. Human infections are possible with all species, but have not been demonstrated for T. zimbawensis. T. native is highly pathogenic to humans.

Species	Genotype	Hosts	Type of Cycle	Geographical Distribution	Cyst Wall Present
T. spiralis	T1	Pig, carnivores, rats (rarely birds)	Urban and sylvatic	Cosmopolitan	+
T. nativa	T2 + T6	Carnivores, bear, walrus, rodents	Sylvatic	Arctic, subarctic (holarctic)	+
T. britovi	T3	Carnivores, also horse, rodents, insectivores	Sylvatic	Temperate regions down to West Africa	+
T. murelli	T3	Carnivores, bear, horse	Sylvatic	Nearctic temperate regions	+
T. nelsoni	T7	Carnivores, hyena, lion, warthog	Sylvatic	Africa	+
T. pseudospiralis	T4	Birds and mammals	Sylvatic	Cosmopolitan	–
T. papuae	T10	Mammals, reptiles	Sylvatic	Papua New Guinea, Africa	–
T. zimbabwensis	T11	Mammals, reptiles, man?	Sylvatic	Zimbabwe	–

2.2 Chromadorea

The class *Chromadorea* contains the majority of nematode parasites of vertebrates.

- The characteristics of *Chromadorea* are:
  - ✓ L3 infects the vertebrate host
  - ✓ Presence of a single testis
  - ✓ Presence of particular sensory organs in the tail region, phasmids
  - ✓ Location of amphids (sensory invaginations, innervated by the cuticle) on the lips

- ✓ Absence of caudal glands

2.2.1 *Strongyloides stercoralis*

A nematode of humans occurs in tropical and subtropical regions (Figure 69).

It causes problems in immunocompromised individuals or patients receiving immunosuppressive therapy.

In some circumstances, infection can be fatal.

The parasite inhabits the mucosa of the upper small intestine.

S. stercoralis has no intermediate host.

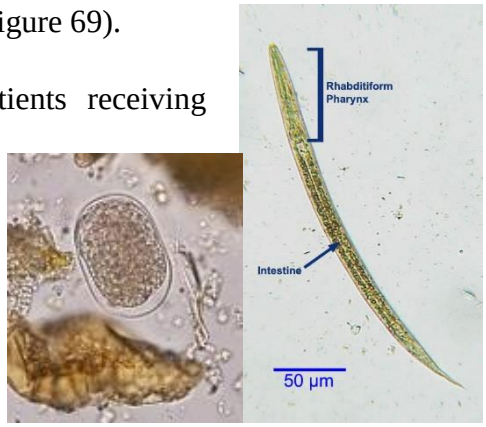
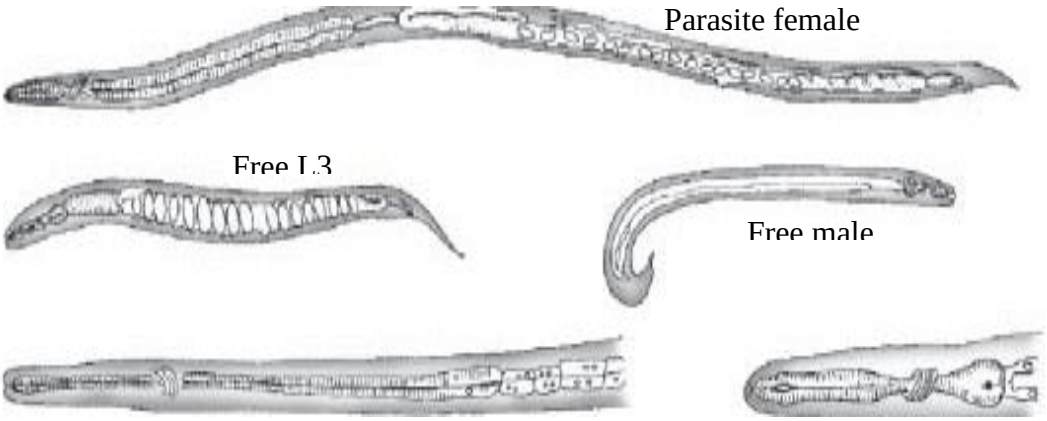


Figure 69 Strongyloides stercoralis a: egg, b: adult female

- It has two life cycle phases (Figure 70):
    1. Free living phase: occurs directly after throwing eggs with the host's stools, the reproduction is sexual.
    2. Parasitic phase: occurs after the penetration of a free L3 filariform, from contaminated soil, through the host's skin, the reproduction is parthenogenetic.

The parasitic phase begins when L3 filariforms invade the body, usually through the feet.

- Parthenogenetic females in the intestine are 2.1–2.7 m long.
- The infective filariform L3 is 490–630 µm long, the rhabditiform L1 passed in the feces is 180–240 µm long.
- The eggs are thin-shelled and embryonated.
- They measure 54 × 32 µm.



Anterior end of filariform larva with typical esophagus

Anterior end of rhabditiform larva with typical esophagus.

Figure 70 Strongyloides stercoralis forms

2.2.2 *Ancylostoma duodenale and Necator americanus*

Human hookworms are of great importance in tropical and subtropical regions (Figure 71):

- They inhabit the small intestine.
- Eggs are excreted at the two- to eight-cell stage and embryonate in the feces.
- The worms are curved at the anterior end, giving them a hook shape.
- L1 and L2 feed on bacteria and excrement found in the soil.
- The infective L3 is enveloped by the sheath of the second-stage larva. It actively migrates into the upper soil layers, invades the host percutaneously, usually in the feet, sheds its sheath and enters the subcutaneous blood and lymphatic vessels.
- The prepatent period is 3-4 weeks
- *N. americanus* can live up to 15 years
- Here is a table based on the provided content:

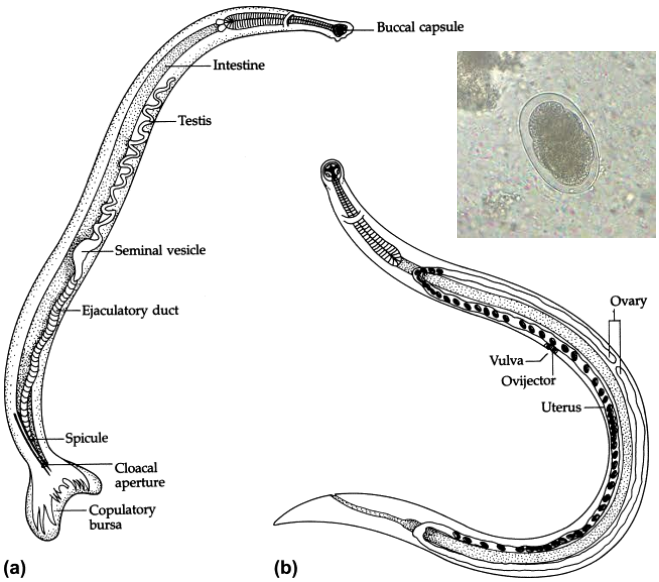


Figure 71 Ancylostoma duodenale a: male, b: female, c: egg

Below is a comparative table highlighting the key differences between the two significantly human pathogen hookworms *Ancylostoma duodenale* and *Necator americanus* in terms of their distribution, morphology, and biological characteristics (Table 11).

Table 11 Differences between Ancylostoma duodenale and Necator americanus in term of distribution, morphology and biology

Characteristic	_*Ancylostoma duodenale*_	_*Necator americanus*_
Distribution	Subtropical: South Europe, northern Africa, Middle and Far East	Tropical: Southern USA, Latin America, Africa south of the Sahara, India, Southeast Asia, Oceania
Female length	10–13 mm	9–11 mm
Male length	8–11 mm	7–9 mm
Mouth capsule	Two pairs of ventral teeth on the anterior margin directed inward	Two dorsal cutting plates directed downward
Vagina	In posterior third	Shortly in front of middle
Eggs size	50–80 × 36–42 µm	64–75 × 36–40 µm

Prepatent period	38–74 (53) days	44–46 days
Larval development (temperature)	At 22–26 °C	At 31–44 °C

2.2.3 *Angiostrongylus cantonensis*

They are pulmonary parasites of animals.

The final hosts of *Angiostrongylus cantonensis* are rats, the intermediate hosts are snails and slugs, in which third-stage infective larvae develop.

L3s migrate into the definitive host through the intestinal wall and blood vessels into the brain and then into the pulmonary artery, where they mature into adults.

Females are 17–34 mm Males 15–25 mm L3s 425–524 μm long.

Eggs hatch in the lungs and first-stage larvae are transported via the trachea to the intestine and are passed in the rodent feces.

When taken up by the intermediate host, they develop into infective L3s.

Humans become infected by eating raw or undercooked intermediate hosts.

2.2.4 *Haemonchus contortus*

The red stomach worm *Haemonchus contortus*, also called wireworm or barberworm, is a parasite mainly of sheep and goats, more rarely of cattle.

It is one of several species that cause parasitic gastroenteritis in domestic ruminants.

The prepatent period is between 12 and 24 days.

The eggs are excreted by the host in the morula stage and embryonated in the faeces.

The first two larval stages (rhabditiform) feed on bacteria in the faeces.

The sheathed, filariform, infective L3 resulting from the second moult after 5 days is very active, leaves the faeces and crawls upwards on damp grass blades

When taken orally by a suitable host, it sheds its sheath and moults to become a blood-sucking L4.

Adults also suck blood.

2.2.5 *Dictyocaulus viviparus*

Unlike other *Trichostrongylidae*, this species inhabits the lungs of cattle.

In this infection, parasite eggs that have passed from the bronchi to the trachea are coughed up and swallowed.

From these eggs, L1s hatch while still in the intestine and develop into L3s in the feces.

L3s are dispersed throughout the pasture by the fungus *Pilobulus* which spreads its own spores by an explosive mechanism, a mechanism that increases the chances of reaching the coprophobic bovine host.

Protection against *D. viviparus* can be achieved by the use of a live irradiated L3 vaccine.

2.2.6 *Ascaris lumbricoides*

Giant roundworm, one of the most known cosmopolitan parasites of humans (Figure 72)

Females measure 30 to 40 cm

In fact, Ascariasis occurs in all areas where soil moisture is sufficient.

The development of the zygote in the egg only begins when the egg is excreted with the feces and sufficient oxygen is available

To reach L3 it takes 8 to 10 days in tropical environments and 16 to 18 days in temperate regions.

The L3 pierces the intestine and settles in the liver where it molts into L4, then it migrates to the lungs after 12 days the larvae are transported with the mucus in the trachea and then swallowed.

In the small intestine, they molt into adults. They live from 6 to 18 months.

They are extremely resistant to strong chemicals and low temperatures, but are destroyed by desiccation.

Naturally, children who play on the floor are at greatest risk and most seriously infected, although Ascariasis often occurs as familial infections.

2.2.7 *Ascaris suum*

The large Ascarid of pigs, it is present in a high percentage of pigs, even when extensive anthelmintic treatment is given.

The biology, morphology and pathology are essentially the same as in *A. lumbricoides*. *A. suum* is considered a sister species of *A. lumbricoides*.

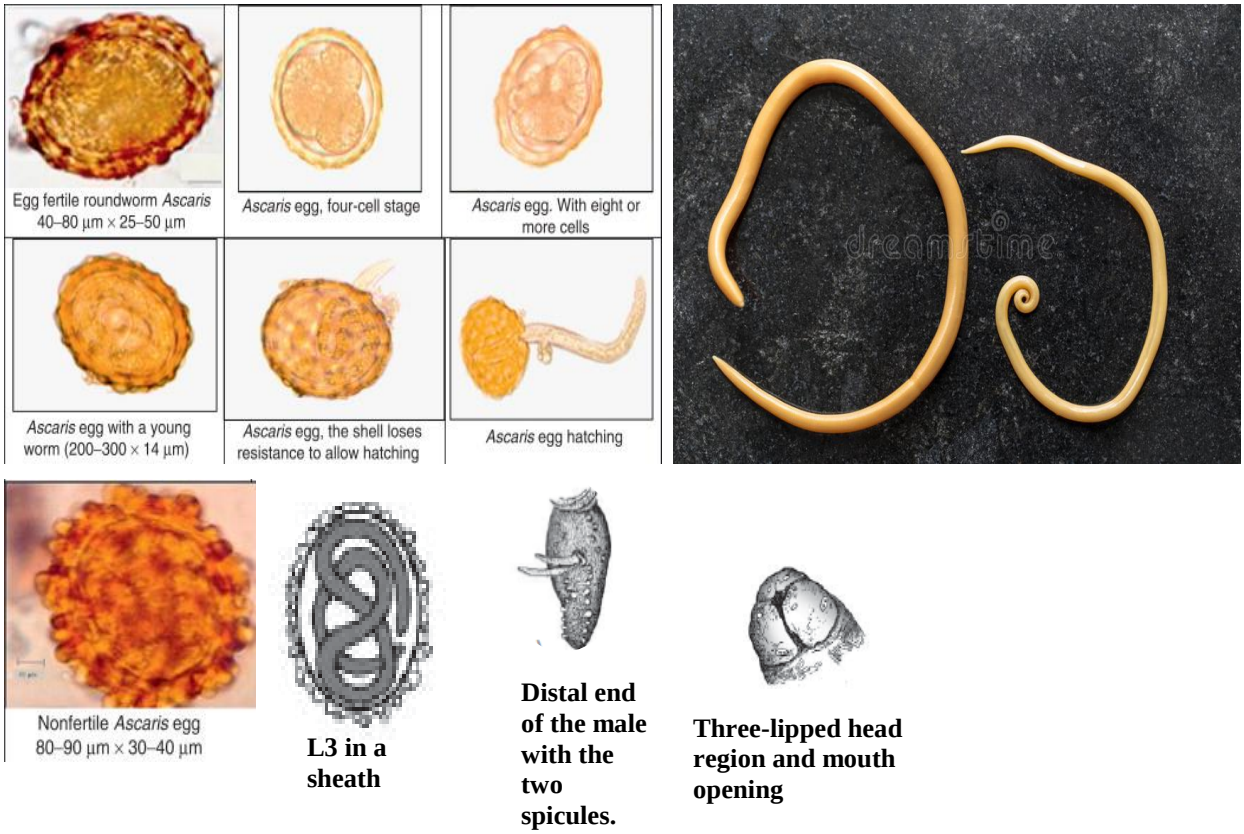


Figure 72 Ascaris lumbricoides: different stages

2.2.8 *Toxocara canis*

The dog roundworm *Toxocara canis* is also a member of the *Ascaridae* family and has a worldwide distribution.

It is of medical importance, because in humans (paratenic hosts) the larvae can cause damage, especially to the eyes.

Females are 6.5–10 cm, males 4–6 cm long.

Eggs are 75–90 µm and have a net-like surface.

2.2.9 *Anisakis simplex and Anisakis spp.*

Herring worms are of some importance for food hygiene, humans can be intermediate hosts when eating raw fish dishes.

Adult worms inhabit marine mammals such as whales, seals or dolphins.

The eggs embryonate in seawater and release a second stage larva.

Some crustaceans are the intermediate hosts (development in L3 -2 to 3 cm-)

Following the ingestion of contaminated fish, nausea and vomiting can occur within a few hours and the larvae can be regurgitated.

If the larvae penetrate the stomach or intestinal wall, severe intestinal symptoms can occur 1 or 2 weeks later

2.2.10 *Dracunculus medinensis*

Guinea worm that causes Dracunculiasis, a tropical disease that has been completely eradicated, but there is no evidence that the parasite has disappeared.

The infective L3 and L4 of *Dracumculus medinensis* migrate through the human body until they reach sexual maturity (Figure 73).

At their final destination, the male worms, which are only 30 to 40 mm long, die after fertilizing the females.

Females are viviparous, very long and threadlike, measuring 0.8 to 1 m

The female lives in the subcutaneous tissue, mainly in the extremities.

A year after infection, the female induces a blister on the host's skin, just above the vulva in the region of the female's head.

The vesicle contains thousands of L1 and bursts upon contact with water.

The blister then turns into an ulcer that releases larvae each time it is immersed in water.

Ingested afterwards by small crustaceans

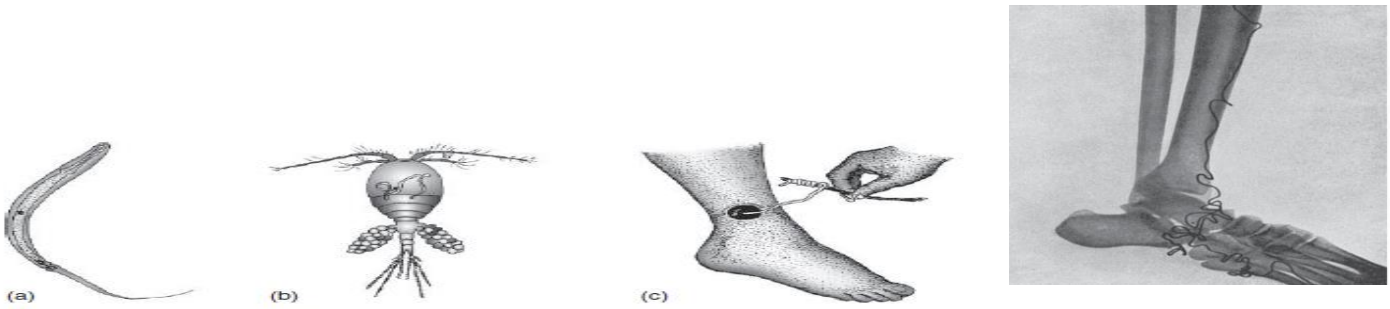


Figure 73 Dracunculus medinensis. (a) L1 released in the water. (b) L3 in the body cavity of a copepod. (c) Extraction of a female worm.

2.2.11 *Enterobius vermicularis*

It is a pinworm of the family *Oxyuridae* contains medium-sized nematodes, parasites of the digestive tract of invertebrates and mainly herbivorous vertebrates, with a direct single-host life cycle. The infective larva develops in the external environment.

The pinworms are characterized by a strong pointed posterior end of the females

It is a common intestinal parasite of humans,

It has a worldwide distribution with about 200 million people infected, most of them children.

Females are 8–13 mm long, males only 1–4 mm.

Males have a truncated bursa copulatrix and a tiny spiculum of 70 μm.

The eggs measure 50–60 × 20–30 μm and are flattened on one side

2.3 Filariae

The nematodes of the superfamily *Filarioidea* are commonly called filariae. This worms are long and threadlike, and inhabit tissues or body cavities, but never the intestine.

Other features:

- They do not lay eggs but give birth to larvae called microfilariae.
- These are transmitted by blood-sucking arthropods, mainly insects (rarely mites).
- While the family *Filariidae* contains parasites of veterinary importance, the *Onchocercidae* include all the important human filarial parasites (human filariasis).
- Adult worms are long-lived

2.3.1 *Wuchereria bancrofti and Brugia malayi:*

They occur in Asia, causing human lymphatic filariasis (elephant's foot).

They are transmitted by mosquito species of the genera *Culex, Aedes, Anopheles, Mansonia* and (only for *Wuchereria bancrofti*) *Coquillettidia*,

Adults of W. bancrofti and *B. malayi* are very similar.

Females are 65–100 mm long and 0.2–0.3 mm thick, males are smaller, measuring 40 × 0.1 mm.

Microfilariae of the two species can be differentiated on blood smears. They are sheathed and measure 290 μm (*W. bancrofti*) and 222 μm (*B. malayi*).

2.3.2 *Onchocerca volvulus*

This species is the causative agent of river blindness in humans and is present in Africa, particularly in the Volta Basin, less frequently eastwards to Sudan and Tanzania, and southwards to Angola

The intermediate hosts of *Onchocerca volvulus* are dipteran *Nematocera* of the family *Simuliidae*, black flies

The female worm is 20–70 cm and can live 9–11 years

Males are 3–12 cm long

2.3.3 *Loa loa and Dirofilaria immitis*

Loa loa also called African eyeworm,

Transmitted by two species of deer flies (*Tabanidae)* of the genus *Chrysops, Chrysops silacea* and *Chrysops dimidiata*, also called mango flies or mangrove flies

Females measure 57 mm, males 34 mm.

Dirofilaria immitis, the heartworm, lives in the pulmonary arteries and sometimes in the right ventricle of the heart of its definitive host, the dog (cat).

Transmitted by mosquitoes (*Aedes, Culex, Anopheles, Mansonia*)

Adult females measure 230–310 mm long

3 PHYLUM OF *ARTHROPODS*

3.1 Class *Arachnida* (Acari)

General characteristics:

- Free-living or parasitic arachnids, usually tiny in size.
- The body consists of two parts: a complex of mouthparts (gnathosoma) and an unsegmented idiosoma containing the intestine and reproductive organs.
- A pair of spiracles (except in astigmata) (Table 12).
- Six-legged larva, several stages of eight-legged nymph
- Parasitic forms are usually ectoparasites.
- After the egg, there are up to six stages of development with a molt between each, as follows:
    1. A hexapod (six-legged) pre-larva inside the eggshell.
    2. A hexapod larva.
    3. Three stradia of octopod (eight-legged) nymphs without visible genitalia externally (protonymph, deutonymph, tritonymph).
    4. Fully developed adult octopods (Figure 74).
- Some of the immature stages may be missing in some groups.

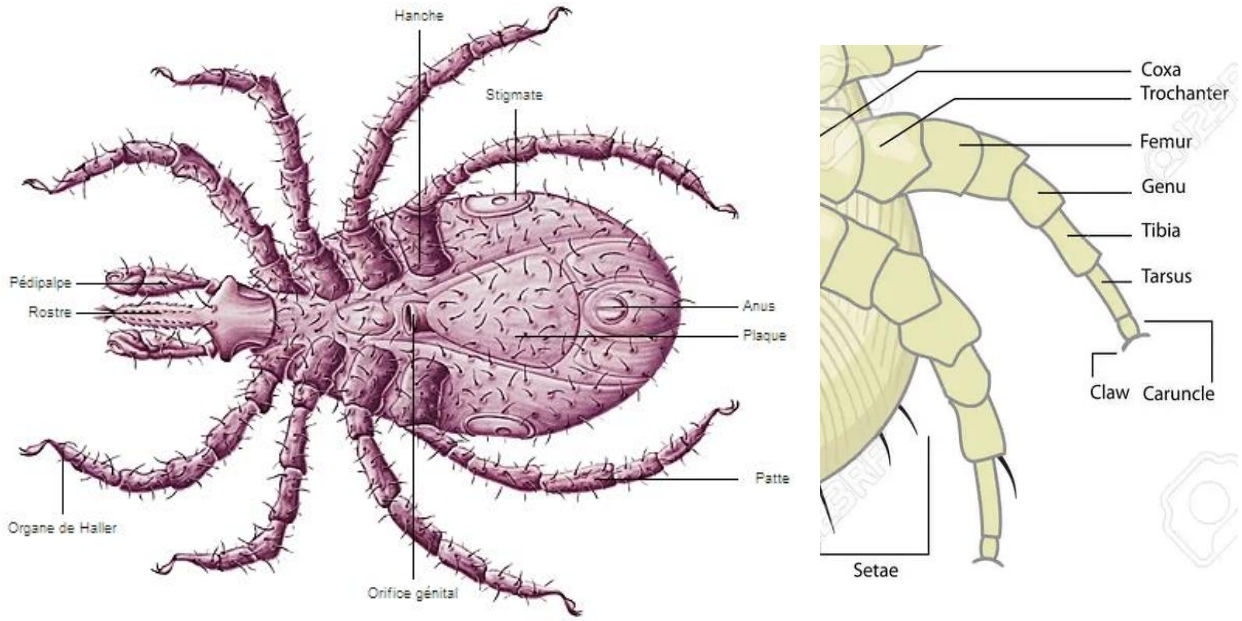


Figure 74 Anatomy of Acari adult

Table 12 Classification of Acariformes and Parasitiformes: Morphological Elements and Alternative Taxonomic Groupings"

Super	Or	Morphological	Other possible
Acariformes	O. Oribatida	Cryptostigmates	s/O Sarcoptoidea
	O. Astigmata	Astigmates	
	O. Prostigmata	Prostigmates	s/O Trombidoidea
Parasitiformes	O. Mesostigmata	Mésostigmates	s/O Gamasoidea
	O. Ixododida	Métastigmates	s/O Ixodoidea

3.1.1 *Demodex – Acariens du visage*

The family *Demodecidae* includes tiny mites that live on and in the skin of mammals, including humans (*Demodex folliculorum*, *Demodex brevis*, *Demodex canis*).

There are more than 65 species, but only two species have been described in humans: D. folliculorum, mainly located on the face, and D. brevis, a smaller species located in the sebaceous glands of the thorax.

3.1.2 *Trombiculidae - Harvest mites, Augustats:*

Figure 75 Neotrombicula autumnalis

Trombiculidmite larvae are known as harvest mites, or itch mites. They cause intense itching reactions and dermatitis in their hosts. Adults and deutonymphs are free-living and protonymphs are parasitic.

Neotrombicula autumnalis: parasitizes a range of birds and mammals, will attack humans at harvest time in early autumn (Figure 75)

Trombicula alfreddugesi: American harvest mites, attacks humans.

Leptotrombidium deliense: transmits scrub typhus

3.1.3 Order *Anactinotrichida (= Parasitiformes)*

3.1.3.1 Sub-order *Mesostigmata*

Mostly free-living oranisms; the parasitic species are parasites of terrestrial vertebrates, some residing in the respiratory tract.

Spiracles position between coxae III and IV, lacking in larva (Figure 76).

The peritreme is narrow, usually projected forward.

Developmental stages: six-legged larva, protonymph, deutonymph, adult.

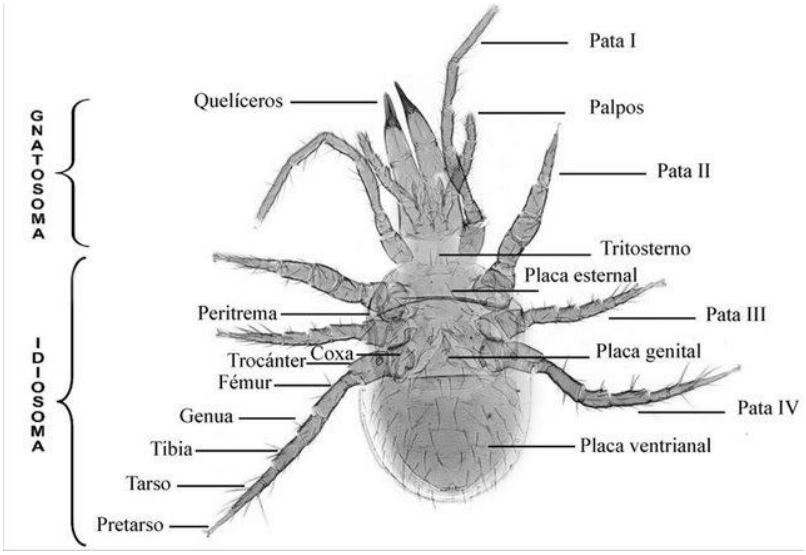


Figure 76 Morphology of Mesostigmata

3.1.3.1.1 *Dermanyssus gallinae*

The poultry red mite can cause serious damage.

If suitable hosts are not available, the mite will attack humans and cause a skin disease.

Since the mite is nocturnal, it can be neglected for some time until the hosts become restless and produce less blood.

During the day, the mites hide in cracks and crevices and are easily overlooked.

The larva does not feed, but the nymphs and adults feed on blood.

3.1.3.1.2 *Pneumonyssus simicola*

It is a pulmonary parasite of the rhesus monkey.

3.1.3.1.3 *Sternostoma tracheaculum*

It is a respiratory parasite of canaries and Gouldian finches.

3.1.3.1.4 *Ornithonyssus bacoti (= Bdellonyssus)*

The tropical rat mite, is a parasite of many wild rodents that can live on humans. Morphologically, it closely resembles *Dermanyssus gallinae* (identification requires a specialist). It is an intermediate host of the filaria *Litomosoides carinii*

3.1.3.1.5 *Varroa destructor*

Ectoparasite of the honeybee:

- It is a devastating pest of bees causing "varroosis".
- It has a major economic impact on the beekeeping industry.
- It is encountered in Asia with the sister species *Varroa jacobsoni*

3.1.3.2 Sub-order *of Metastigmata ((= Ixodida or Ixodoidea, Ticks)*

Ectoparasites of vertebrates :

- All stages of the life cycle are obligate haematophagous ectoparasites of terrestrial vertebrates.
- Stigmata position behind coxae IV, not present in larvae.
- Peritrema round or oval, surrounding the stigma.
- Hypostome with strong teeth facing backwards.
- Haller's organ dorsally on tarsus I.
- Life stages: six-legged larva, nymph(s), adult.

- Vectors of many diseases.
- The Ixodida, or ticks, are the only group of mites consisting exclusively of obligate haematophagous parasites.
- They are the largest mites and fully fed females of tropical species can measure up to 30 mm.
- About 900 species are known from a wide range of hosts.
- Some ticks are brightly colored while most are brown or buff.
- Ticks cause toxicoses and dermatoses by their physical presence
- They transmit viruses, bacteria, protozoa and nematodes, which cause disease in their hosts.
- Ticks consist of three families with many biological and morphological differences between them (Table 13):

1. Ixodidae (hard ticks) with 14 genera (Figure 77),
2. Argasidae (soft ticks) with six genera,
3. Nuttalliellidae with one species (*Nuttalliella namaqua*) in Africa.

- They spend part of their life on the ground (moulting), and another part anchored on the skin of the host
- After mating, the male dies; the female dies after laying eggs
- Species are classified according to the type of habitat:

Famille Ixodidae « Tique dure »

Prostriata

Sous-famille Ixodinae

✓ *Ixodes*

Ixodes ricinus

Metastriata

Sous-famille Rhipicephalinae

- ✓ *Dermacentor*
- ✓ *Hyalomma*
- ✓ *Rhipicephalus*
- ✓ *Cosmiomma*
- ✓ *Anomalohimalaya*
- ✓ *Margaroporus*
- ✓ *Nosomma*
- ✓ *Rhipicentor*

Dermacentor reticulatus

Sous-famille Amblyommidae

✓ *Amblyomma*

Amblyomma variegatum

Sous-famille Haemaphysalinae

✓ *Haemaphysalis*

Haemaphysalis leporispalustris

Sous-famille Bothriocrotinae

✓ *Bothriocroton*

Bothriocroton hydrosauri

1. Hygrophilous species (from humid environments);
2. Xerophilous species (from dry environments).

- The life cycle is called "triphasic", three meals and two moults; with three parasitic phases: larva, nymph, adult.
- Other species are:
  1. "diphasic" when it only has two parasitic phases (the phase: larva-nymph, the adult phase)
  2. "monophasic" when the tick completes its entire development cycle (three meals and two moults) on the same host individual.

Famille Argasidae « Tique molle »

Sous-famille Argasinae

✓ *Argas*

Argas reflexus

Sous-famille Ornithodorinae

✓ *Ornithodoros*
✓ *Antricola*
✓ *Carios*
✓ *Otobius*
✓ *Nothoaspis*

Ornithodoros savigny

Famille Nuttalliellalidae

✓ Nuttalliella
N. namaqua

Nuttalliella namaqua

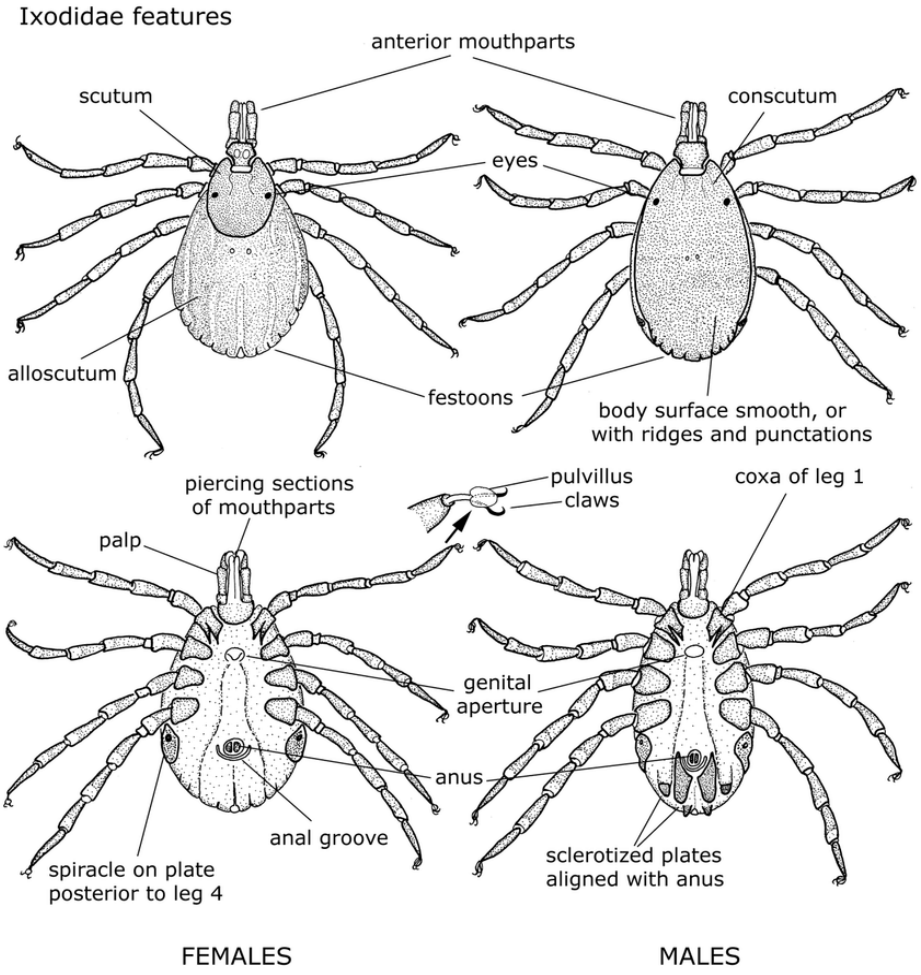


Figure 77 Morphology of Ixodidae

Table 13 Important characteristics of ticks.

Characters	Ixodidae	Argasidae
Lifestyle	Non-nidicolous	Nidicolous (Living in or near nests or burrows of hosts)
Sexual differences	Females larger than males	Equal size
Capitulum	Visible from above	Not visible from above
Shields	One dorsal shield (Scutum)	Absent
Idiosoma surface	Smooth	Leathery, tuberculate
Stigmata	Behind coxae IV	Between coxae III and IV
Peritreme	Round, oval, or elliptical	Round, small, discreet
Hypostome	Robust, with strong teeth	Thin and weak teeth
Palpal tarsi	Retracted into the tibia	Normal, visible

Pretarsal pulvillus	Present	Absent in nymphs and adults
Coxal glands	Absent	Between coxae I and II, absent in larvae
Porose area	Present	Absent
Eye position	Lateral on the scutum	Usually above and between coxae II and III

3.1.4 Ordre *Actinotrichida(= Acariformes)*

3.1.4.1 Sub-ordre *Prostigmates = Actinedida = Trombidiformes*

This group is a very heterogeneous, non-monophyletic group:

- ✓ Most are free-living
- ✓ Some are ectoparasites, and rarely endoparasites of vertebrates and invertebrates.
- ✓ Setae are often feather-like.
- ✓ Developmental stages include a six-legged larva, deutonymph, tritonymph, and adult.

3.1.4.1.1 *Demodex – Facial Mites:*

The *Demodecidae* family includes tiny mites that live on and in the skin of mammals, including humans; like: *Demodex folliculorum, Demodex brevis, Demodex canis* (Figure 78).

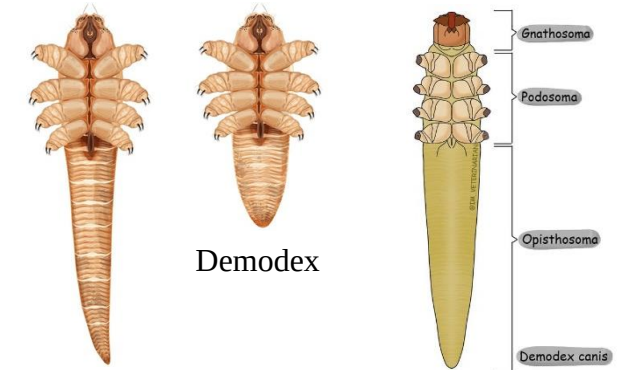


Figure 78 the three species of the genus Demodex

3.1.4.1.2 *Trombiculidae - Harvest Mites, Harvest Mites:*

The larvae of trombiculidmites are known as harvest mites, or berry bugs. They cause intense itching reactions and dermatitis in their hosts. Adults and deutonymphs are free-living and protonymphs are parasitic.

3.1.4.1.3 *Neotrombicula autumnalis:*

Parasitizes a range of birds and mammals, will attack humans at harvest time in early autumn (Figure 79).

Figure 79 Neotrombicula autumnalis

3.1.4.1.4 *Trombicula alfreddugesi:*

American harvest mites, attacks humans.

3.1.4.1.5 *Leptotrombidium deliense:*

Transmits scrub typhus.

3.1.4.2 Sub-ordre *Astigmata=Acaridida=Sarcoptiformes*

Most of them live in freedom:

- ✓ Stigmata absent.
- ✓ Often with sexual dimorphism.
- ✓ Two groups:

1. Free-living *Acaridia* or those associated with arthropods and
2. *Psoroptidia*, ectoparasites of birds and mammals.

3.1.4.2.1 *Sarcoptes – Scabies Mites:*

The family *Sarcoptidae* includes mites that live in the skin of birds and mammals and spend their entire lives in burrows in the skin.

Figure 80 Sarcoptes scabiei

They are globose with a finely striated cuticle and cutting chelicerae.

The female is tiny (300–400 μm). She burrows into the epidermis 0.5–5 mm per day using her chelicerae and legs. One to two eggs are laid per night.

The complete cycle takes 10–14 days. The lifespan is 30–60 days, during which a female will lay 40–50 eggs.

3.2 Class *Insecta*

The general characteristics of insects are:

- Body (usually visibly) divided into three parts: head, thorax and abdomen.
- Head with one pair of antennae, mandibles and maxillae.
- Often two pairs of wings (on meso- and metathorax).
- Development as incomplete (hemimetabolous) or complete (holometabolous) metamorphosis.
- Hexapod, arthropods with three pairs of legs on thorax.

- Some groups are mainly wingless, others have wings on thorax which may or may not be lost secondarily
- Life cycle is in general: egg, immature stages (larvae, pupa) –sexually immature-, adult –sexually mature-
- Some groups are obligatory parasites while others are facultative parasites.
- Some groups are chewing insects while others are hematophagous.

3.2.1 *Phthiraptera–Lice*

They are hemimetabolous strictly host-specific ectoparasites of birds and mammals; obligate, stationary, secondarily flightless, where:

- Eggs ("nits") are adhered to hairs or feathers.
- Their eggs are oval and have an operculum (lid) with micropyles (small holes) for respiration.
- During oviposition, the female secretes an adhesive onto the shaft of hairs or feathers, embedding the egg and covering it entirely except for the operculum.
- There are three nymphal stages and, as adults, they are flattened dorsoventrally.
- The eyes are reduced or absent.
- The three segments of the thorax are fused to each other.
- The legs end in claws, which may be specialized to fit the host's hairs or feathers.
- The abdomen has nine distinct segments.

Depending on their nutrition mode, it exsits two groups of lice:

3.2.1.1 *Mallophaga – bird lice or chewing lice*

They consist of two distinct groups, the Amblycera and the Ischnocera. All have mouthparts modified for chewing rather than piercing (Figure 81):

- Their heads are as wide as or wider than the thorax, and the abdominal margins are slightly smooth.
- The eggs have a hexagonal surface sculpture.
- Both groups feed on birds and mammals; 57% of species parasitize mammals and 43% birds in the Amblycera and 13% on mammals and 87% on birds in the Ischnocera.
- Some species are vectors for nematodes (*Eulimdana* spp., *Filarioidea*), while the dog louse *Trichodectes canis* serves as a host for the cestode *Dipylidium caninum*.

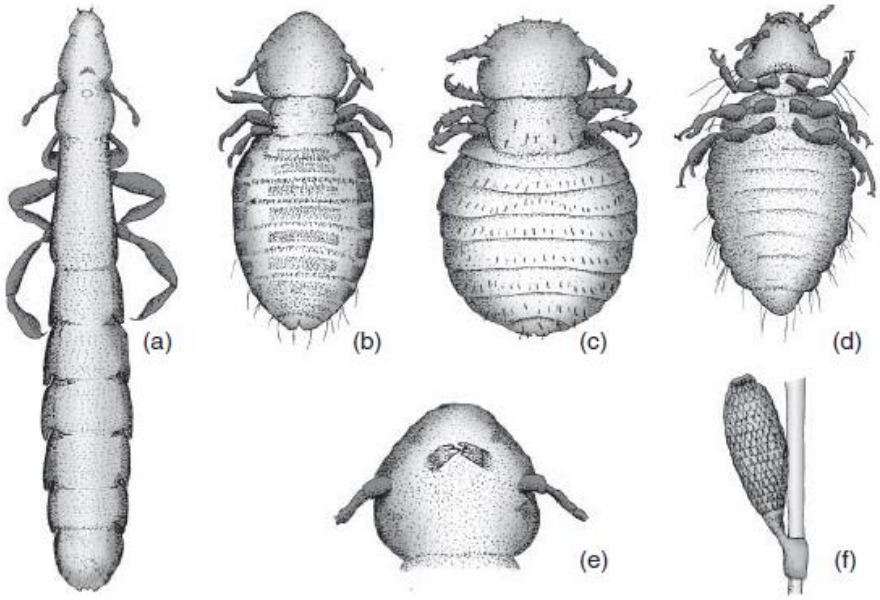


Figure 81 Phthiraptera. (a–c) Ischnocera: (a) Columbicola columbae. (b) Bovicola bovis. (c) Trichodectes canis. (d) Amblycera: Menopon gallinae. (e) Dorsal view of the head of an ischnoceran, with the mandibles visible through. (f) Egg of Trimenopon hispidus from

3.2.1.2 *Anoplura – sucking lice*

There are about 490 species strict host specificity, distributed in nine families, one of which, the *Echinophthiridae*, even lives on pinnipeds (seals), in their nostrils. They parasitize only placental mammals, as permanent, wingless parasites, physiologically adapted to the blood of their particular host:

- The three nymphal stages and adults must take a blood meal at least once, adults often several times a day.
- Adults measure 0.5 × 8 mm. Their head is narrower than the thorax and is cone-shaped in front of the slender antennae. A few species have eyes. The mouthparts are modified for piercing and sucking and are coiled in the head (Figure 82)

3.2.1.2.1 *Pediculus humanus capitis*

- The head louse (*P. h. capitis*) is on average slightly smaller than the body louse, but more oval.
- A female head louse produces about 270 eggs during her 30-35 day life
- The eggs are attached to the hair shaft mainly on the neck or behind the ears, about 1 cm from the skin in cooler climates and 15 cm or more in warmer climates.
- The life cycle lasts 17-22 days.
- Head lice do not transmit infections
- Damage is caused mainly by scratching the itchy bites and the effect of salivary proteins and other molecules on the host.

3.2.1.2.2 *Pediculus humanus humanus*

- The body louse (*P. h. humanus*) evolved from the head louse thousands of years ago when the use of clothing increased.
- Because human body hair is sparse, the body louse cannot live directly on human skin, but instead resides in clothing, only traveling to bare skin to feed.
- Eggs are laid on clothing, commonly by vagrants (who cannot change and wash their clothes regularly).
- Transmit epidemic or louse-borne typhus and other diseases
- Body lice infestations cause a striped rash with post-inflammatory brownish pigmentation, swelling, and bacterial inflammation, a condition known as "vagrant skin."

3.2.1.2.3 *Pthirus pubis*

- *P. pubis*, the pubic louse or crab louse, lives on hairs larger in diameter than those inhabited by *Pediculus*, preferentially on pubic hair and more rarely on axillary, chest or eyelash hair
- It is found only on the host, just like the head louse; and is transmitted by sexual contact.
- *P. pubis* is much larger than the head or body louse, flattened, 1.5 to 2.0 mm long, and somewhat resembles a crab
- The thoracic segments are fused and the distal legs are longer and stronger than the proximal ones. Abdominal segments 5 to 8 have cone-shaped lateral appendages, the longest on the last segment. A total of 30 eggs are laid during the 3 to 4 week lifespan of a female.

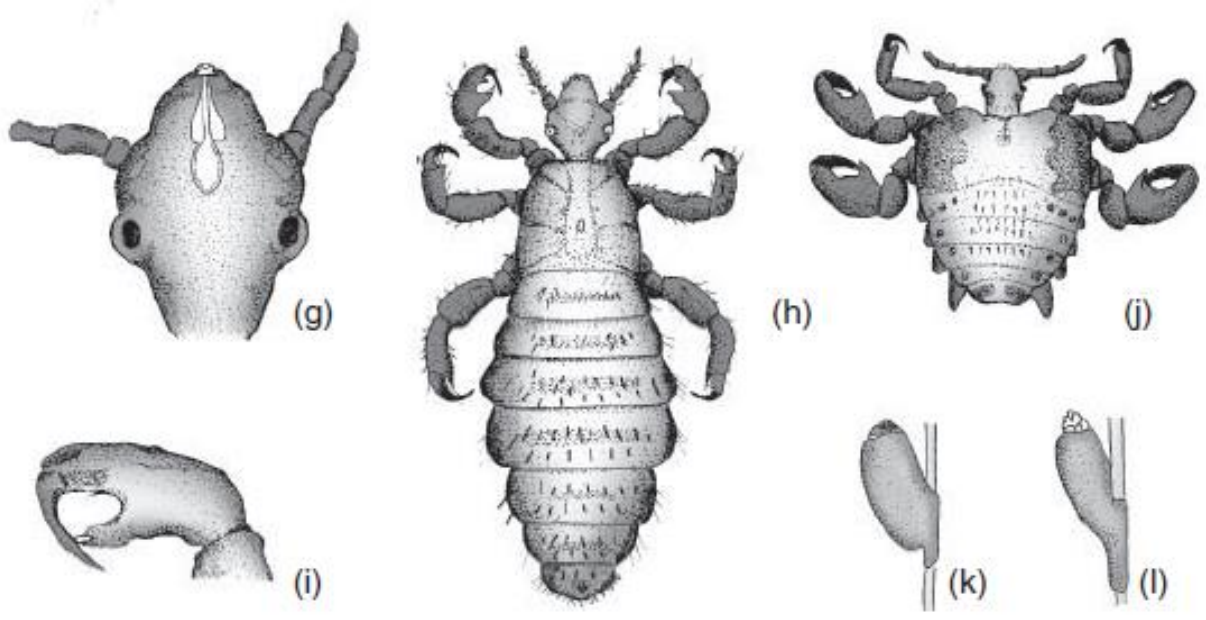


Figure 82 (g–l) Anoplura. (g) Head of a louse with piercing-sucking mouthparts visible. (h) Pediculus humanus. (i) Clasps of a louse leg, consisting of a tibia and a thorn-like tarsus. (j) Pthirus pubis. (k) Nit of P. h. capitis. (l) Nit of P. pubis.

3.2.2 *Heteroptera – True Insects*

Characteristics:

- Hemimetabolous.
- Five nymphal stages.
- Feeding mainly on plants, some feed on vertebrates.
- Both sexes feed on blood.
- Mainly include:

✓ *Reduviidae*, vectors of *Trypanosoma cruzi* in Latin America.

✓ *Cimicidae*, including the bedbug: no transmission of pathogens.

3.2.2.1 *Triatominae*

The Reduviidae (assassin bugs) contain species adapted to hunt and feed on other insects. However, a subfamily Triatominae (kissing bugs) has adapted to feed on the blood of terrestrial vertebrates from an altricial lifestyle, a common evolutionary pathway for ectoparasites:

- There are about 120 species of triatomine bugs ranging from 5 to 45 mm in length and occurring primarily in the Americas.
- All species are primarily bloodsuckers and more than half have been shown naturally or experimentally to be susceptible to infection by *Trypanosoma cruzi*, which causes Chagas disease in humans.
- The female lays 100 to 600 eggs in small batches between blood meals.

3.2.2.2 *Cimicidae – Bedbugs*

Bed bugs are a well-defined group of oval, flattened insects that inhabit "nests" or resting sites and feed on the blood of birds, bats, and humans:

- There are about 100 species, two of which feed on humans.
- Some species are pests of poultry (*Cimex lectularius*, *C. hemipterus*, *C. columbarius*), causing severe irritation, anemia, and weight loss from their profuse bites. Bat-associated species can transmit several species of trypanosomes.
- The common bed bug (*C. lectularius*) is a parasite of humans, birds, bats, and domestic animals. Measuring 5–7 mm, they are brown, oval, flat insects with large, prominent eyes (Figure 83).

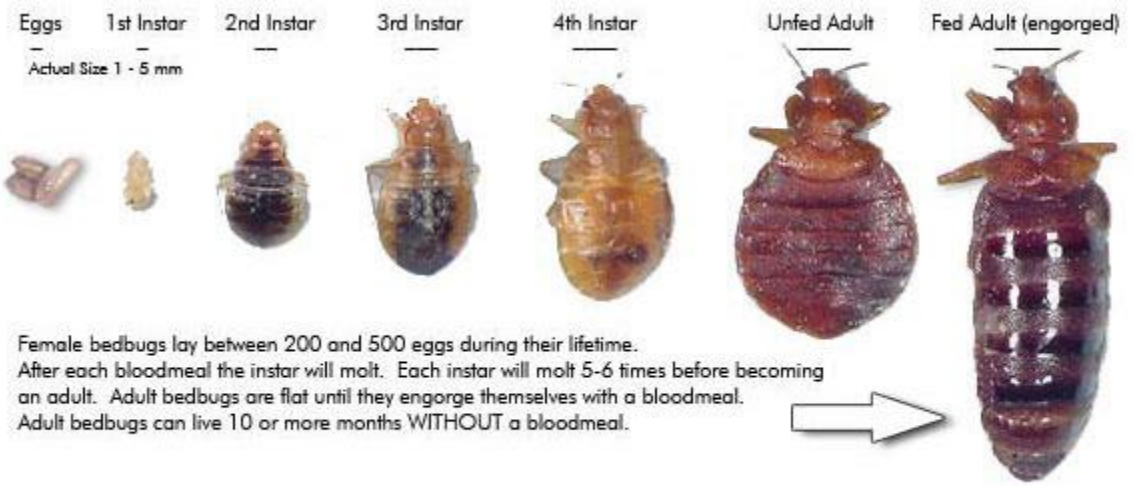


Figure 83 Bedbug life stages

3.2.2.3 *Siphonaptera – Fleas*

They are obligate ectoparasites of birds and mammals (Figure 84):

- Haematophagous in both sexes.
- Holometabolous, secondarily wingless.
- Three legless scavenging larval stages plus pupa.
- Vectors of plague.
- Eggs are produced between blood meals and are dropped into the litter of the host's nest or burrow.
- Fleas are small insects, 1–6 mm long, easily recognised by their lack of wings, their laterally compressed bodies to facilitate movement on the host, and their large jumping hind legs, which they use for locomotion

3.2.2.3.1 *Pulex irritans*

This cosmopolitan flea, commonly misnamed the human flea, occurs on large, coarse-haired mammals including pigs, canids, mustelids, deer, tapirs, and peccaries as well as humans. It can transmit plague and erysipeloids (a bacterial disease) in Central Asia. It is an intermediate host of the cestode *Dipylidium caninum* in parts of Europe.

3.2.2.3.2 *Ctenocephalides: cat and dog fleas*

The cat flea *Ctenocephalides felis* has become the real human flea in developed countries much more than the dog flea *Ctenocephalides canis* or *Pulex irritans*. The cat flea infests dogs, cats and other domestic and wild mammals, as well as cattle and sheep.

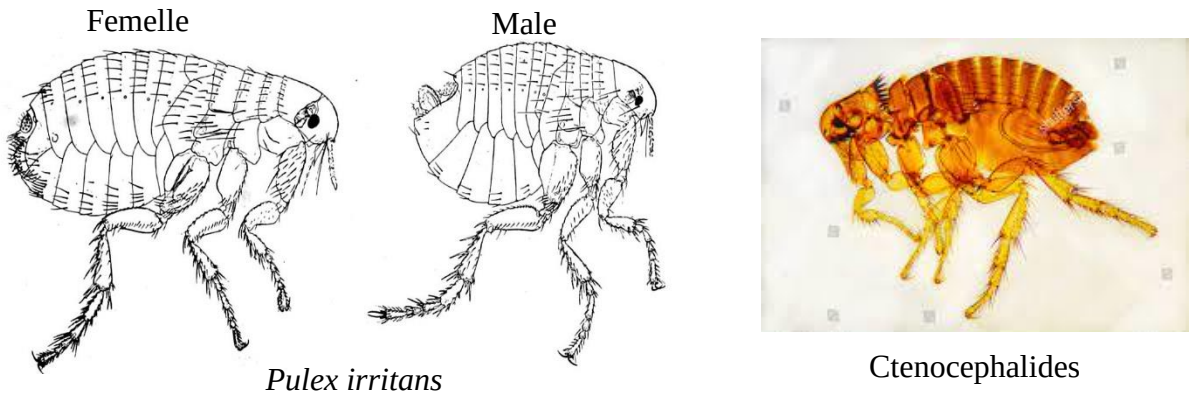


Figure 84 Siphonaptera – Fleas

3.2.2.3.3 *Tunga penetrans -The sand flea-*

Figure 85 Tunga penetrans

This species is a good example of the evolutionary change that a flea can undergo physically and behaviorally. In total, 10 species are known, two of which, *Tunga penetrans* (Figure 85) and the more recently described *Tunga trimamillata*, infest humans by burrowing into the skin (tungiasis). Both are native to Central and South America.

3.2.2.4 *Diptera*

Diptera insects include numerous families, some of whose members are considered hematophagous parasites; however, most of them require a host only for blood feeding to mature their eggs, and leave the host immediately after feeding.

Their general characteristics are:

- A single pair of wings, the second pair replaced by "halteres or balancers".
- Adult mouthparts are sucking or piercing, but never chewing parts.
- Larvae legless, eyeless, with chewing mouthparts.
- Pupa present.
- Adults of some groups are important vectors of parasites responsible for some of the most dangerous diseases of man and domestic animals.

- Larvae of other groups are obligate endoparasites in the tissues of terrestrial vertebrates, a stage known as myiasis.

3.2.2.4.1 *Host-dependent egg-laying parasites*

Include all species needing a host for egg production:

- These species require a blood meal to mature their eggs.
- They lay their eggs in water or moist environments (except for the tsetse fly, which gives birth to larvae).

Table 14 Host-dependent egg-laying parasites

Genus/Species	Host	Location of Egg Laying	Description
Culex spp.	Humans, birds, mammals	Lays eggs in standing water, needs a blood meal for egg maturation	Mosquitoes, vectors for diseases like malaria, dengue, and Zika
Aedes spp.	Humans, other mammals, birds	Lays eggs in water or moist environments, needs blood for egg production	Mosquitoes, vectors for diseases like dengue, chikungunya, and yellow fever
Anopheles spp.	Humans, other mammals	Lays eggs in standing water, requires blood for egg maturation	Malaria-carrying mosquitoes
Tsetse fly (Glossina spp.)	Humans, livestock	Lays larvae directly, but needs a blood meal to produce and mature the larvae	Vectors for sleeping sickness (trypanosomiasis)
Tabanus spp.	Livestock, horses, humans	Lays eggs in moist, sandy soil, requires blood feeding for egg maturation	Horseflies, painful biters, vectors for diseases
Simulium spp.	Humans, livestock	Lays eggs in fast-moving, clean water, needs blood for egg maturation	Black flies, vectors for onchocerciasis (river blindness)
Chrysops spp.	Livestock, other mammals	Lays eggs in aquatic or damp environments, requires blood for egg maturation	Deer flies, vectors for loiasis (African eye worm)

3.2.2.4.2 *Host-dependent larval development parasites*

Include all species needing a host for larval development:

- They are obligate endoparasites in the tissues of terrestrial vertebrates typically involve species from the families *Oestridae*, *Calliphoridae*, *Sarcophagidae*, and *Cochliomyiidae.*
- They often cause myiasis, which can be cutaneous, nasal, or affect deeper tissues, depending on the species and the host.

Table 15 Host-dependent larval development parasite species

Genus/Species	Host	Location of Larvae	Type of Myiasis
Hypoderma bovis	Cattle, large mammals	Subcutaneous tissues, particularly around the back	Warble fly myiasis
Hypoderma lineatum	Cattle, large mammals	Subcutaneous tissues	Warble fly myiasis
Oestrus ovis	Sheep, ruminants	Nasal passages, sinuses	Nasal myiasis (bot fly)
Gasterophilus intestinalis	Horses, equids	Stomach, intestines, esophagus, or rectum	Gastrointestinal myiasis (bot fly)
Gasterophilus nasalis	Horses, equids	Stomach, intestines	Gastrointestinal myiasis (bot fly)
Gasterophilus haemorrhoidalis	Horses, equids	Stomach, intestines	Gastrointestinal myiasis (bot fly)
Cordylobia anthropophaga	Humans, other mammals	Skin (typically in tropical regions)	Cutaneous myiasis (Tumbu fly)
Chrysomya bezziana	Livestock, humans	Open wounds (flesh)	Flesh myiasis (screw-worm fly)
Sarcophaga carnaria	Mammals, including humans	Open wounds (flesh)	Flesh myiasis (flesh fly)
Sarcophaga bullata	Mammals, including humans	Open wounds (flesh)	Flesh myiasis (flesh fly)
Cochliomyia hominivorax	Livestock, humans	Open wounds (flesh)	Flesh myiasis (screwworm fly)

3.3 Class *Crustacea*

- Subphylum *Arthropoda*, linked to water with the exception of Isopods.
- Mostly marine and free-living.
- Biramous appendages on the head, thorax and abdomen.
- Two pairs of antennae, the first uniramous.
- First larva common to all crustaceans is called Nauplius.

3.3.1 *Argulus foliaceus*

The fish parasitic copepods (called commonly sea lice) have become well known recently with the increase in fish farming, particularly of trout and salmon:

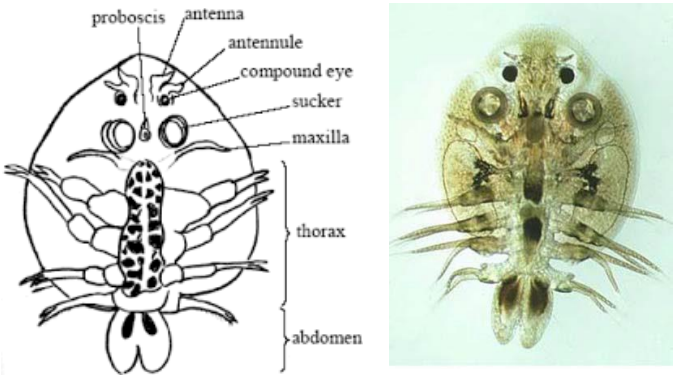


Figure 86 Argulus foliaceus

- The genus *Argulus* is distributed worldwide and belongs to a small group of freshwater ectoparasites (the *Branchiura*), containing about 150 species.
- Sea lice suck blood from the gills and fin bases.
- Adult females leave the host every few days to lay up to 1000 eggs on submerged solid surfaces in two to four rows (Figure 86).
- Measure 3–7 × 2.5–5 mm, females being larger than males.

3.3.2 *Sacculina carcini*

Parasite of crabs. It forms between the thorax and the abdomen of its host, a yellow ovoid mass that can reach 2.5 cm. The adult females are mainly made up of a network of filiform extensions penetrating the body of decapod crustaceans in order to capture nutrients (Figure 87.

Figure 87 Sacculina carcini

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