PARA-SITE

Welcome to "**PARA-SITE:**
an interactive multimedia electronic resource dedicated to parasitology",
developed as an educational initiative of the ASP (Australian Society of Parasitology Inc.) and the ARC/NHMRC (Australian Research Council/National Health and Medical Research Council) Research Network for Parasitology.

PARA-SITE was designed to provide basic information about parasites causing disease in animals and people. It covers information on:

- parasite morphology (fundamental to taxonomy);
- host range (species specificity);
- site of infection (tissue/organ tropism);
- parasite pathogenicity (disease potential);
- modes of transmission (spread of infections);
- differential diagnosis (detection of infections); and
- treatment and control (cure and prevention).

This website uses the following devices to access information in an interactive multimedia format:

PARA-SIGHT life-cycle diagrams and photographs illustrating:

> developmental stages

> host range

> sites of infection

> modes of transmission

> clinical consequences

PARA-CITE textual description presenting:

> general overviews for each parasite assemblage

> detailed summaries for specific parasite taxa

> host-parasite checklists

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Foreword

In developing this resource, we considered it essential that students get to know the parasite assemblages themselves in order to understand the ways in which they interact with their hosts and cause disease, as well as to understand the logic behind different diagnostic techniques and various treatment and control strategies. By learning basic parasitological information in a clinical context, it is hoped students will develop their skills to:

- diagnose the major parasitic groups in host tissues and fomites;
- deduce their modes of transmission from their sites of infection;
- indicate their pathogenicity for different host groups;
- identify boundaries to their distribution and abundance;
- recommend appropriate treatment and control strategies; and
- assess their significance with respect to human and animal health and welfare.

The impetus for this work was provided by the apparent absence of textbooks giving the right degree and mix of biological and clinical information. Many general biology texts only give cursory information on a small range of parasites while most clinical texts concentrate on a few of the most serious parasitic diseases of medical and veterinary significance. At the other end of the spectrum, there are many specialist texts dealing exclusively with individual parasitic groups and the information presented can be overwhelming to students. This electronic resource was designed in an attempt to find some common middle ground between the generalist and specialist texts available.

This resource has a distinctly Australian flavour as it was based on published accounts of parasites in Australian hosts (host-parasite checklists, parasite-host checklists and associated bibliographies are attached). This does not mean that the resource is only pertinent to students of Australian parasitology but rather that locally available parasites are used as examples. In many cases, the parasites are cosmopolitan species which are found worldwide (particularly in humans and their domestic and companion animals) whereas other examples are restricted to endemic species found only in Australia (especially in our unique native animals). Other parasite species do not occur naturally in Australia but are introduced as unwanted guests in international travellers, imported livestock or zoo animals. Knowledge of all these different parasites is essential for their differential diagnosis, treatment and control.

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Introduction to Parasitology

Parasitism is the most common way of life; more than 50% of all animal species are parasites. Parasites occur in all animal species and they may have a profound effect on the health of people, domestic animals and wildlife. Parasitology is the study of parasitism; a multidisciplinary subject covering many topics including morphology, taxonomy, biology, behaviour, life-cycles, pathogenesis, epidemiology, ecology, physiology, biochemistry, genetics and molecular biology, as well as the diagnosis, immunology and treatment of infections.

Parasites live at the expense of their hosts whereas other symbiotes may be mutualists (living in mutual benefit with host) or commensals (living without benefit or detriment to host). Parasites may infect the gastrointestinal tracts or circulatory systems of their hosts, they may invade different tissues and organs or they may live on the external surfaces of their hosts. Many infections may be asymptomatic whereas others may cause acute (transient) or chronic (persistent) clinical diseases ranging markedly in severity (mild to fatal). Parasitic infections may cause mortality (foetal, neonatal, adult death), morbidity (disease manifest by enteritis, fever, anaemia, etc.), production losses (reduced meat, milk, fibre production), and tissue lesions (reduced marketability of product). Despite many advances in parasite treatment and control, infections still persist due to many factors, including urbanization (crowding together); more intensive farming systems, greater translocation of animals, further land and marine development, inadequate effluent disposal, emergence of parasite drug resistance, and spread of vector insecticide resistance.

Parasite assemblages

Many types of organisms have adopted a parasitic mode of existence; that is, they require a host for their own survival. Three major groups of parasites are recognized: protozoa (belonging to the kingdom Protista), and helminths and arthropods (belonging to the kingdom Animalia, or Metazoa).

protozoa

helminths

arthropods

Protozoa: Over 10,000 species of single-celled protozoa have been described in the gut, blood or tissues of vertebrate and invertebrate hosts. Parasitic flagellates cause enteric diseases such as giardiasis, urogenital diseases such as trichomoniasis, systemic diseases such as sleeping sickness, and tissue diseases such as Chaga's disease and kala azar. Parasitic amoebae cause dysentery, meningoencephalitis and corneal lesions. Spore-forming sporozoa cause many serious diseases: Apicomplexa cause coccidiosis, malaria and tick fevers; Microspora parasitize fish and insects; and Ascetospora cause seasonal mortalities in oysters. Parasitic ciliates cause diarrhoea or lesions in humans and animals while commensal species cause serious fouling problems in aquaculture.

Helminths: Around 50,000 species of multicellular helminths (worms) have been described from a wide range of hosts. Roundworms (nematodes) cause much morbidity and mortality in humans and animals throughout the world. Serious infections include filiariases, hookworm and threadworm diseases. Larval and adult tapeworms (cestodes) may be found in many vertebrate hosts. Some species do not cause clinical disease whereas others may cause severe weight loss, diarrhoea, abdominal pain or space-occupying lesions. Flukes (trematodes) include many important species such as sheep liver fluke and human schistosomes or blood flukes.

Arthropods: Thousands of arthropods are parasitic at some stage in their life-cycles. Many cause serious diseases and limit agricultural productivity. Parasitic insects include biting and sucking lice which may cause skin lesions or anaemia, fleas which may cause allergic dermatitis, and various flies which suck blood as adults or produce larvae which feed on host tissues. Parasitic arachnids include ticks which feed on blood and may cause anaemia or paralysis and mites which feed on skin and may cause mild itching, hair loss or severe mange.

Overview

Three general environments are available for life as we know it: terrestrial, aquatic and biotic. By definition, parasites are those animals which occupy the last niche, i.e. live in or on another species, their **host**. **Parasitism** is a form of **symbiosis**, an intimate relationship between two different species. There is a **biochemical interaction** between host and parasite; i.e. they recognise each other, ultimately at the molecular level, and host tissues are stimulated to react in some way. This explains why parasitism may lead to disease, but not always. It is often a life-long relationship for the parasite, which cannot survive without its host.

While it is often claimed (even by definition) that a parasite must damage its host in some way (to distinguish parasitism from **commensalism** and **mutualism**), in practice this can be impossible to establish, because we know so little about most symbiotic relationships; certainly, many human parasitic infections are asymptomatic (which is not the same as non-pathogenic).

Parasitism must have arisen very early in the history of life on Earth, when primordial microrganisms learnt to survive inside other cells which they had invaded either passively (e.g. by phagocytosis) or actively (e.g. by penetration). When multicellular organisms with alimentary tracts appeared, they would have inevitably (accidentally or intentionally) eaten free-living microorganisms (and, later, free-living helminths). Ingested animals that managed to survive in this new environment would have appreciated the nutrient-rich environment; energy saved in looking for food could then be diverted to proliferating and resisting the host's efforts to dislodge them. With time, these parasites became so adapted to life in the host, they "forgot" how to survive outside. However, to succeed, they still needed to produce offspring that could negotiate the outside world to find new hosts.

Not surprisingly, all parasitic animals have free-living counterparts to which they are clearly related, and the greatest diversity of parasites is still found within the alimentary tracts of "higher" animals. As host species diverged with evolution, they "carried" with them their parasites. It is virtually the rule today that parasitic protozoa and helminths found in any vertebrate species have almost identical relatives in related vertebrates, and most of them are exquisitely host-specific. For example, the two common amoebae of the human colon, *Entamoeba histolytica* and *E. coli*, have almost identical relatives within a wide range of vertebrate hosts. There is even *E. moshkovskii*, a species that has been found only in sewers, which probably evolved from parasitic species! *E. gingivalis* occurs only in the human mouth, and has lost its cystic stage, presumably because trophozoites are so efficient at transferring between hosts. The same occurs with helminths, e.g. the roundworm of the human small intestine, *Ascaris lumbricoides*, has counterparts in pigs, dogs, cats, flying foxes, elephants, dolphins and many other mammals.

Once established in the host intestine, some parasites "learned" to invade the gut mucosa and deeper tissues, or to survive in the guts of predators that consumed their original hosts. Involvement of invertebrate "micropredators" in such life-cycles could then have led to parasite transmission via blood or tissue ingestion. Other parasites, in their infective stages, developed the ability to invade via the skin. It is not too difficult to conceptualise how complex life-cycles, utilizing a range of different hosts, might have arisen. Many examples of "missing links" in parasite evolution can still be found today, although far more are well-and-truly extinct. It is misleading to think of extant protozoan or helminth species as "primitive", for they have been evolving as long as all other species, including *Homo sapiens*, and utilise sophisticated survival mechanisms that we are only beginning to understand.

Parasitism clearly has advantages over independent existence, for parasites greatly outnumber free-living animals, both in terms of individuals and species; from an evolutionary viewpoint, it is the ultimate life-style. The obvious benefit to the parasite is that its host provides, *gratis*, a relatively stable, nourishing home. The energy saved in seeking food, shelter and transport is then concentrated on reproducing and evading host defence mechanisms, which are provoked in virtually every case, although not always obviously.

Medical Parasitology is the study of those organisms which parasitise humans. According to the definition above, parasites could include the **viruses**, **bacteria**, **fungi**, **protozoa** and **metazoa** (multicellular organisms) which infect their host species. However, for historical reasons (and because they are NOT classed as animals), the first three have been incorporated into the discipline of **Microbiology**.

Parasitology claims those **protozoa** (unicellular animals), **helminths** (worms) and **arthropods** (insects and arachnids) whose existence depends on the availability of host animals, i.e. they are **obligate** parasites. Some rare parasites are called **facultative**, because they can survive and reproduce without a host, but very few that infect humans belong to this group (e.g. free-living amoebae). While we could argue about whether certain insects and mites are "temporary parasites" or "micro-predators", insects as a group belong to the discipline of **Entomology**, while ticks and mites are the concern of **Acarology**. Another crude way of distinguishing these is to label them **ectoparasites** (living on the host body surface), in contrast to the **endoparasites** (which live inside the host). The major contribution of insects in Parasitology is as vectors of several infections, although several are true parasites in their own right.

The disciplines also differ in ways other than taxonomic boundaries. In Microbiology, while morphology or staining properties (e.g. with Gram's stain) are important in the basic categorisation of the organisms, species identification generally depends on culturing and identifying specific enzymatic reactions, antigenic configurations or DNA sequences; i.e. the test-tube is important. In Parasitology, morphological recognition remains foremost, so that parasites (or their vectors) are still identified on characteristic shapes and sizes; i.e. the microscope rules supreme. Subspeciation or strain-typing is less well-developed, and may depend on molecular configurations or host-specificity. Culture has been a basic tool in Microbiology almost from its inception, and cell-culture is especially important in Virology (where viruses are not observed directly, but initially recognised by their effects on cultured cells). In Parasitology, culture was for a long time virtually impossible for most organisms, including protozoa.

Nevertheless, in recent years, technical advances have allowed the *in vitro* cultivation of increasing numbers of parasite species, including even some helminths, although this is a procedure still in its infancy and used largely in research, rather than for routine clinical diagnosis. Advances in molecular biology are revolutionising all the biological sciences, including Parasitology. However, the organisms still must be identified initially on their morphology, and this is the basis of most parasite diagnoses made in clinical pathology laboratories.

Every known species (living and extinct) is assigned a unique combination of **genus** and **species** names which, by convention, are printed in italics or underlined. Infections with parasites are often indicated by the abbreviated genus name plus the suffix **-osis**. Some authorities use the suffix **-iasis** if the infection causes disease, but this distinction is often meaningless or impossible to establish. Purists argue that -osis belongs to species names derived from Greek, while those with Latin parentage deserve -iasis (it becomes tricky if you don't know the name's origins). Either can be used, depending on which sounds better (although a recent international convention aims to standardise all this), and we must be tolerant of the many exceptions, e.g. tuberculosis (mycobacteriosis), malaria (plasmodiosis), elephantiasis (lymphatic filariasis, or filariosis). If more than one parasite belongs in the genus, then the species name may be added to qualify the infection, *e.g.* schistosomiasis mansoni (not italicised).

Life-cycles

While parasites are adapted to living in or on their hosts, they can only survive by producing offspring capable of finding new hosts. The key to understanding their dispersal through the world is through knowledge of their **life-cycles** or modes of **transmission**, involving many aspects of parasite biology, reproduction and epidemiology.

Protozoa, in their motile, feeding, growing, asexually-multiplying forms are known as **trophozoites** (*trophe* = nutrition; *zooite* = minute animal) These are adapted for existence in the host and, generally, are unable to survive the rigours of life outside. Under appropriate conditions, which we do not yet understand, some trophozoites of gut protozoa coat themselves in a protective shell and shut down metabolically, to become **cysts**. These are designed to survive in the outside world long enough to reach new hosts. In the most highly-evolved protozoa (apicomplexans), which are obligate intracellular parasites, asexual division of the trophozoite (**schizogony**; *schizein* = to divide, or split; *-gony* = reproduction) leads to the generation

of many **merozoites** (*meros* = piece, segment) which then invade other host cells. Eventually, instead of undergoing further schizogony, merozoites undergo sexual reproduction (**gamogony**) developing into either **macrogametocytes** (female) or **microgametocytes** (male). Fertilisation results in the formation of a zygote, termed an **oocyst** (= egg-cyst), which is designed to survive in the outside world so that it may infect another host. The ripe (sporulated) oocyst contains infective "seeds" known as **sporozoites**, which arise during its maturation (**sporogony** = generation of spores).

The metazoan parasites (multi-celled, *i.e.* worms and arthropods) generally are **dioecious**, i.e. adults occur as separate males and females. Tapeworms and most flukes are the exceptions (**hermaphrodites**). After copulation, females produce fertile eggs, each containing an embryo. This undergoes embryonation developing into a juvenile or **larva** which will hatch out under suitable conditions. The egg may be the infective stage, or larvae may develop in the outside world to infectivity, or larvae may develop further in one or more intermediate hosts before they are able to reinfect their definitive hosts. Because their larvae must develop outside the host, adult helminths cannot multiply directly within a host (in stark contrast to protozoa which can proliferate to large numbers).

Many parasites complete their developmental cycle in a single host species (**monoxenous** life-cycles) while others require multiple host species (**heteroxenous** life-cycles). When multiple hosts are involved, the **definitive host** is that species in which the adult (or sexual) form of the parasite occurs, whereas the **intermediate host** is the species which supports the development and/or multiplication of the non-sexual, or larval (for helminths), stages of the parasite. Intermediate hosts which physically carry the infective stage from one host to another are also termed **vectors**; they are **mechanical** vectors if they simply transmit the parasite (unchanged and non-multiplied), and **cyclical** vectors if they also function as true intermediate hosts that support essential development and/or proliferation of the parasite.

Intermediary hosts may be optional in some helminth life-cycles; the parasite might not undergo essential development in them, although it may increase in size. These **paratenic hosts** carry parasites through food chains to the definitive host, ensuring successful transmission even when the hosts are thinly dispersed through the environment. Some parasites exhibit low specificity for their definitive and/or intermediate hosts and so can develop in a range of animal species. A **zoonosis** is a human infection caused by an organism which occurs naturally in other animals, known as **reservoirs** of infection. Most parasite life-cycles that are known have only been worked out quite recently; i.e. within the last 100 years. Information is therefore fragmentary and many ambiguities exist. We could argue about whether the mosquito genus *Anopheles* or the primate species *Homo sapiens* is the definitive host for malaria parasites as gamogony in initiated in the human but culminates in fertilization in the mosquito.

Host-specific parasites are very particular about which species they will use; this can apply to definitive as well as intermediate hosts. Host-specificity is determined by a complex of factors, some obvious and others still obscure. The first requirement is that the prospective host shares its environment with the parasite (**ecological** specificity); e.g. parasites of dolphins might not have much luck infecting humans who don't live near the sea (although modern food transport networks have changed this!). Secondly, host behaviour must expose it to the parasite (**ethological** specificity); e.g. people who eat dolphin food (fish) may acquire parasites intended for dolphins. Finally, once the parasite comes into contact with the host, it must recognise appropriate cues and feel comfortable within its new surroundings (**physiological** specificity); e.g. if a parasite of dolphins thinks it is in a large fish or a dolphin when it arrives in the human gut, it may then behave accordingly. Obviously, this last determinant of host-specificity is the one we understand least.

Parasites interact with host secretions and surfaces and membranes: they must recognise and respond to molecular configurations (receptors/ligands). Detection of subtle variations in metabolites allows them to follow road-maps; they need to make critical changes in behaviour and development according to changes in host physiology/behaviour (neural/endocrine cues?); and they must be satisfied with their diet (host intestinal contents, blood and/or tissues). Clearly, all these combinations are unique for each host species, and vary even among individuals within a species, within an individual host throughout its own life-cycle and even throughout a 24-hour day. Likewise, each population of parasites is heterogeneous, so some individuals succumb very easily if in the wrong host ("losers") whereas others persist and may come close to full development ("pioneers"). This is the driving force of evolution, and parasites are the most rapidly evolving animals.

Epidemiology

This is the descriptive and analytical study of how diseases or infective organisms are distributed in human populations. A parasite is **endemic** to a geographical region if it is sustained by transmission amongst people living there. An infection maintained in animal populations is **enzootic** (which must apply to all zoonoses), although this term is going out of fashion. An infection acquired locally (usually in an endemic region) is **autochthonous**. Infected people who bring an organism into a non-endemic area are labelled **imported** cases; should the parasite then transfer to another person in that region, the secondary case becomes an **introduced** infection. If the parasite establishes in the new population, it becomes newly-endemic.

The level of infection in a population is measured by prevalence and incidence. **Prevalence** refers to the prevailing level of a condition within a defined population, and is best applied to conditions without a clearly identifiable onset, such as most helminthic infections, chronic toxoplasmosis, Chagas' disease (or malignant, degenerative or metabolic diseases). It is measured by a single study of a population over a brief time-period (cross-sectional survey). **Incidence** refers to the number of new cases acquired per unit of population per unit of time, and is more meaningful for acute, short events (incidents), with an identifiable beginning (or end!) e.g. many viral infections, acute malaria (or deaths, or accidents). It can be measured only by monitoring a population over a sufficient period or time (longitudinal study) and determining the rate increase or decrease. Obviously, the incidence, prevalence and duration of a particular condition are closely and simply inter-related. An **epidemic** occurs when the incidence of new cases significantly exceeds the usual rate; if the disease is protracted, this will be reflected by an increase in prevalence as well.

Quantitation of infection

Infective organisms have been categorized as either **microparasites**, which multiply directly within the host (all the microbes, plus protozoa) or **macroparasites**, which generally cannot multiply in the host; their numbers depend on how many infective eggs or larvae are taken on board. Ectoparasites do not happily fit into this classification, for they are clearly "macro", but often can multiply to huge populations on the one host. However, their development may be considered "external", as they usually reside outside the host on the surface. The term "infestation", sometimes used for macroparasitic infections, is going out of fashion, but can be applied to contaminated inanimate objects, e.g. a house infested with fleas, or bushland infested with ticks.

Infection with microparasites is an all-or-none situation; you either have measles, influenza, bubonic plague, toxoplasmosis, giardiasis, etc., or you don't. It is not often possible, or necessary, to quantify reliably the **intensity** of such an infection (number of organisms on board a host). In many instances, the severity of disease is not reliably related to the numbers of parasites detectable in blood, tissues or secretions (a notable exception is malaria, in which the percentage of infected red cells can be estimated and sometimes is important clinically). In the case of helminths and arthropods, which are generally visible macroscopically as discrete individuals, the number of organisms is meaningful, because it can be measured and does influence the likelihood or severity of disease. Therefore, in epidemiological studies of macroparasitic infections, their intensity becomes important, in addition to incidence and prevalence. Virtually all population studies have shown that the intensity of infection does not follow a normal distribution, but exhibits an "aggregated" or "overdispersed" pattern: a small number of hosts harbour most of the parasites, whereas most individuals carry few or no parasites (characterised mathematically as a "negative binomial distribution").

Clinical and pathological considerations

While, by definition, a parasite should evoke a host reaction, there need not be any obvious adverse effects because, in the great majority of cases, infected individuals exhibit little evidence of disease. In many cases, it can be difficult or impossible to determine whether an organism is a parasite or commensal (e.g. many intestinal protozoa, and worms). However, other parasite infections do cause serious disease, to such an extent that they become major public health problems. It is generally assumed that, the longer a parasite and its host species have co-evolved, i.e. have had time to adapt to each other, the less pathogenic the infection becomes. On the other hand, infections with parasites that are poorly adapted to humans, i.e. zoonoses, are more likely to cause serious disease. However, there are many exceptions to these "rules". Remember, in the clinical world, we see only those individuals who develop disease; there may be many more who remain well, even though infected. Apart from host factors, the major important determinant here is parasite **virulence**, i.e. capacity to induce disease, including the inter-related factors of invasiveness (motility, enzyme secretion, presence of specific tissue receptors, induction of phagocytosis), fecundity (rate of producing offspring), means of egress from host, stimulation and/or suppression of immunity and inflammation, production of exo- and endo-toxins and resistance to host defences.

Such virulence-determinants often correlate directly with the parasite's capacity to survive and reproduce, but they also may adversely affect host survival and fecundity. This applies a pressure on host populations that selects out more resistant individuals; it has even been argued that parasites serve to improve the fitness of their host species (Red Queen Hypothesis), and were a major influence in the evolution of sex! However, genetic changes that increase resistance to infection often handicap the host in other ways, generating a dynamic equilibrium between protection against infection and susceptibilty to other diseases (**balanced polymorphism**). There is no doubt that infectious organisms exert a powerful and continuous evolutionary pressure on host populations (and *vice versa*).

In the field of infectious diseases, it is conceptually important not to confuse aetiological agents with their effects on the host. An **infection** occurs when an **organism**, i.e. the parasite, is found in its host. Some experts don't like to label this an infection, unless there is evidence of a response in host tissues; this applies particularly to commensal organisms, which normally occur on human skin or in the gastrointestinal tract, but which cause disease only when they breach the surface barriers. Infection is a host-organism interaction; it cannot exist without a host. Presence of infective organisms in the environment, e.g. in food, on fomites or in water, is not infection, but contamination (or "infestation"). We should not talk about "infected water supplies", for example.

Moreover, an infection is not the same as a **disease**, which is a pathological change in the host, i.e. abnormalities induced in tissues by direct mechano-chemical damage and/or release of toxins and/or inflammatory mediators. **Illness** occurs when the host suffers the effects of the disease and becomes a patient, i.e. complains of **symptoms** (subjective, felt by the patient) which interfere with normal life, and perhaps manifests clinical **signs** (objective, detectable by the doctor), always with psychosocial undertones and ramifications. This is summarised as follows:

ORGANISM ⇔ INFECTION ⇔ DISEASE ⇔ ILLNESS

Where you start in the above sequence depends on whether you are the parasite or the patient! The illness is what the patient complains about to the doctor (often with judicious prompting), the disease is what the clinician may detect on physical examination (and the pathologist confirms in laboratory tests or at autopsy), and the causative organism (or its products, or antibodies to it) is what the diagnostic laboratory usually seeks and identifies. In any particular patient, all of these apparent components might be totally unrelated, so that linking them together becomes a major and still unresolved difficulty, even in some very common infections. Such distinctions may seem pedantic, but their appreciation helps in understanding stages in the evolution of an infectious disease, and is important to minimise confusion. Many people are infected; in fact, every one of us has at some time harboured at least one parasite species, and most of the world's people carry many parasites most of the time. However, relatively few are diseased, and not all of them suffer illness. Infections without illness are called **subclinical** or **asymptomatic**. Note that this does not mean being free of disease.

If you conclude, from the foregoing discussion, that infection with parasites is a normal state in humans, you would be right, partly. To be able to distinguish normal from abnormal, and to know when to intervene and when simply to reassure, are good reasons for medical students to be aware of and understand human parasitic infections. Seemingly innocuous parasitoses can turn nasty unpredictably, whereas harmless species with exotic names, when they appear in patients' pathology reports, can generate panic in medical practitioners.

The interval between **exposure** to infection and the onset of illness is known as the **incubation**, **latent** or **pre-patent** period or phase. Some authorities define this period as the time from exposure to the time of becoming infective to others, but not all agree with this. Others define the latent period as the time from exposure to the first occurrence of recognisable specific manifestations, be they symptoms, signs, positive serology or other laboratory findings; if for symptoms, then it is called the incubation period. With many parasitic infections in endemic areas, these definitions may be of little use clinically, because people are repeatedly being exposed to infection.

An infection is **patent** when direct evidence of the organism can be detected, e.g. in the patient's faeces, blood or secretions, regardless of whether symptoms have appeared. Some infections may be patent but subclinical; others may cause illness, yet not be patent. However, the individual who has patent infection is essential to transmission of the organism, because it can then be transferred directly to other hosts, to vectors, or into the environment, where it may need to develop through stages to infectivity. Obviously, the detection of patency depends on the sensitivity of the test being used to identify the organism.

Often, indirect evidence of infection is the best that can be offered by the diagnostic laboratory, in the form of circulating antibodies generated against antigens of the infecting organism. Apart from the issues of **specificity** and **sensitivity**, another difficulty common to all antibody tests is distinguishing between ongoing, active infection and recently resolved or past infection. In other cases, serology may be even less adequate, for the simple reason that a test has not been developed, and the infection is known as **cryptic**. In some infections, specific monoclonal antibodies can be used to identify parasite antigens, and the polymerase chain reaction is becoming increasingly available to identify nucleotide sequences from infective organisms, although the limitations of these technological advances have not been well-established.

Usually, disease results predominantly from the host's efforts to deal with the parasite, involving immunological and other less well understood responses to an organism which refuses to go away, and which utilises effective strategies to avoid being damaged. The principles (and even details) of host responses to infecting organisms apply equally to microbial and parasitic infections and, as we learn more about the precise mechanisms, the more difficult it becomes, in the clinical context, to justify the separation of these groups of pathogens. Obviously, viruses may succumb more readily than worm larvae to protective mechanisms involving antibodies, complement, lymphocytes, phagocytes and other effector cells and molecules, but all infections initially trigger similar basic repertoires of responses. A major discriminating influence is whether the organisms are intra- or extra-cellular, which partly determines the class of MHC molecules with which they interact. The minute parasitic protozoa that multiply in host cells have much in common with viruses, so that host responses to these infections and the resulting diseases can be so similar that, clinically, they may be indistinguishable. Patients have only a limited range of symptoms to complain about, so that generally it is impossible to diagnose the causative organism from the clinical features. However, a careful history, taken to evaluate the likelihood of exposure to specific parasites, often narrows the range of options (differential diagnosis), and indicates the specimens which should be sent to the laboratory for definitive diagnosis.

Parasitology in perspective

Parasitic infections of humans can be studied from many angles: we can focus on the parasites, their hosts, the environments they share and the ways in which they interact. People working in this field come from numerous backgrounds, including zoology, physiology, biochemistry, immunology, molecular biology, pharmacology, ecology, economics, anthropology, sociology, engineering, agriculture, education, mathematics and, of course, human and veterinary medicine. Irrespective of background, it can be very helpful to compartmentalize and consider parasitological information under the following headings:

- **AETIOLOGY** (causative organisms): colloquial and scientific (binomial) species name, broad group e.g. amoeba, nematode; stages occurring in humans (larva, cyst, trophozoite etc.); approximate size/shape.

- **LIFE-CYCLE** (summary of biology): Hosts – definitive, intermediate, paratenic; anatomical locations and sites of multiplication; development and survival in intermediate host/environment.

- **EPIDEMIOLOGY** (dispersal in populations): distribution, prevalence, demographics, transmission; ecological determinants, *i.e.* geography, climate, vectors, human behaviour and resources

- **PATHOGENESIS** (dispersal within host; mechanisms of disease): sites affected; mechanical and/or chemical damage; local and systemic host responses (acute and chronic); effectiveness of immunity

- **CLINICAL MANIFESTATIONS** (how patient affected): logical extension of knowledge on pathogenesis; know mainly which organ system(s) involved and how manifests; symptoms and signs.

- **DIAGNOSIS** (how detected): specimens required; collection, preservation, transport, tests, reliability of results (sensitivity, specificity, predictive values); safety aspects, disposal

- **TREATMENT** (therapy): Is it necessary? effective? safe? Drugs, modes of action; contra-indications, side-effects; compliance; susceptibility/resistance

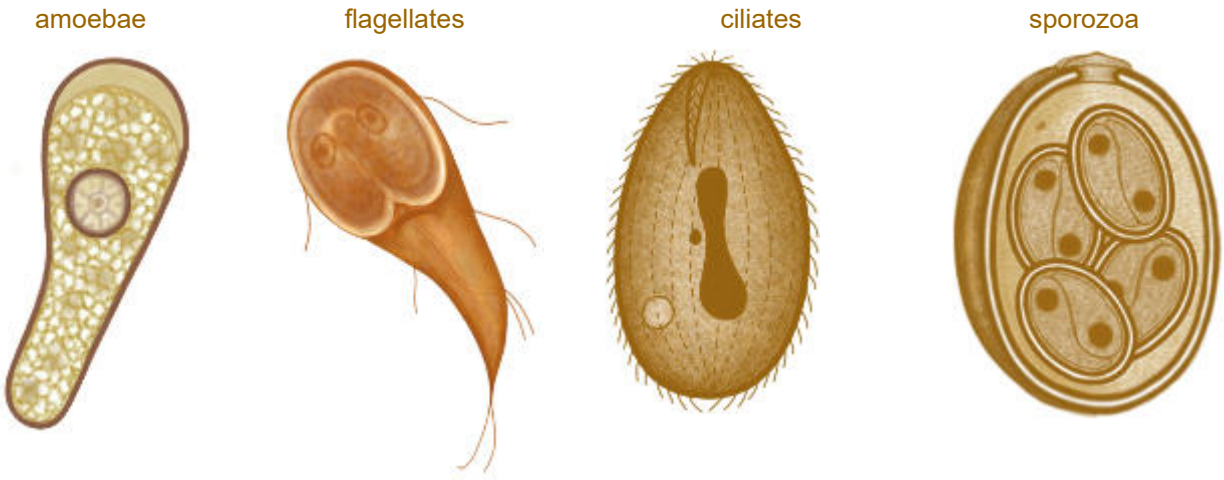
- **PREVENTION/CONTROL** (prophylaxis/intervention/management): public health; chemoprophylaxis; interruption of transmission; education; screening, vaccination; environment/food/water contamination

Protozoan Parasites

The name ‘proto-zoa’ literally means ‘first animals’ and early classification systems grouped the protozoa as basal members of the animal kingdom. However, they were recognized as a discrete assemblage on the basis of their unicellularlity and were assigned to the taxon Protozoa (but still invariably figured as the trunk of the animal tree of life). Members of the subkingdom Protozoa are quite disparate; indeed the taxon has never been considered a natural assemblage of organisms but rather one of convenience. More recently, the protozoa have been classified together with several algal and fungal groups in the kingdom Protista (protozoa representing the motile protists). Irrespective of contemporary classification systems, most parasitological texts continue to use the name protozoa for historical reasons.

Protozoa are eukaryotic organisms (with a membrane-bound nucleus) which exist as structurally and functionally independent individual cells (including those species which are gregarious or form colonies). None have adopted multicellular somatic organisation characteristic of metazoan organisms. Instead, protozoa have developed relatively complex subcellular features (membranes & organelles) which enable them to survive the rigours of their environments. Most protozoa are microscopic organisms, only a few grow to a size large enough to be visible to the naked eye. As unicellular eukaryotes, protozoa display all the same essential life activities as higher metazoan eukaryotes: they move about to survive, feed and breed.

Four main groups of protozoa are recognized on the basis of their locomotion using specialized subcellular and cytoskeletal features:



- Amoebae use pseudopodia (singular: pseudopodium) to creep or crawl over solid substrates. Pseudopodia (or ‘false feet’) are temporary thread-like or balloon-like extensions of the cell membrane into which the protoplasm streams. Similar amoeboid motion has been observed in cells of many life-forms, especially phagocytic cells (e.g. human macrophages).
- Flagellates use elongate flagella (singular: flagellum) which undulate to propel the cell through liquid environments. Flagella are ‘whip-like’ extensions of the cell membrane with an inner core of microtubules arranged in a specific 2+9 configuration (2 single central microtubules surrounded by 9 peripheral doublets). This configuration is conserved throughout eukaryotic biology, many organisms produce flagellated cells (e.g. human spermatozoa).
- Ciliates use numerous small cilia (singular: cilium) which undulate in waves allowing cells to swim in fluids. Cilia are ‘hair-like’ extensions of the cell membrane similar in construction to flagella but with interconnecting basal elements facilitating synchronous movement. Ciliated cells are found in specialized tissues and organs in many other higher life-forms (e.g. human bronchial epithelial cells).
- Sporozoa (‘spore-formers’) were originally recognized not on the basis of their locomotion, but because they all formed non-motile spores as transmission stages. Recent studies, however, have shown that many pre-spore stages move using tiny undulating ridges or waves in the cell membrane imparting a forward gliding motion, but the actual mechanisms involved are not yet known.

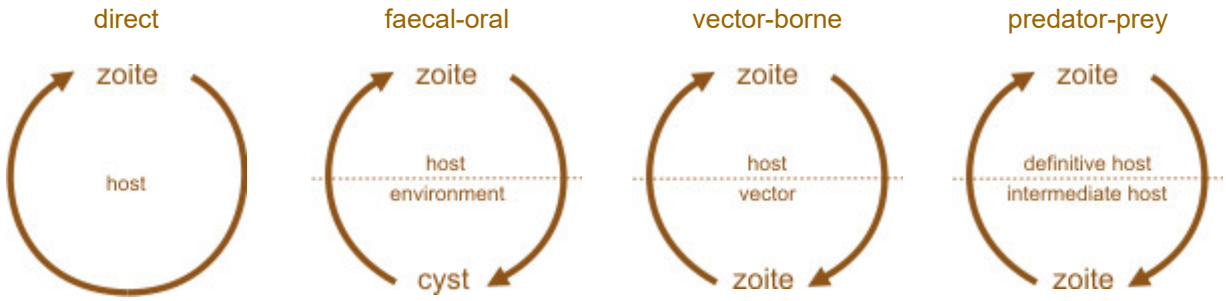
Biodiversity

Protozoan biodiversity (or species richness) includes counts (or estimates) of some 32,000 extant (living) species and another 34,000 extinct (fossil) species (especially foraminifera). Of those alive today, some 21,000 species occur as free-living organisms in aquatic or terrestrial environments, whereas the remaining 11,000 species are parasitic in vertebrate and invertebrate hosts. There are approximately 6,900 flagellate species (1,800 parasitic, 5,100 free-living), 11,550 amoebae species (250 parasitic, 11,300 free-living), 7,200 ciliate species (2,500 parasitic, 4,700 free-living) and 5,600 sporozoan species (all parasitic).

Life-cycles

Most protozoa have enormous reproductive potential because they have short generation times, undergo rapid sequential development and produce large numbers of progeny by asexual or sexual processes. These characteristics are responsible for many protozoan infections rapidly causing acute disease syndromes. Parasites may multiply by asexual division (fission/splitting or internal/endogenous budding) or sexual reproduction (formation of gametes and fertilization to form zygote, or unique process of conjugation where ciliates exchange micronuclei).

Protozoan developmental stages occurring within hosts generally consist of feeding trophozoites, and they may be found intracellularly (within host cells) or extracellularly (in hollow organs, body fluids or interstitial spaces between cells). While trophozoites are ideally suited to their parasitic mode of existence, they are not very resistant to external environmental conditions and do not survive long outside of their hosts. To move from host-to-host, protozoan parasites use one of four main modes of transmission: direct, faecal-oral, vector-borne and predator-prey transmission.



> direct transmission of trophozoites through intimate body contact, such as sexual transmission (e.g. *Trichomonas* spp. flagellates causing trichomoniasis in humans and bovine infertility in cattle).

> faecal-oral transmission of environmentally-resistant cyst stages passed in faeces of one host and ingested with food/water by another (e.g. *Entamoeba histolytica*, *Giardia duodenalis* and *Balantidium coli* all form faecal cysts which are ingested by new hosts leading to amoebic dysentery, giardiasis and balantidiasis, respectively).

> vector-borne transmission of trophozoites taken up by blood-sucking arthropods (insects or arachnids) and passed to new hosts when they next feed (e.g. *Trypanosoma brucei* flagellates transmitted by tsetse flies to humans where they cause sleeping sickness, *Plasmodium* spp. haemosporidia transmitted by mosquitoes to humans where they cause malaria).

> predator-prey transmission of zoites encysted within the tissues of a prey animal (e.g. herbivore) being eaten by a predator (carnivore) which subsequently sheds spores into the environment to be ingested by new prey animals (e.g. tissue cysts of the sporozoan *Toxoplasma gondii* being ingested by cats, and tissue cysts of the microsporan *Thelohania* spp. being ingested by crustaceans).

Taxonomic overview

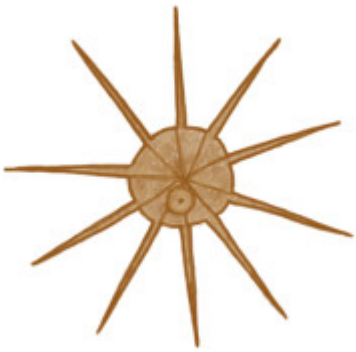
Flagellates and amoebae are considered to be closely related, because some amoebae form transient flagellated stages (to aid in dispersal) and some flagellates exhibit intermittent amoeboid motion. Two groups of flagellates are recognized on the basis of the presence or absence of chloroplasts:

Phytoflagellates with chloroplasts derive energy by photosynthesis. Most are free-living aquatic organisms and some exhibit periodic blooms (e.g. red tides). Others contain potent neurotoxins and cause paralytic shellfish poisoning.

Zooflagellates without chloroplasts derive energy by the absorption of nutrients or the ingestion of food particles. Many species occur as free-living aquatic organisms whereas others live in insects and some vertebrates as symbiotes, commensals or parasites (several species cause major human diseases such as sleeping sickness, Chagas disease, kala azar and diarrhoea).

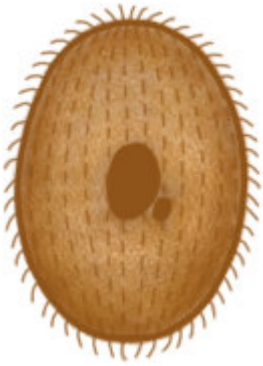
Two groups of amoebae are recognized on the basis of the types of pseudopodia formed with or without regular microtubule arrays:

Rhizopod amoebae produce broad lobopodia, fine filopodia or net-like reticulopodia which do not contain regular microtubule arrays. Many aquatic species contribute to water quality by consuming bacteria and algae whereas terrestrial species contribute to soil health via nutrient cycling. Some species, such as foraminifera, build unique tests (shells) which contribute to fossil records.

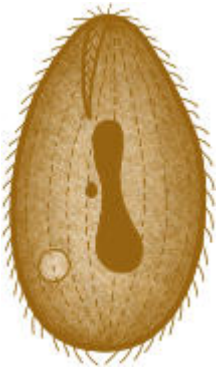


Actinopod amoebae form radial axopodia which are stiffened by internal arrays of microtubules arising from an organizing centre. All species are free-living planktonic organisms, marine species known as radiolaria, and freshwater species known as heliozoa (or sun animacules).

The ciliates are regarded to be quite separate from other groups, more because they possess 2 types of nuclei (vegetative macronuclei and reproductive micronuclei) than because they possess cilia. Three groups are recognized on the basis of their patterns of somatic (body) and buccal (oral) ciliature:



Lower holotrichs have simple body and oral ciliature. Most are free-living aquatic species but some are highly specialized symbionts aiding cellulose digestion in herbivores.



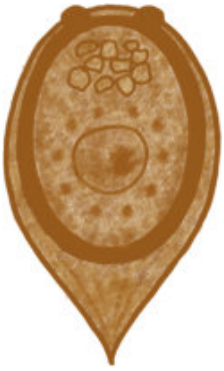
Higher holotrichs have simple body ciliature but more specialized oral ciliature forming membranelles. Most occur as free-living aquatic organisms but some live as commensals or parasites in a range of animals.

Spirotrichs have reduced body ciliated but well developed oral ciliature forming an adoral zone of membranelles. The majority are bactivores living in aquatic and terrestrial habitats.

All sporozoa are obligate parasites, they form temporary non-motile spores which contain infective cells. Four major groups are recognized on the basis of different spore morphology:

Apicomplexan parasites form distinctive oocysts containing infective sporozoites. Many species occur only in invertebrates whereas others may infect vertebrates causing severe diseases (such as malaria, tick fever, diarrhoea or abortion).

Microsporan parasites form unicellular spores containing coiled polar tubes used to infect host cells. Most species infect invertebrates (especially insects) although some form cysts in vertebrates (mainly fish).



Haplosporidian parasites form unicellular spores without polar filaments in the tissues of aquatic invertebrates. They cause significant morbidity and mortality in oysters throughout the world.

Paramyxean parasites form unique spore-within-spore arrangements within the tissues of bivalves and polychaetes. They cause QX and Aber disease in oysters

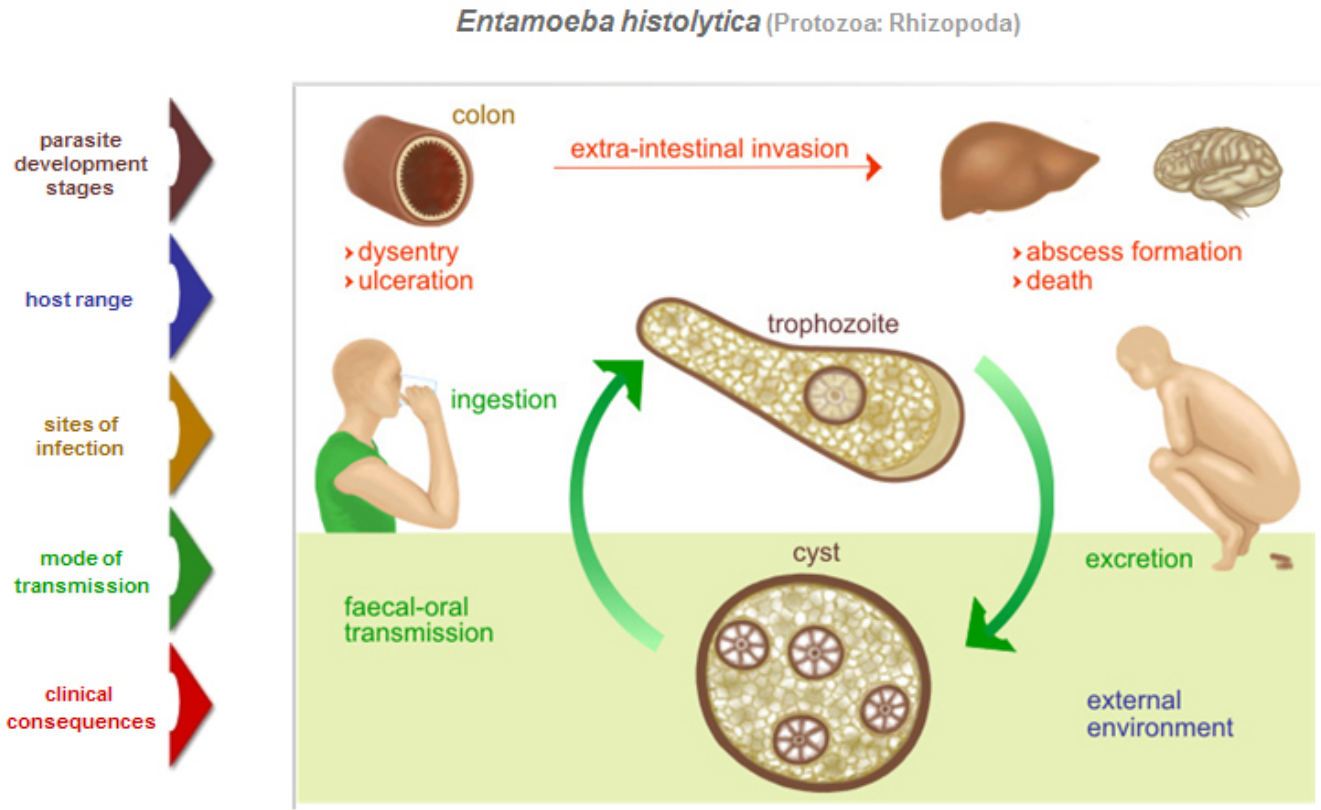
Entamoebidae

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Sarcomastigophora	(with pseudopodia and/or flagella)
Sarcodina	(amoeboid protista)
Rhizopodea	(lobopodia, filopodia, reticulopodia)
Lobosea	(locomotion by broad lobopodia)
Amoebida	(naked amoebae with simple life-cycles)

Family: Entamoebidae

These rhizopod amoebae form broad lobopodia and do not produce fruiting bodies like the mycetozoa (or slime molds). They are naked amoebae with simple life-cycles and do not form temporary flagellated stages. Most members are parasites or endocommensals in the digestive tracts of arthropod or vertebrate hosts. Individual species are differentiated on the basis of nuclear structure but all are characterized by the possession of a vesicular nucleus with a central endosome. Trophozoites form single lobopodia and they form cysts.



Entamoeba histolytica [causes amoebic dysentery in man and primates]

Parasite morphology: The trophozoites are 20-30 µm in diameter and contain a vesicular nucleus with a central endosome, peripheral chromatin and radial achromatic fibrils (imparting a 'cart-wheel' appearance). The cysts are spherical measuring 10-15 µm in diameter and have 4 nuclei.

Host range: *Entamoeba histolytica* is predominantly found in primates (including humans) and occasionally in dogs, cats, cattle and pigs. The parasite has a worldwide distribution and is prevalent in tropical and subtropical countries. However, it is readily confused with *Entamoeba dispar*, an identical species but apparently not pathogenic. With the "wisdom" of hindsight, asyptomatic infections in Australia are thought to be due to *E. dispar*. Another species *Entamoeba polecki* has occasionally been found in association with disease in pigs, monkeys and sometimes humans. The species *Entamoeba invadens* is considered to be a serious pathogen of snakes and lizards (especially captive animals).

Site of infection: Trophozoites generally infect the large intestinal mucosa but under certain conditions they may perforate the gut and invade other organs (especially liver, lungs and brain).

Pathogenesis: Many infections remain asymptomatic whereas others cause severe diarrhoea (amoebic dysentery), ulceration and perforation of the colon, and secondary lesions in other organs. Virulence factors are not yet known.

Mode of transmission: Trophozoites passing posteriad condense into spherical precysts (containing chromatoidal bars) which then mature into cysts (containing 4 nuclei). The cysts are very resistant to environmental conditions and are usually ingested with contaminated food or water.

Differential diagnosis: Infections are diagnosed by repeated stool examinations for trophozoites and cysts. Considerable expertise is required to differentiate pathogenic species from harmless commensals on the basis of nuclear and cyst morphology.

Treatment and control: Patients may be treated with luminal, hepatic and/or tissue amoebicides as warranted (metronidazole appears most effective). Control may be facilitated by maintaining high standards of hygiene and ensuring proper water and sewage treatment.

Human enteric amoebae	Cyst diameter	Number of nuclei per cyst	Nuclear characteristics
Entamoeba histolytica	10-15 µm	4	cartwheel
Entamoeba polecki	10-15 µm	4	cartwheel
Entamoeba dispar	10-15 µm	4	cartwheel
Entamoeba hartmanni	7-9 µm	4	cartwheel
Entamoeba coli	15-30 µm	8	cartwheel
Iodamoeba buetschlii	9-15 µm	1	1
Endolimax nana	7-9 µm	1	1
Dientamoeba fragilis	no cyst formed	no cyst formed	

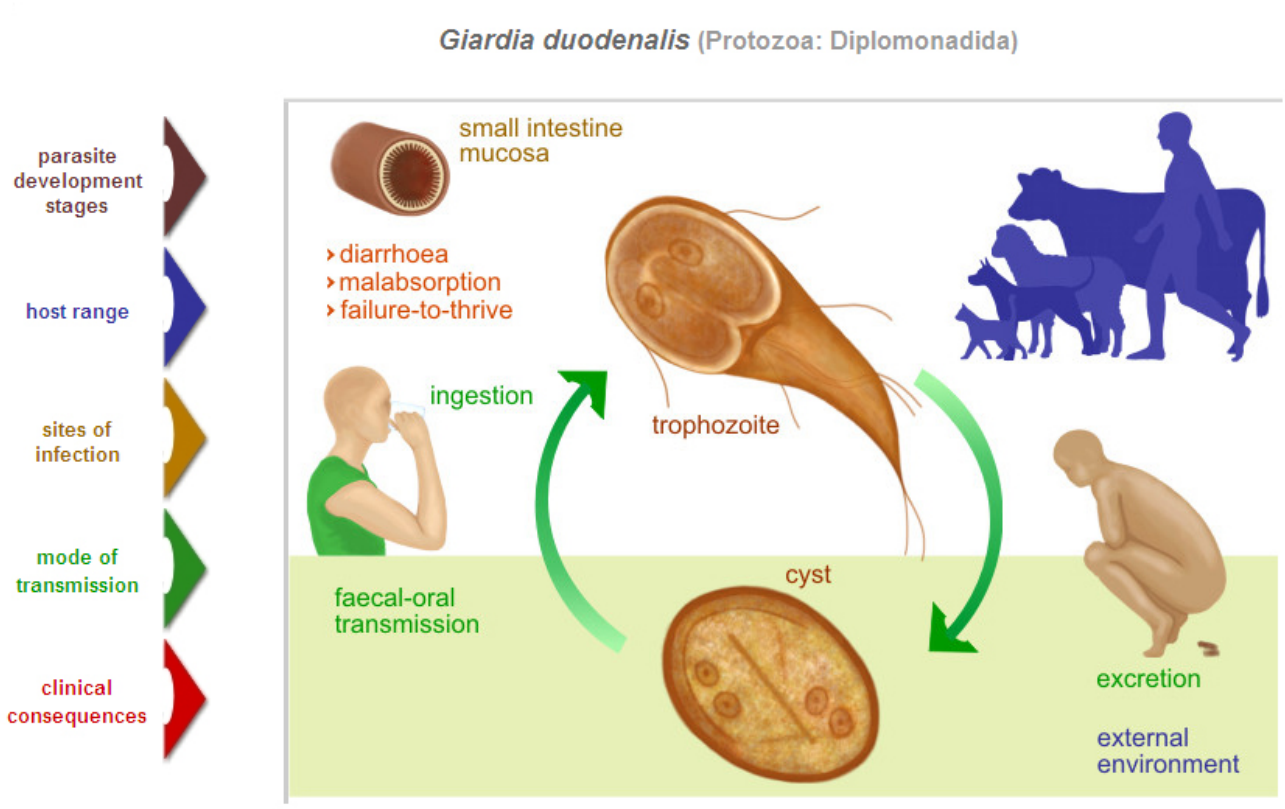
Giardia

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Sarcomastigophora	(with pseudopodia and/or flagella)
Mastigophora	(flagellates)
Zoomastigophora	(zooflagellates, without chloroplasts)
Diplomonadida	(zoites with two nuclei)

Family: Hexamitidae

Diplomonads have complex nucleus-associated karyomastigonts and are defined by the possession of two nuclei and unique bilateral symmetry (diplozoic appearance). They typically form reproductive cysts (each containing four nuclei) which facilitate their transmission between hosts. Hexamitids are parasites or commensals in mammals, birds, reptiles and fish. Several parasitic species cause severe clinical disease in man and domestic animals. All species are characterized by their pyriform shape and bilateral symmetry with two equal nuclei lying side by side, two intracytoplasmic granular axonemes and 6-8 flagella.



Giardia duodenalis [this species causes giardiasis (diarrhoea) in vertebrates]

Parasite morphology: The parasite forms two developmental stages: trophozoites and cysts. The trophozoites are pyriform (10-30 µm long) and have 8 flagella (2 anterior, 2 lateral, 2 ventral and 2 caudal), a prominent ventral adhesive disc, 2 longitudinal axonemes and 2 tangential curved median bodies. Cysts are ovoid to ellipsoid (11-14 µm in length by 7-10 µm in width), membrane-bound (sometimes imparting a halo-appearance) and contain 4 nuclei, axonemes and median bodies.

Host range: Infections have been recorded in many human and animal populations throughout the world. Some 40 species have been described on the basis of host occurrence but most are morphologically indistinguishable. Three species groups have been recognized on the basis of trophozoite morphology; thin elongate trophozoites assigned to the *G. agilis* group found mainly in birds and frogs, short stout trophozoites belonging to the *G. muris* group found mainly in rodents, and medium-sized trophozoites belonging to the *G. duodenalis* group found mainly in mammals. Host specificity within each group remains contested. Epidemiological studies have frequently suggested zoonotic and water-borne transmission between mammals. Indeed, common regional names for the disease often suggest animal or water sources of human infection (e.g. beaver fever, backpacker's malady, traveller's diarrhoea). While cross-transmission studies are difficult to perform due to biological, technical and ethical concerns, experimental studies with *G. duodenalis* isolates have not confirmed broad host specificity. Instead, molecular characterization techniques have identified a range of genotypes which vary in their host specificity and zoonotic potential. Genes used to characterize types have included small subunit ribosomal DNA, glutamate dehydrogenase, triose-phosphate isomerase and beta giardin. Three main zoonotic genotypes have been found in humans (designated A1, A2, B3) while a growing number of other genotypes have been found in domestic animals and wildlife.

Group	Synonyms	Host range	Trophozoite size
G. duodenalis	*G. intestinalis*, *G. lamblia*	mammals (including man), birds, reptiles	12-15 x 6-8 µm
G. muris	*G. ardae*	rodents, birds, reptiles	10-12 x 5-7 µm
G. agilis	*G. gracilis*	amphibia, birds, reptiles	20-30 x 4-5 µm

Site of infection: Flagellated trophozoites are found in the small intestines of their hosts, especially the duodenum. Trophozoites have been observed swimming with a distinct corkscrew motion in luminal content as well as adhering to the gut mucosal surface with their ventral adhesive discs (when they detach, they leave distinct oval impressions in the microvillous layer).

Pathogenesis: Infections interfere with the normal absorptive functioning of the small intestines, thereby causing osmotic overload of the large intestines resulting in watery diarrhoea. Attached parasites may physically blanket the small intestinal mucosa significantly reducing the surface area for absorption. It is also thought some parasite molecular products may exert a chemical action on mucosal cells. Infections apparently damage and increase the turnover rate of epithelial cells culminating in villous atrophy which further reduces the surface area for absorption. These factors contribute to malabsorption of fats and other nutrients resulting in watery diarrhoea and steatorrhea accompanied by dehydration, intestinal pain and flatulence. Most clinical infections are self-limiting and resolve spontaneously but some persist leading to chronic weight loss, retarded growth and 'failure-to-thrive' syndrome. Young individuals are most susceptible to clinical infections and focal outbreaks are common in child day-care centres and among intensively-reared and housed young animals. Not all infected individuals, however, develop clinical signs but may remain asymptomatic carriers.

Mode of transmission: Infections are passed between hosts by the faecal-oral transmission of encysted parasite stages. When trophozoites pass through the colon, they form nonflagellated cysts which are excreted and contaminate the environment. The cysts are said to be reproductive in that they undergo nuclear division as they mature becoming quadrinucleate. Following their ingestion by a new host, they excyst in the small intestine releasing two trophozoites. Excystation stimuli include various post-gastric digestive conditions (bile salts, enzymes, pH, microaerophilic conditions, etc). Most infections are transmitted accidentally by 'hand-to mouth' contact whereby objects contaminated with faecal material are placed in the mouth (e.g. contaminated fingers, utensils, clothing, etc). The cysts are quite resistant to external environmental conditions and can survive for some time, particularly in cool moist conditions. The cysts also contaminate water supplies and cause infections when subsequently ingested with drinking water or the consumption of food-stuffs diluted or washed with contaminated water. Infections have also been associated with recreational water use, including swimming pools, lakes and water-theme parks. Conventional water treatment procedures (filtration and chlorination) are not wholly effective against *Giardia* cysts as they are quite small and hardy.

Differential diagnosis: Faecal cysts may be detected by routine coprological examinations (stained smears, or sedimentation/flotation concentration techniques) but test sensitivity is poor due to intermittent cyst excretion. Endoscopic techniques (gastroscopy through to duodenum) have been used in chronic cases to detect trophozoites in intestinal biopsy material. More recently, sensitive and specific immunological techniques have been developed to detect parasite antigens in faecal preparations (copro-antigen tests). Similar monoclonal antibody immunoreagents are also used in many countries to detect cysts in water samples using immuno-magnetic separation techniques.

Treatment and control: Flagyl (metronidazole) is the drug of choice for giardiasis despite mild side-effects (such as nausea). However, there are growing problems with metronidazole-resistant parasite strains. Other nitroimidazole derivatives (tinidazole), nitrofurans (furazolidone), acridine drugs (quinacrine) and microtubule inhibitor anthelmintics (albendazole) have been reported effective. Control depends largely on good sanitation, proper effluent disposal and effective water treatment (well-maintained sand filtration or microfiltration, optimum chlorination or ozonation).

Trypanosoma

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Sarcomastigophora	(with pseudopodia and/or flagella)
Mastigophora	(flagellates)
Zoomastigophora	(zooflagellates, without chloroplasts)
Kinetoplastida	(presence of extranuclear DNA, kinetoplast)

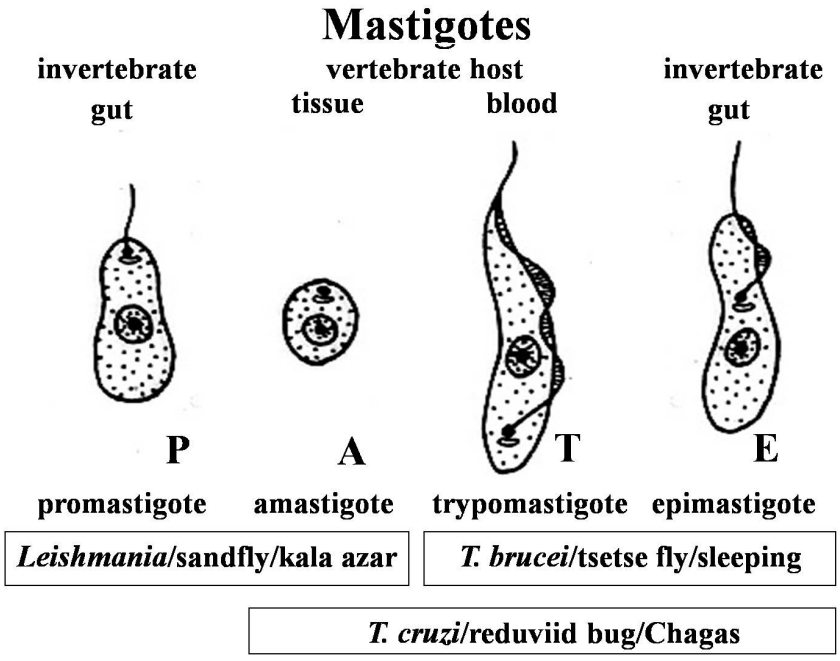
Family: Trypanosomatidae

All species are characterized by the possession of a kinetoplast, a unique structure formed by massed DNA (circles or lattice) within the single large mitochondrion closely associated with the flagellar basal body. Four main developmental stages are formed: trypomastigotes (with a posterior kinetoplast and an emergent flagellum forming a long undulating membrane); epimastigotes (with an anterior kinetoplast and an emergent flagellum forming a short undulating membrane); promastigotes (with an anterior kinetoplast and a short emergent flagellum, but no undulating membrane); and amastigotes (with a kinetoplast but no emergent flagellum or undulating membrane). Many trypanosome species are parasitic only in insects whereas others are transmitted by insect vectors to a wide range of vertebrate hosts. Three main groups infect the blood and/or tissues of humans and animals causing severe clinical diseases:

> **salivarian trypanosomes** which undergo anterior station (foregut) development in the insect vector and are transmitted via saliva to the blood of vertebrate hosts (e.g. tsetse flies transmit *T. brucei* which causes sleeping sickness in humans and nagana in cattle)

> **stercorarian trypanosomes** which undergo posterior station (hindgut) development in vectors and are transmitted via faecal contamination of bite site to infect blood and tissues of vertebrate hosts (e.g. reduviid bugs transmit *T. cruzi* which causes Chagas' disease in humans)

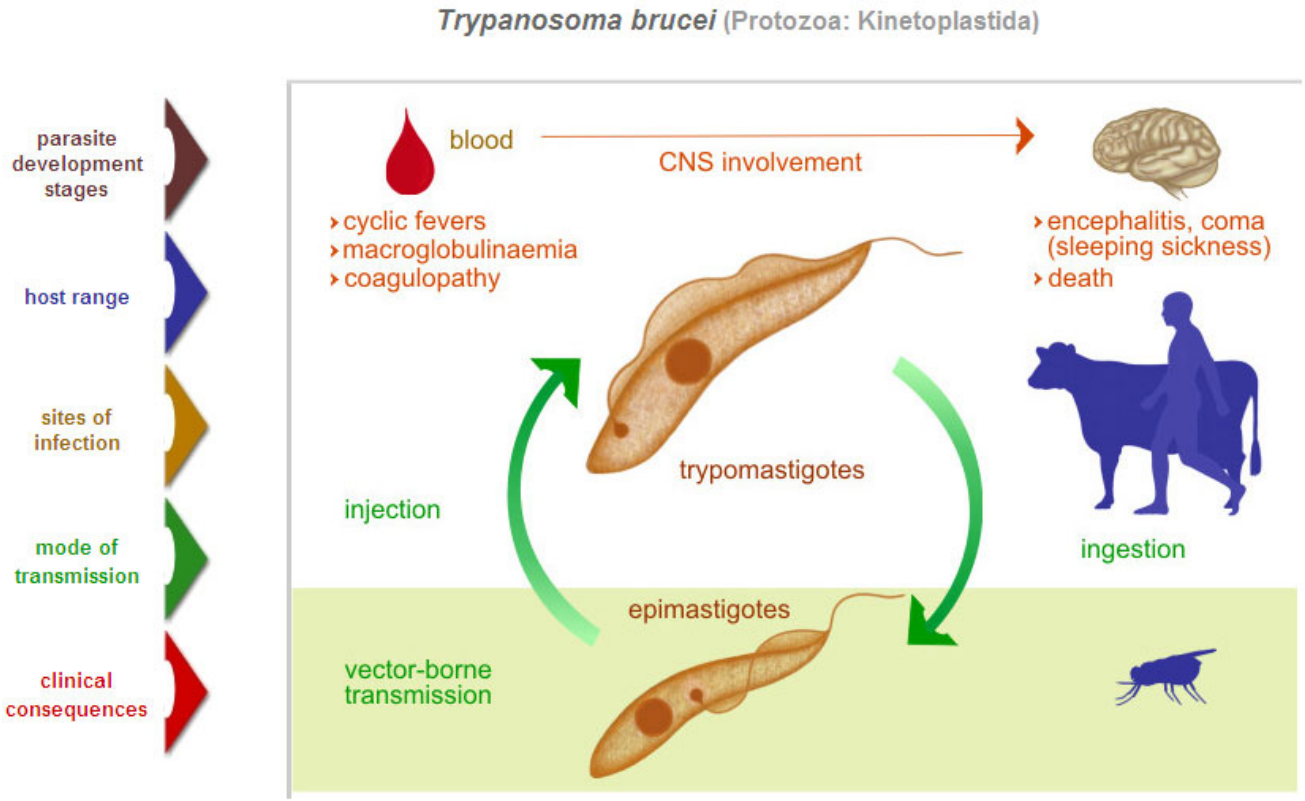
> **leishmanias** which develop in foregut of insect vectors and are transmitted via bite to the tissues of vertebrate hosts (e.g. sandflies transmit *Leishmania* spp. causing 3 types of leishmaniasis in humans and animals)



***Trypanosoma* spp.**	**Mastigote length**	**Vertebrate hosts**	**Disease**	**Insect vector**	**Distribution**
CYCLIC TRANSMISSION (parasite development within vector)					
SALIVARIA (anterior station development)					
T. b. gambiense	16-30 µm	man, domestic animals	sleeping sickness	tsetse fly	West Africa
T. b. rhodesiense	18-30 µ*m*	man, some ruminants	sleeping sickness	tsetse fly	East Africa
T. b. brucei	18-42 µm	ruminants, monogastrics	nagana	tsetse fly	tropical Africa
T. congolense	9-18 µm	cattle, domestic animals	nagana	tsetse fly	tropical Africa
T. vivax	14-27 µm	ruminants, horses	souma	tsetse fly	tropical Africa
T. simiae	12-24 µm	pigs, some ruminants	virulent trypanosomiasis	tsetse fly	Africa
STERCORARIA (posterior station development)					
T. cruzi	15-24 µm	man, domestic/wild animals	Chagas' disease	reduviid bugs	Americas
T. theileri	25-120 µm	cattle	nonpathogenic	tabanid flies	worldwide
T. melophagium	25-70 µm	sheep	nonpathogenic	sheep ked	worldwide
T. lewisi	20-35 µm	rats	nonpathogenic	rat fleas	worldwide
T. rangeli	25-32 µm	man, rats	nonpathogenic	reduviid bugs	Sth America
NON-CYCLIC TRANSMISSION (no parasite development within vector)					
MECHANICA (mechanical transmission)					
T. evansi	18-34 µm	ruminants, horses, dogs	surra, murrina	biting flies/bats	Asia, America
T. equinum	20-30 µm	horses, ruminants	mal de caderas	biting Diptera	America
T. equiperdum	18-30 µm	horses	dourine	coitus	tropics

Trypanosoma brucei **[this species causes sleeping sickness in humans and nagana in cattle]**

Parasite morphology: The parasite forms trypomastigotes in vertebrate hosts and epimastigotes in the insect vector. The trypomastigotes (with posterior kinetoplast and long undulating membrane) are pleomorphic in size ranging from 16-42 µm in length by 1-3 µm in width. They occur as elongate slender dividing forms (with long free flagellum) or stumpy non-dividing infective (metacyclic) forms (with no free flagellum). The epimastigotes (with anterior kinetoplast and short undulating membrane) are also variable in size ranging from 10-35 µm in length by 1-3 µm in width.



Host range: Salivarian trypanosomes are confined to tropical Africa, corresponding in distribution with their tsetse fly vectors. Three closely-related subspecies are found: *Trypanosoma brucei brucei* (*T. b. brucei*) which is primarily parasitic in native antelopes and other wild ruminants (asymptomatic carriers, trypanotolerant) but infects introduced domestic animals; *T. b. rhodesiense* which causes acute disease in humans in East Africa; and *T. b. gambiense* which produces a much more chronic disease in humans in West Africa.

Site of infection: Trypomastigotes are found extracellularly in the blood and lymph of infected individuals (including lymph nodes and spleen) but may invade the central nervous system and other tissues.

Pathogenesis: The disease is known as Old World (African) trypanosomiasis. Although there are many regional common names given depending on the parasite subspecies and hosts involved, the disease is often called sleeping sickness in humans, and nagana in animals. Parasites injected into the host by the insect vector first cause an inflammatory reaction characterized by a localized tender reddish swelling (known as a chancre). Trypanosomes then multiply in the plasma and interstitial fluid causing acute to subacute febrile illness. A classic sign of *T. b. gambiense* infection is the enlargement of the cervical lymph glands at the back of the neck (known as Winterbottom's sign). *T. b. rhodesiense* infections in humans usually cause acute systemic disease with haemolymphatic involvement, swollen lymph nodes, fever and rapid weight loss. *T. b. gambiense* usually causes chronic disease with neurological involvement, meningoencephalitis, lethargy and coma (hence 'sleeping' sickness). Parasite development occurs in cyclic waves moderated by host immune responses. Trypanosomes have a glycoprotein coat on the outer surface of the cell membrane which is highly antigenic and leads to the production of host antibodies which

act, together with complement, to lyse parasites. Trypanosomes, however, repeatedly change the molecular arrangement of the coat so some individuals avoid immune destruction and divide to produce a new wave of infection. This antigenic variation is under genetic control and while synthesis of successive variant surface glycoproteins does not occur in a fixed sequence, it is not entirely random. The repeated cycles of host antibody production and parasite destruction leads to cyclic fevers, macroglobulinemia, microvascular damage, coagulopathy, and perivascular inflammation. When parasites penetrate the blood-brain barrier (within weeks for *T. b. rhodesiense* or up to years for *T. b. gambiense*), they cause encephalitis, coma and death. The clinical course of *T. b. brucei* infections depends on the susceptibility of the host species. Horses and dogs are particularly susceptible and may succumb within 2-3 weeks Cattle and pigs are more refractory to disease and may survive for several months. Clinical signs include anaemia, fever, oedema and progressive paralysis. Native animal species (antelope and other wild ruminants) are trypanotolerant and may act as asymptomatic carriers.

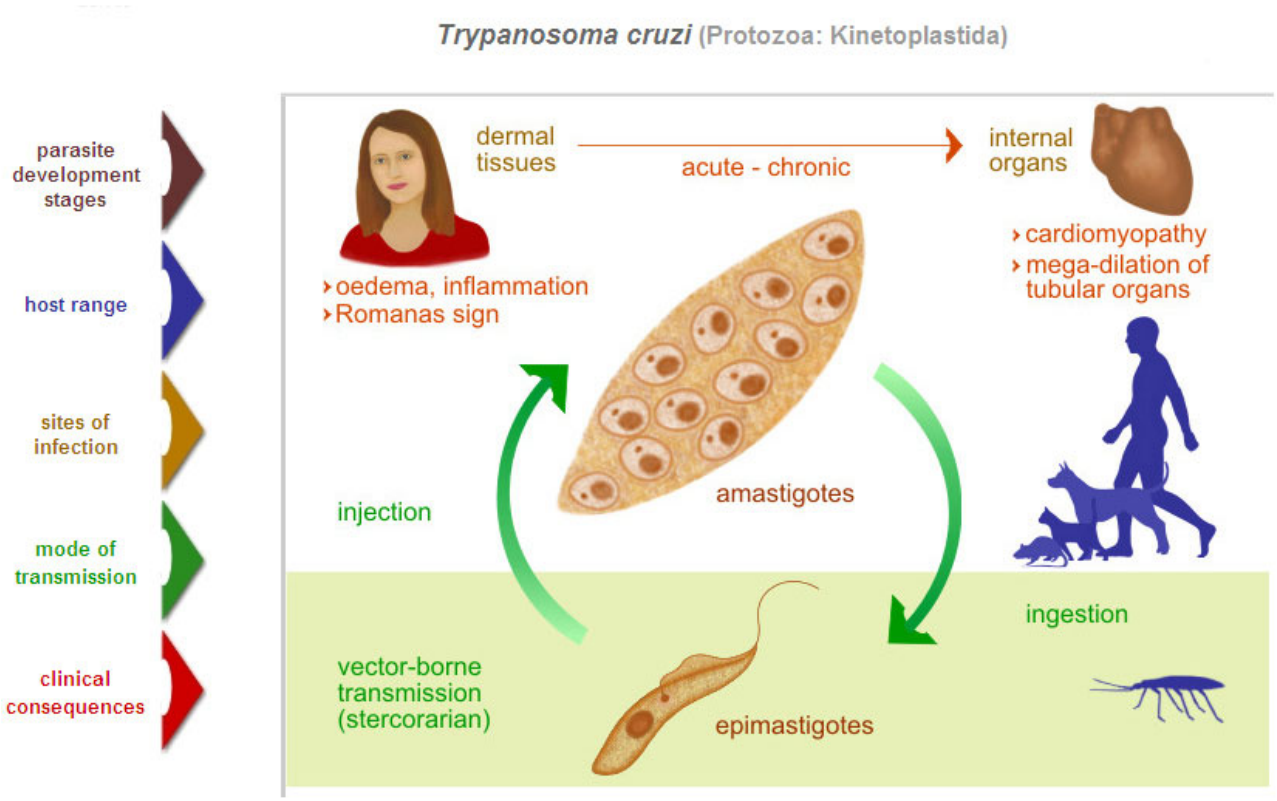
Mode of transmission: All salivarian trypanosomes are transmitted by tsetse fly vectors (*Glossina* spp.). Metacyclic trypomastigotes ingested during feeding transform into procyclic trypomastigotes in the midgut. These stages migrate through gut membranes and invade the salivary glands where they transform into epimastigotes which undergo anterior station development to produce infective metacyclic trypomastigotes which are injected during feeding.

Differential diagnosis: Infections were conventionally diagnosed by the direct detection of parasites in blood, bone marrow or cerebrospinal fluid by microscopic examination before or after centrifugation. *In vitro* cultivation has proven difficult and *in vivo* inoculation into laboratory animals yields variable results. More recently, a variety of immunoserological tests have been developed to detect host antibodies using fluorescent, agglutination or enzyme markers. Card-agglutination and dot-spot tests are available for field use. Molecular characterization techniques utilizing polymerase chain reaction (PCR) amplification of parasite DNA have yielded good results in species/strain differentiation with certain genes (e.g. SRA gene, serum-resistant-associated).

Treatment and control: Historically, arsenical drugs have been used despite major toxicity problems. Melarsoprol and trypursamide are used to treat chronic infections (involving CNS signs). Other drugs have proven more effective against systemic infections (suramin, pentamidine) and neurological infections (berenil, eflornithine, difluoromethylornithine). Prevention involves avoiding being bitten by tsetse flies, but this can be difficult as they are persistent daytime feeders and can bite through thin clothing. Control measures based on vector eradication (using insecticidal sprays, fly traps, or clearing vegetation) and managing wild game reservoirs of infection (by fencing, culling or creating wildlife corridors) have only proven partially effective. Some recent success has been recorded in breeding trypanotolerant domestic livestock (e.g. Ndama cattle).

Trypanosoma cruzi [this species causes Chagas disease in humans]

Parasite morphology: Three developmental stages are formed: trypomastigotes, amastigotes and epimastigotes. Trypomastigotes are elongate thin stages with a posterior kinetoplast and an undulating membrane along the length of the body. They are often curved in shape ranging from 15-20 µm in length by 1-3 µm in width. Amastigotes are small rounded non-flagellated cells with an eccentric nucleus and kinetoplast. These cells are among the smallest known eukaryotic cells ranging from 1.5-4.0 µm in diameter. Epimastigotes are long thin cells with an anterior kinetoplast, a short undulating membrane and a long free flagellum. They are pleomorphic in shape and range in size from 10-20 µm in length by 1-3 µm in width



Host range: *T. cruzi* occurs in humans throughout most of South and Central America and in several southern areas of North America. Infections occur in many mammalian species, but not other animals. Companion animals, such as dogs and cats, may act as reservoir hosts as well as rodents and other wild animals, such as armadilloes, racoons, opossums and even vampire bats. Other stercorarian trypanosomes are nonpathogenic and include *T. rangeli* in man and rats in South America and *T. theileri*, *T. melophagium* and *T. lewisi* in cattle, sheep and rats throughout the world.

Site of infection: Amastigotes are found within vertebrate hosts in many different tissues. Host cells most frequently invaded are reticuloendothelial cells of the spleen, liver and lymphatics and cells in cardiac, smooth and skeletal musculature. The amastigotes divide repeatedly ultimately lysing the host cell and infecting neighbouring cells, sometimes resulting in cyst-like colonies (called pseudocysts) in muscle cells. Some amastigotes give rise to haematozoic trypomastigotes which circulate in the blood.

Pathogenesis: This parasite causes New World (or American) trypanosomiasis, a chronic condition commonly known as Chagas' disease. The first sign is often inflammation and swelling of the skin at the site of infection (lesion called a chagoma). If this involves the conjunctiva of the eye, unilateral orbital oedema (known as Romana's sign) may develop. Amastigotes infect many cells, either actively or by phagocytosis, and undergo proliferation causing cell lysis and tissue lesions. Acute clinical signs include inflammation, fever, hepatosplenomegaly, lymphadenopathy and cardiac arrhythmia. Chronic infections are characterized by cardiomyopathy, myositis and 'megasyndrome' dilation of tubular organs (especially the oesophagus and colon).

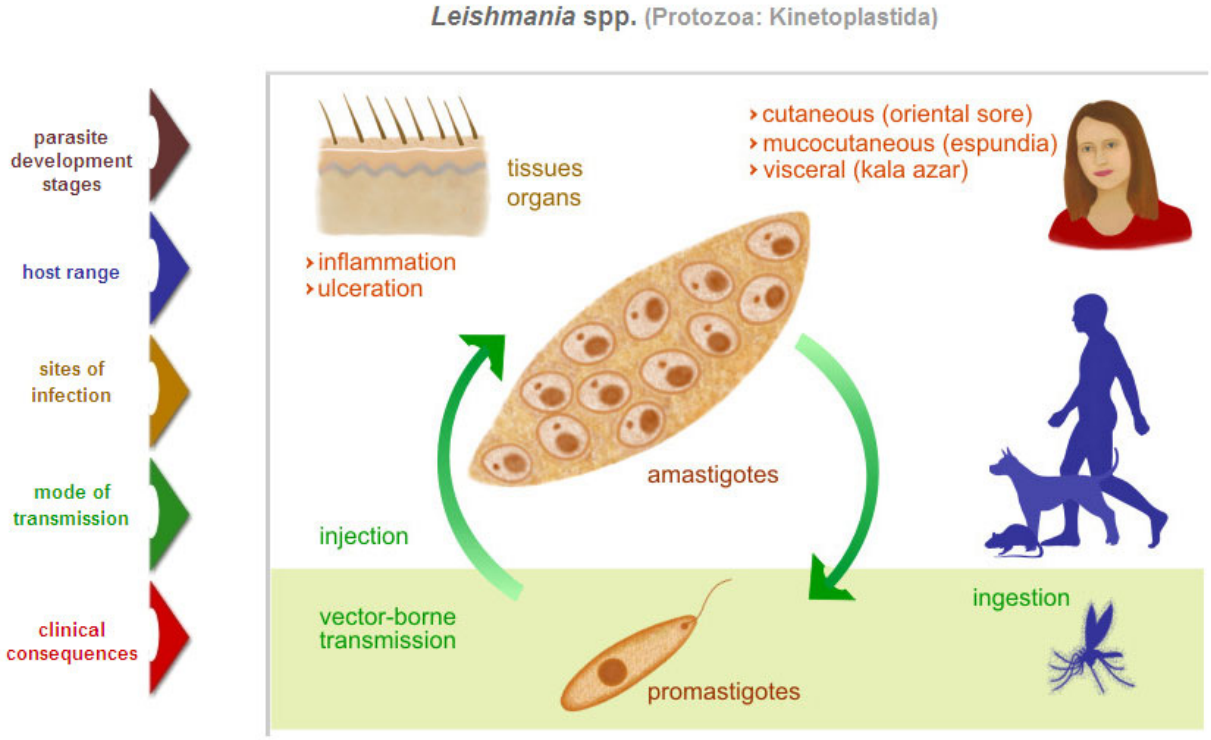
Mode of transmission: Infections by *T. cruzi* are transmitted by blood-sucking reduviid bugs belonging to the subfamily Triatominae, commonly known as assassin- or kissing-bugs because they often feed around the lips of sleeping persons. The disease is often associated with poverty, because the bugs live in cracks in the mud walls of houses in poor areas. The parasites undergo posterior station (stercorarian) development where epimastigotes develop in the hindgut and metacyclic trypomastigotes are passed in the bug faeces during or after feeding. The parasites enter the vertebrate host through the bite site, scratched skin or through mucous membranes rubbed with contaminated fingers. Amastigotes multiply within host cells giving rise to haematozoic trypomastigotes which are taken up by feeding vectors. Infections by *T. cruzi* and *T. rangeli* are transmitted by reduviid bugs whereas *T. theileri*, *T. melophagium* and *T. lewisi* are transmitted by tabanid flies, sheep ked and rat fleas, respectively

Differential diagnosis: Trypanosomes may be detected in blood, lymph, cerebrospinal fluid or biopsy tissues before or after laboratory culture. The parasites grow well *in vitro* in a range of media (especially nutrient agar-blood mixtures) and they readily infect laboratory mice. In the past, xenodiagnosis has also been used where clean laboratory-reared reduviid bugs are allowed to feed on patients and then examined several weeks later for parasites. A range of immunoserological tests have been developed to detect host antibodies and more recently, polymerase chain reaction (PCR) techniques have been used to amplify parasite DNA from clinical samples. Molecular characterization studies have identified various biodemes, zymodemes, schizodemes and genetic lineages which have been grouped into *T. cruzi* I (mainly in wild mammals and sylvan triatomines), *T. cruzi* II (usually in humans) and other non-grouped strains. Sequences examined have included 24S ribosomal DNA, kinetoplast DNA, mini-exon genes and microsatellites (tandem array repetitive DNA).

Treatment and control: Infections do not respond well to chemotherapy due to the ‘hidden’ intracellular location of the amastigotes. Nifurtimox, benznidazole and allopurinol have been reported to apparently reduce the severity of some early stage infections but they have serious adverse and toxic side-effects and are not effective against chronic infections. Control measures based on vector eradication using insecticidal sprays have proven partially effective but expensive. Prevention includes avoiding bug bites through the use of bed nets, and eliminating potential bug habitats by repairing cracked walls and using better building products and techniques.

***Leishmania* spp.** [cause cutaneous, mucocutaneous or visceral leishmaniasis in humans]

Parasite morphology: Two developmental stages are formed: amastigotes and promastigotes. The amastigotes are small spherical non-flagellated cells ranging from 2-4 µm in diameter. The nucleus and kinetoplast are surrounded by small ring of vacuolated cytoplasm and the cells are among the smallest nucleated cells known. Promastigotes are thin elongate cells with an anterior kinetoplast and an emergent free flagellum. They are generally lance-like in shape and range in size from 5-14 µm in length by 1.5-3.5 µm in width. Different parasite species are generally not differentiated by morphological differences, but rather on the basis of geographical, biological and clinical features.



Host range: All *Leishmania* spp. infect mammals and are most commonly found in humans, dogs and rodents. Infections are confined to tropical areas, different parasite species being found in the Old World (Middle-East and Africa) and the New World (Central and South America).

Site of infection: Amastigotes invade macrophage cells of the reticuloendothelial and lymphoid systems of the skin, nasopharynx or viscera depending on the parasite species. The parasites survive within phagosomes but resist digestion by lysosomal enzymes. They multiply and grow, ultimately rupturing the host cell and releasing stages to infect new macrophages, including those which circulate in the blood (monocytes).

Pathogenesis: The parasites cause three distinct types of clinical disease, cutaneous, mucocutaneous and visceral leishmaniasis. Old World cutaneous leishmaniasis is caused by *L. tropica* and *L. aethiopica* while New World cutaneous leishmaniasis is caused by *L. mexicana* and *L. braziliensis*. Infections generally involve only one or a few lesions at the bite site; they do not spread to other sites. Active lesions appear as open sores/ulcers with pronounced inflammation. Most lesions heal spontaneously, leaving the host with solid protective immunity to re-infection. However, under certain conditions (esp. immuno-compromised hosts), some *L. aethiopica* infections may spread giving rise to disseminated cutaneous leishmaniasis (not unlike leprosy in appearance). Infections by *L. braziliensis* are also often confined to single skin lesions, but sometimes they spread to the mucocutaneous junction in the pharynx and may cause severe destructive nasopharyngeal lesions. Visceral leishmaniasis is caused by *L. donovani* whereby infected macrophages congregate in the viscera, notably the liver and spleen, producing hepatosplenomegaly, oedema and anaemia. It is a slow but progressive illness, with bouts of irregularly recurring fever, and is invariably fatal, unless treated.

Leishmania species	Vertebrate hosts	Disease	Insect vector	Distribution
CUTANEOUS LEISHMANIASIS				
L. aethiopica	humans, hyraxes	diffuse or dry cutaneous	*Phlebotomus*	Ethiopia, Kenya
L. tropica minor	humans, dogs, rodents	dry cutaneous	*Phlebotomus*	Mediterranean
L. tropica major	humans, dogs, rodents	wet cutaneous, oriental sore	*Phlebotomus*	Mediterranean
L. peruviana	humans, dogs	uta, cutaneous	*Lutzomyia*	Peru
L. mexicana mexicana	humans, rodents	chicleros ulcer, cutaneous	*Lutzomyia*	Central America, Mexico
L. mexicana amazonensis	humans, rodents	diffuse, cutaneous	*Lutzomyia*	South America
L. mexicana pifanoi	humans, rodents	cutaneous, mucocutaneous	*Lutzomyia*	Venezuela
L. braziliensis	humans, rodents, sloths	espundia, mucocutaneous	*Lutzomyia*	Mexico-Brazil
VISCERAL LEISHMANIASIS				
L. donovani donovani	humans, dogs, foxes	kala azar, dum-dum fever, Old World visceral	*Phlebotomus*	Mediterranean, South America
L. donovani infantum	humans, dogs	infantile, visceral	*Phlebotomus*	Mediterranean
L. donovani chagasi	humans, foxes, cats	New World visceral	*Lutzomyia*	South America

Mode of transmission: All species are transmitted by small blood-sucking sandflies, notably *Phlebotomus* spp. in the Old World and *Lutzomyia* spp. in the New World. Only the females feed on blood. Amastigotes ingested during feeding transform in the midgut or hindgut into promastigotes which multiply by binary fission. The parasites migrate forward to the foregut and proboscis where some become swept away by saliva into the bite site when the fly feeds.

Differential diagnosis: Amastigotes may be detected microscopically in biopsy tissues, smears or secretions before or after culture. Parasites are best visualized using Giemsa's or Leishman's stains, and suitable culture media include conventional nutrient agar-blood mixtures. Serological tests have been developed but there are difficulties in distinguishing between recent and chronic infections and between infections by different parasite species, although a delayed-type hypersensitivity (DTH) skin test has shown good promise as a marker of cured symptomatic or asymptomatic visceral infection. Modern molecular characterization techniques have used the polymerase chain reaction (PCR) to amplify parasite DNA from host tissues.

Treatment and control: Some cutaneous infections require no treatment as lesions may heal within several months. Systemic therapy with pentavalent antimonials (sodium stibogluconate or meglumine antimonate) is the treatment of choice for disfiguring and visceral infections. The development of antimonial drug resistance, however, is a growing problem in many endemic areas, including South America, India and the Middle-East. Pentamidine or amphotericin B can be used if antimonials are ineffective, and miltefosine and aminosidine (paromomycin) have shown promise as treatment options, especially when combined with immunotherapy using the tumour-necrosis factor-alpha (TNF-α) inhibitor pentoxifylline. Preventive measures include protection from sandfly bites but this can be difficult as they are so small that they can penetrate most mosquito nets. Reducing the size of reservoir host populations (especially dogs) has proven beneficial in many endemic urban areas. Many cutaneous infections, however, are acquired in forests away from human habitation, as the reservoir hosts are wild animals (esp. rodents). The prevention of sandfly bites in forest areas is almost impossible but may be minimized by the use of protective clothing, insect repellants and insecticidal sprays in houses.

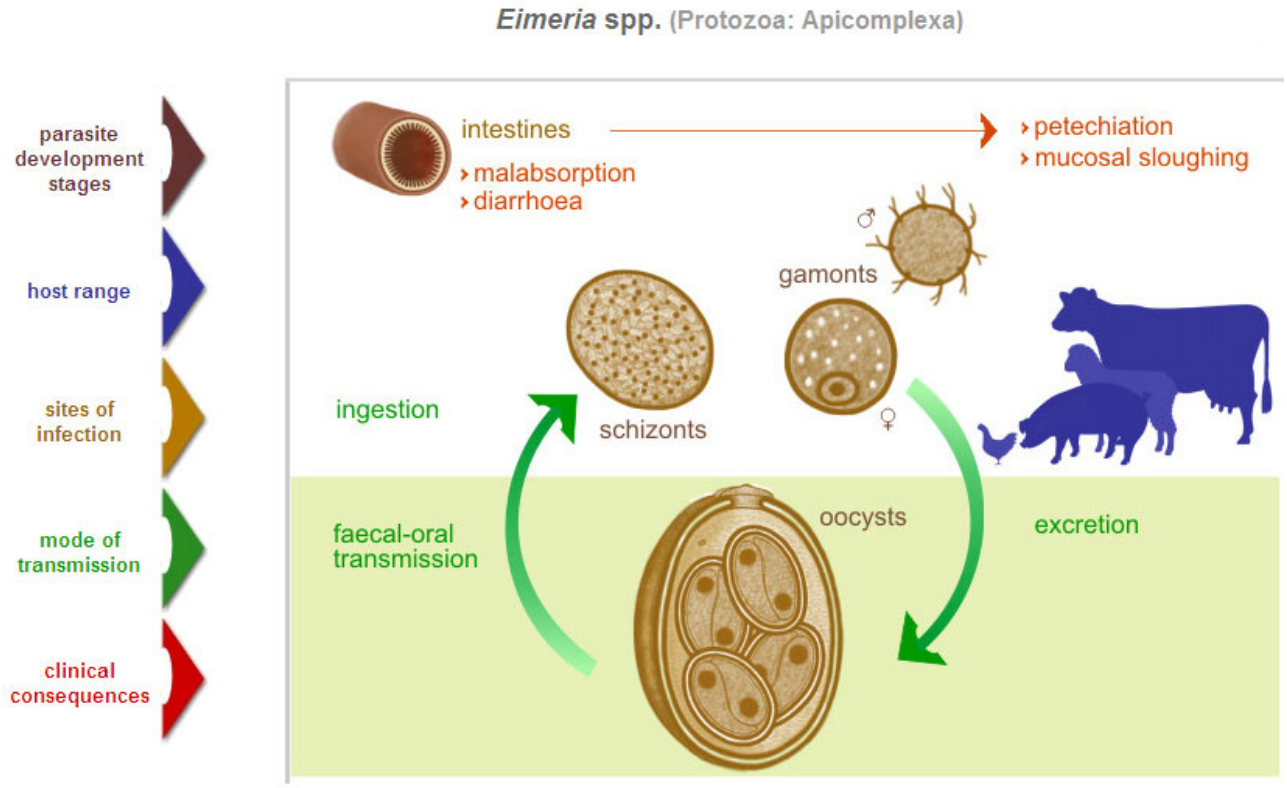
Eimeria

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Coccidea	(gamonts small and intracellular, form small resistant spores called oocysts)
Eimeriida	(gametes develop independently without syzygy; known as coccidian parasites)

Family: Eimeriidae

These protozoa are known as the enteric coccidia; monoxenous (one-host) parasites in the digestive tracts of herbivores or carnivores causing diarrhoeal disease (known as coccidiosis). Parasites form environmentally-resistant oocysts which undergo faecal-oral transmission between hosts. There are three sequential stages in the parasite life-cycle: endogenous multiplication by asexual merogony (variously known as schizogony) followed by sexual gamogony (♂ microgametes fertilize ♀ macrogametes producing oocysts) which are excreted and undergo asexual sporogony (forming sporocysts containing infective sporozoites). Many genera are recognized on the basis of oocyst configuration (the number of sporocysts per oocyst, and the number of sporozoites per sporocyst).



***Eimeria* spp.** [these species cause coccidiosis in vertebrates, especially herbivores]

Parasite morphology: Coccidian parasites form three developmental stages: schizonts, gamonts and oocysts. Schizonts range in size depending on parasite species, location in the host and stage of maturity. They begin as small basophilic rounded cells (mother meronts) located intracellularly within host cells. The meronts form numerous daughter merozoites by endogenous division of the nucleus followed by cytokinesis. Mature schizonts appear as membrane-bound clusters of small basophilic bodies (similar to bunches of grapes). Individual schizonts usually range in diameter from 10-100 µm but some species form enormous megaloschizonts (up to 1 mm in diameter). Gamonts exhibit sexual differentiation, with microgamonts (♂) apparent as multinucleate basophilic stages ultimately shedding small biflagellated microgametes; and macrogamonts (♀) evident as uninucleate eosinophilic cells with a single ovoid nucleus. Developing oocysts contain numerous eosinophilic wall-forming bodies which give rise to the tough outer oocyst walls. Unsporulated oocysts contain a developing sporoblast which eventually undergoes sporulation forming sporocysts which contain the infective sporozoites. *Eimeria* oocysts exhibit a characteristic 1:4:2 configuration, that is, each oocyst contains 4 sporocysts each containing 2 sporozoites. Oocysts are generally ovoid to ellipsoid in shape, range from 10-40 µm in length by 10-30 µm in width, and may contain specialized structures, such as polar caps, micropyles, residual and crystalline bodies.

Host range: Infections have been recorded throughout the world in most vertebrate species, including eutherian and metatherian mammals, birds, reptiles and fish. Most coccidian species are considered to be highly host-specific and only parasitize single host species (oioxenous), although some species in birds and reptiles may parasitize closely-related hosts (stenoxenous) and a few species in fish may parasitize unrelated hosts (euryxenous). Many hosts also harbour multiple species of coccidia which may vary considerably in morphology, developmental cycle, site of infection and pathogenicity. Twelve *Eimeria* spp. have been described from cattle, 11 species from sheep, 9 from goats, and 7 from chickens. In general, the small rapidly-developing species are generally the most pathogenic

Site of infection: Most species undergo endogenous development in the intestinal mucosa (small and/or large intestines) whereas some species develop in the liver, gall bladder or kidneys. They generally exhibit rigid tissue tropism, infecting host cells in particular locations. The parasites undergo several cycles of schizogony culminating in the lysis of host cells to release merozoites. Ultimately, gamonts are formed which mature to produce micro- and macro-gametes that undergo fertilization forming a non-motile zygote (oocyst) which is excreted with host faeces.

Pathogenesis: Most species are not significant pathogens and cause little or no disease. Certain species, however, are highly pathogenic and cause catarrhalic or haemorrhagic enteritis by severe erosion of the mucosal membranes through cell lysis resulting in profuse watery-to-bloody diarrhoea. Clinical disease is not usually manifest until cumulative tissue damage associated with second or third generation schizogony. Moderately-affected animals may show progressive signs such as poor weight gain or weight loss, weakness and emaciation, while severely-affected individuals may die soon after the appearance of disease. Pathogenicity depends on many factors; such as parasite species, viability, infectivity, virulence, tropism, host age, nutritional status, immunological competence, as well as prevailing environmental conditions (temperature, moisture) and management practices. Young animals are most susceptible to clinical disease, although survivors develop strong specific protective immunity against subsequent infection and disease

Mode of transmission: Oocysts excreted with host faeces contaminate the external environment, but they must undergo internal sporulation (sporozoite formation) before they become infective. New hosts are infected when they ingest sporulated oocysts contaminating food or water supplies (faecal-oral transmission). Following ingestion, oocysts and sporocysts excyst in the intestines releasing their contained sporozoites which invade host cells to begin merogony. Excystation stimuli include appropriate post-gastric physico-chemical conditions, such as oxygen levels, pH, bile salts, pancreatic enzymes, etc

Differential diagnosis: Clinical signs usually coincide with parasite patency (patent period = period during which oocysts are produced). Infections are usually diagnosed by the coprological examination of host faeces for coccidial oocysts (concentrated using various sedimentation-flotation techniques). Unstained oocysts are best observed by light microscopy using suboptimal transmitted illumination (condenser wound

down to introduce diffraction), phase-contrast or interference-contrast optics. Fresh faecal samples may only contain unsporulated oocysts so differential specific diagnosis may sometime require short-term storage to facilitate sporulation (2% potassium dichromate is often used to suppress microflora during storage, but not for piscine species, and refrigeration can slow the process down if so required for field samples). Researchers have recently used a range of molecular techniques to characterize genetic variation between and within parasite species, but few techniques are suitable for routine diagnostic use.

Treatment and control: Disease progression is usually so rapid that any therapeutic (curative) treatment may simply be too late. For this reason, continuous in-food or in-water medication is often used for prophylactic (preventative) treatment in many intensive animal industries. A wide range of drugs are available, including those with coccidio-static (reversible suppressive) activity or coccidio-cidal (irreversible lethal) activity. The main drug groups include sulfonamides (sulfanilamide, trimethoprim, ethopabate), pyridinoles (clopidol, decoquinate), nitrobenzamides (zoalene), organic arsenicals (roxarsone), nitrofurans (furazolidone, amprolium), quinazolinones (halofuginone), polyether ionophorous antibiotics (monensin, laslocid, salinomycin, narasin), asymmetric (diclazuril) and symmetric (toltrazuril) triazines. Regrettably, there are mounting problems being encountered with drug resistance amongst many coccidian species, especially that against synthetic drugs which tends to persist within parasite populations. Many industries recommend periodic rotation between different drug groups and the use of combination (cocktail) drugs to minimize the occurrence of resistance. Most coccidial infections stimulate the development of strong protective immune responses, albeit transient unless premunitive (short-lived unless parasites persist). There has been considerable success with control through immunoprophylaxis using attenuated or precocious strains of parasites, particularly in the poultry industry. Researchers are now attempting to develop recombinant subcellular vaccines. Outbreaks can generally be controlled by management practices based around improving hygiene, reducing crowding, removing contaminated litter and isolating infected individuals. Chemical disinfection is usually impractical as the oocysts are resistant to many conventional disinfectants.

Eimeria species	Oocyst size	Host species	Site of infection	Pathogenicity
E. acervulina	18 x 14 µm	chickens	anterior small intestine	high
E. brunetti	26 x 22 µm	chickens	small and large intestines	high
E. maxima	30 x 20 µm	chickens	mid small intestine	moderate
E. mitis	16 x 15 µm	chickens	small and large intestines	low
E. necatrix	20 x 17 µm	chickens	small intestine, caecum	high
E. praecox	21 x 17 µm	chickens	small intestine	low
E. tenella	23 x 19 µm	chickens	caecum	high
E. adenoides	25 x 16 µm	turkeys	small and large intestines	high
E. dispersa	26 x 21 µm	turkeys	anterior small intestine	moderate
E. meleagridis	24 x 18 µm	turkeys	caecum	moderate
E. meleagrimitis	19 x 16 µm	turkeys	anterior small intestine	high
E. gallopavonis	26 x 21 µm	turkeys	small and large intestines	moderate
E. innocua	22 x 21 µm	turkeys	small intestine	low
E. subrotunda	22 x 20 µm	turkeys	small intestine	low
E. alabamensis	19 x 13 µm	cattle	small and large intestines	moderate
E. auburnensis	38 x 23 µm	cattle	small intestine	low
E. bovis	28 x 20 µm	cattle	small and large intestines	high
E. brasiliensis	37 x 27 µm	cattle	unknown	low
E. bukidnonensis	49 x 35 µm	cattle	unknown	low
E. canadensis	32 x 23 µm	cattle	unknown	low
E. cylindrica	23 x 12 µm	cattle	unknown	low
E. ellipsoidalis	23 x 16 µm	cattle	small intestine	low
E. pellita	40 x 28 µm	cattle	unknown	low
E. subspherica	11 x 10 µm	cattle	unknown	low
E. wyomingensis	40 x 28 µm	cattle	unknown	low
E. zuernii	18 x 16 µm	cattle	small and large intestines	high

Eimeria species	Oocyst size	Host species	Site of infection	Pathogenicity
E. ahsata	33 x 23 µm	sheep	small intestine	low
E. bakuensis	29 x 19 µm	sheep	small intestine	low
E. crandallis	22 x 19 µm	sheep	small and large intestines	high
E. faurei	32 x 23 µm	sheep	small and large intestines	low
E. granulosa	29 x 21 µm	sheep	unknown	low
E. intricata	48 x 34 µm	sheep	small and large intestines	low
E. marsica	19 x 13 µm	sheep	unknown	low
E. ovinoidalis	24 x 20 µm	sheep	small and large intestines	moderate
E. pallida	14 x 10 µm	sheep	unknown	low
E. parva	17 x 14 µm	sheep	small and large intestines	low
E. weybridgensis	24 x 17 µm	sheep	small intestine	low
E. alijevi	17 x 15 µm	goats	small and large intestines	low
E. aspheronica	31 x 23 µm	goats	unknown	low
E. arloingi	28 x 19 µm	goats	small and large intestines	high
E. caprina	34 x 23 µm	goats	small and large intestines	moderate
E. caprovina	30 x 24 µm	goats	unknown	low
E. christenseni	38 x 25 µm	goats	small intestine	high
E. hirci	21 x 16 µm	goats	unknown	moderate
E. jolchijevi	31 x 22 µm	goats	unknown	low
E. ninakohlyakimovae	21 x 15 µm	goats	small and large intestines	moderate
E. debliecki	18 x 14 µm	pigs	small intestine	moderate
E. polita	26 x 18 µm	pigs	small intestine	moderate
E. scabra	32 x 22 µm	pigs	small and large intestines	low
E. spinosa	21 x 16 µm	pigs	small intestine	low
E. porci	22 x 15 µm	pigs	small intestine	low
E. neodebliecki	21 x 16 µm	pigs	unknown	low
E. perminuta	13 x 12 µm	pigs	unknown	low
E. suis	18 x 14 µm	pigs	unknown	low

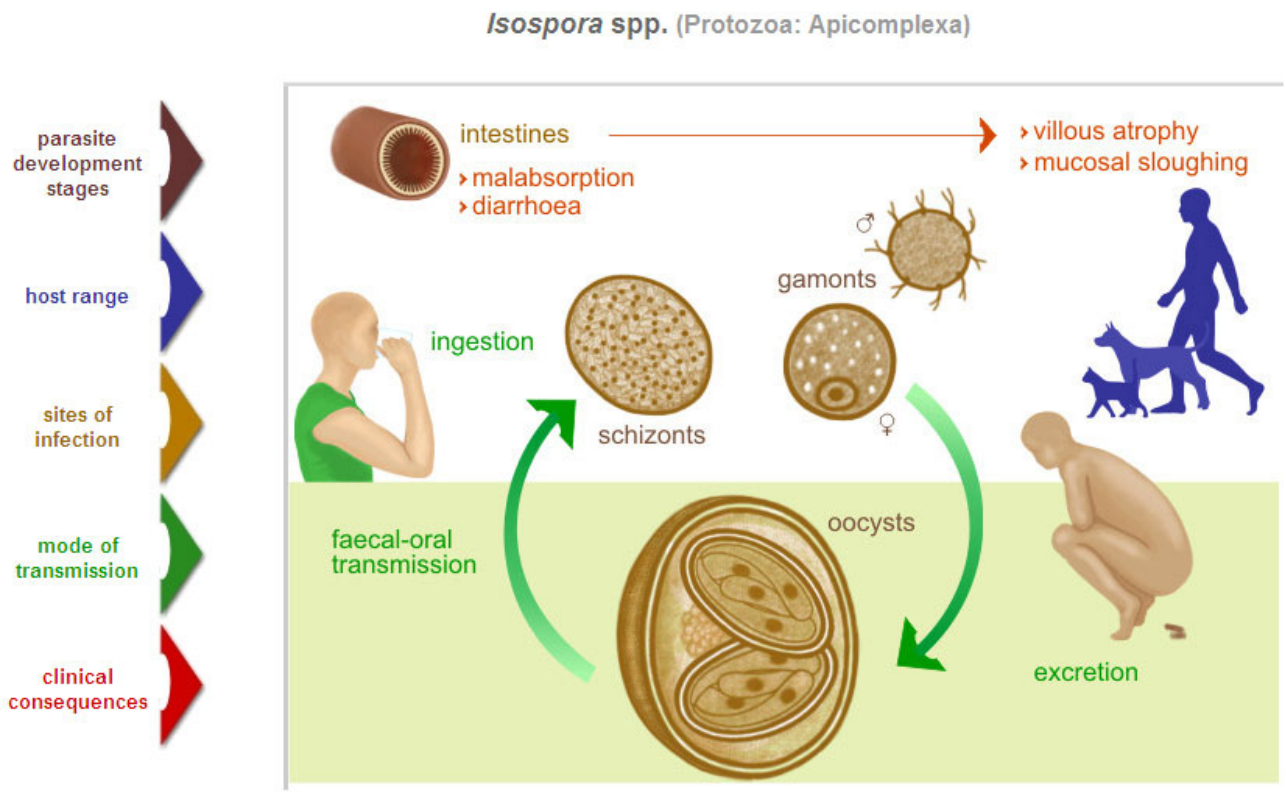
Isospora

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Coccidea	(gamonts small and intracellular, form small resistant spores called oocysts)
Eimeriida	(gametes develop independently without syzygy; known as coccidian parasites)

Family: Eimeriidae

These protozoa are known as the enteric coccidia; monoxenous (one-host) parasites in the digestive tracts of herbivores or carnivores causing diarrhoeal disease (known as coccidiosis). Parasites form environmentally-resistant oocysts which undergo faecal-oral transmission between hosts. There are three sequential stages in the parasite life-cycle: endogenous multiplication by asexual merogony (variously known as schizogony) followed by sexual gamogony (♂ microgametes fertilize ♀ macrogametes producing oocysts) which are excreted and undergo asexual sporogony (forming sporocysts containing infective sporozoites). Many genera are recognized on the basis of oocyst configuration (the number of sporocysts per oocyst, and the number of sporozoites per sporocyst).



Isospora spp. **[these species cause coccidiosis in vertebrates, especially carnivores]**

Parasite morphology: Coccidian parasites form three developmental stages: schizonts, gamonts and oocysts. Schizonts first appear as small basophilic rounded cells (mother meronts) located intracellularly within host cells. The meronts form numerous daughter merozoites by endogenous division of the nucleus followed by cytokinesis. Mature schizonts range in diameter from 10-50 µm and appear as membrane-bound clusters of small basophilic bodies (similar to bunches of grapes). Gamonts exhibit sexual differentiation, with microgamonts (♂) apparent as multinucleate basophilic stages ultimately shedding small biflagellated microgametes; and macrogamonts (♀) evident as uninucleate eosinophilic cells with a single ovoid nucleus. Developing oocysts contain numerous eosinophilic wall-forming bodies which give rise to the tough outer oocyst walls. Unsporulated oocysts contain a developing sporoblast which eventually undergoes sporulation forming sporocysts which contain the infective sporozoites. Isospora oocysts exhibit a characteristic 1:2:4 configuration, that is, each oocyst contains 2 sporocysts each containing 4 sporozoites. Oocysts are generally ovoid to ellipsoid in shape, range from 10-40 µm in length by 10-30 µm in width, and may contain specialized structures, such as polar caps, micropyles, residual and crystalline bodies.

Host range: Infections have been detected throughout the world, mainly in carnivores (particularly canids and felids) as well as in some omnivores (humans, pigs, lizards) and birds (especially passerines). Most coccidian species are considered to be highly host-specific and only parasitize single host species (oioxenous), although some species in birds and reptiles may parasitize closely-related hosts (stenoxenous) or even unrelated hosts (euryxenous). Many hosts also harbour multiple species of coccidia which may vary considerably in morphology, developmental cycle, site of infection and pathogenicity. Three Isospora spp. have been described from dogs, 2 species from cats, one from pigs and one from humans. Other small coccidian species found in some of these hosts include *Sarcocystis*, *Frenkelia*, *Hammondia*, *Besnoitia* spp. and *Toxoplasma gondii.*

Site of infection: Parasites undergo merogony and gamogony in the small intestinal mucosa, located intracellularly within epithelial cells. They undergo several cycles of schizogony, each culminating in host cell lysis releasing merozoites. Ultimately, gamonts are formed which mature to produce micro- and macro-gametes that undergo fertilization forming a non-motile zygote (oocyst) which is excreted with host faeces.

Pathogenesis: Most species are only mildly pathogenic but can cause transient diarrhoea, colic, weight loss and fever. When mature, endogenous developmental stages of the parasite lyse their host epithelial cells lining small intestinal villi, producing villous atrophy, crypt hypertrophy, inflammation, malabsorption and sometimes petechial haemorrhages. There is substantial epidemiological evidence that the severity of infections may be exacerbated by concomitant viral disease or other immunosuppressive agents. Young animals are most susceptible to disease but develop a strong specific protective immunity thereafter.

Mode of transmission: Infections are passed between hosts by the faecal-oral transmission of infective oocysts contaminating the external environment, including food and water supplies. Following ingestion by susceptible hosts, the oocysts and sporocysts excyst in the intestines releasing their contained sporozoites which invade host cells.

Differential diagnosis: Clinical signs generally coincide with parasite patency (period during which oocysts are produced). Infections are usually diagnosed by the coprological examination of host faeces for coccidial oocysts (concentrated using various sedimentation-flotation techniques). Faeces from carnivores can also be pretreated with ether/chloroform to remove fatty material. Unstained oocysts are best observed by light microscopy using suboptimal transmitted illumination (condenser wound down to introduce diffraction), phase-contrast or interference-contrast optics. Alternatively, oocysts can be stained with Giemsa or acid-fast stains of dried smears or with fluorescence dyes (auramine-rhodamine) in wet preparations. Fresh faecal samples may only contain unsporulated oocysts so differential specific diagnosis may sometime require short-term storage to facilitate sporulation (2% potassium dichromate is often used to suppress microflora during storage, and refrigeration can slow the process down if so required for field samples).

Treatment and control: Coccidiostatic drugs, particularly sulfonamides (trimethoprim-sulfamethoxazole), are effective for therapeutic use, acting against endogenous developmental stages to limit infections. Control measures include good sanitation, proper effluent disposal, isolation of infected individuals and avoiding crowding, particularly in intensive husbandry situations, breeding establishments, kennels and

rescue centres. Conventional disinfectants are ineffective against coccidian oocysts, although some ammonia-based products have been shown to kill infective oocysts.

***Isospora* species**	**Oocyst size**	**Host species**	**Site of infection**	**Pathogenicity**
I. belli	35 x 10 µm	humans	small intestine	moderate
I. canis	40 x 30 µm	dogs	small intestine	moderate
I. ohioensis	25 x 16 µm	dogs	small intestine	low
I. burrowsi	12 x 10 µm	dogs	small intestine	low
I. felis	40 x 30 µm	cats	small intestine	moderate
I. rivolta	25 x 16 µm	cats	small intestine	low
I. suis	20 x 18 µm	pigs	small intestine	moderate

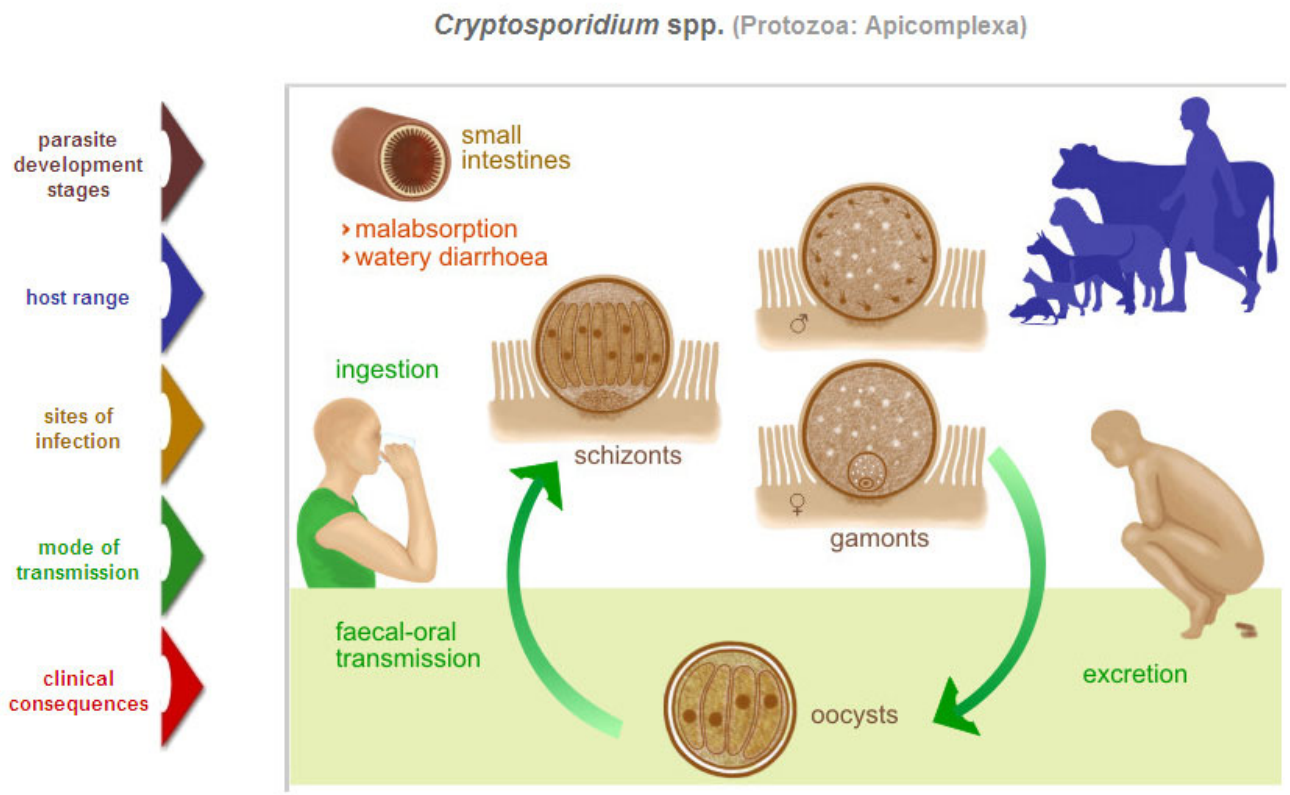
Cryptosporidium

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Coccidea	(gamonts small and intracellular, form small resistant spores called oocysts)
Eimeriida	(gametes develop independently without syzygy; known as coccidian parasites)

Family: Cryptosporidiidae

These parasites are similar to the enteric coccidia; being monoxenous (one-host) parasites in the digestive and/or respiratory tracts of vertebrate hosts. The parasites, however, develop within the brush border (microvillous layer) of host epithelial cells (not in the host cell proper). Endogenous stages have a prominent attachment organelle and they are located within parasitophorous vacuoles formed by a complete covering of microvilli (intracellular yet extracytoplasmic location). They undergo cyclic asexual merogony (schizogony) followed by gamogony (♂ microgametes fertilize ♀ macrogametes) resulting in the formation of small oocysts which undergo exogenous sporulation (forming 4 naked sporozoites not contained within sporocysts).



Cryptosporidium spp. [cause cryptosporidiosis in vertebrates, especially neonates]

Parasite morphology: The parasites form three developmental stages: meronts, gamonts and oocysts. Endogenous developmental stages appear as small basophilic bodies (3-6µm) attached to the luminal surface of host epithelial cells; while exogenous oocysts appear as ovoid phase-bright ovoid bodies (5-7 x 4-6µm) containing four sporozoites and an eccentric residual body.

Host range: Infections have been detected throughout the world in numerous species of mammals, birds, reptiles and fish. Parasite species were originally described primarily on the basis of host occurrence, site of infection, type of disease and, occasionally, differences in oocyst morphometrics. Epidemiological and experimental cross-transmission studies, however, suggested that different parasite species were specific for individual vertebrate classes rather than individual host species. More recently, molecular characterization studies conducted on clinical isolates have identified a range of genotypes (and subgenotypes) that vary in their specificity for mammals; some being highly specific for individual host species (e.g. *C. hominis*) while others were found in multiple host species (e.g. *C. parvum*). Genetic markers used for parasite characterization have included the small subunit (18S) of nuclear ribosomal DNA (SSU rDNA), second internal transcribed spacer of rDNA (ITS-2), 70 kDa heat shock protein (hsp-70), *Cryptosporidium* oocyst wall protein (cowp), thrombospondin-related adhesive protein (TRAP), actin, ?-tubulin, 60 kDa glycoprotein (gp60), and microsatellite loci (ML1 and ML2). The significance of such parasite variation has been used to indicate the anthroponotic and/or zoonotic potential of isolates.

Site of infection: Most parasite species infect the small intestines of their hosts (mammals) whereas others infect the respiratory tract (birds) or stomach (reptiles). The parasites are located within parasitophorous vacuoles covered by host microvillous membranes (intracellular but extracytoplasmic location). They undergo several cycles of asexual merogonous development before gamonts are formed. After fertilization, the oocysts mature in the gut and are usually infective as soon as they are excreted from the host.

Pathogenesis: Infections vary markedly in their presentation ranging from asymptomatic to mild acute to severe chronic disease. Endogenous intestinal stages may cause microvillus destruction, villus atrophy, impaired glucose and electrolyte transport, impaired carbohydrate and protein digestion manifesting in malabsorptive and maldigestive disease. Most clinical infections in immunocompetent individuals involve transient acute disease characterized by profuse watery foul-smelling diarrhoea or acute respiratory signs. Neonates and malnourished individuals are most susceptible, whereas older animals become resistant (immune) to infection. Infections may persist in immunocompromised individuals (those with congenital or acquired immunodeficiencies or those undergoing immunosuppressive therapy) resulting in protracted chronic disease which may prove fatal (especially in AIDS patients). In contrast, infections in reptiles (and possibly fish) cause chronic gastritis typified by postprandial regurgitation.

Mode of transmission: Oocysts excreted by infected hosts contaminate the environment and initiate infections when ingested by susceptible hosts (faecal-oral transmission). Some (thin-walled) oocysts are thought to be auto-infective and may excyst in the same host. Most infections are transmitted by fomites between individuals held in close confinement, such as in child day-care centres, hospitals, zoos, and intensive animal rearing facilities. In addition, oocysts are being detected with increased frequency in treated and untreated water supplies. Many water-borne outbreaks of public health significance have been reported involving contamination of potable and recreational waters (lakes, pools, water parks) by sewage and/or agricultural waste. While conventional methods of water treatment (filtration and chlorination) may reduce contamination levels (quantified by log removal and concentration-time parameters), the small tough oocysts are quite resistant and enough persist to pose a significant problem for water providers. Food-borne transmission has also been recorded (involving milk, cider, salads, sausages), probably attributable to contaminated water being used in food production.

Differential diagnosis: Infections are conventionally diagnosed by the detection of oocysts in smears or concentrates of faecal material or respiratory exudates. Unstained oocysts may be confused with yeasts but they are acid-fast and stain well with basic fuchsin stains. Alternatively, phase-contrast or differential interference contrast microscopy can be used to reveal internal oocyst features, as can vital dyes (DAPI) and fluorescent nucleic acid stains (MPR71059). Although some parasite species can be cultured *in vitro* (in tissue cultures) or *in vivo* (in laboratory or neonatal domestic animals), considerable variation has been observed in parasite infectivity and growth. More success has been reported in detecting oocysts in clinical

and environmental samples using specific monoclonal antibodies for immunomagnetic separation or as fluorescent markers for microscopy or flow cytometry. Researchers have also developed several highly sensitive techniques using polymerase chain reaction (PCR) amplification of partial gene sequences followed by electrophoretic fingerprinting.

Treatment and control: There is currently no effective chemotherapeutic treatment for cryptosporidiosis, although variable success has been reported using paromomycin and nitazoxanide. Supportive treatment by oral or parenteral rehydration may help alleviate symptoms. Some promising results have been obtained using hyperimmune bovine colostrum for passive immunotherapy. Control measures include identification of the source of infection, isolation of infected individuals, maintaining high standards of hygiene, proper effluent disposal and disinfection of contaminated surfaces. Public health authorities also recommend boiling water during outbreak situations and also more regularly for high-risk patients groups (such as HIV-positive individuals).

***Cryptosporidium* species**	**Vertebrate hosts**	**Site of infection**	**Disease**	**Oocyst size**
C. andersoni	cattle	gastric	chronic	7.4 x 5.5 µm
C. baileyi	chickens	enteric, respiratory	acute	6.2 x 4.6 µm
C. canis	dogs, humans	enteric	acute	5.0 x 4.7 µm
C. fayeri	red kangaroo	enteric	?	4.9 x 4.3 µm
C. felis	cats, humans	enteric	acute	5.0 x 4.5 µm
C. galli	chickens	enteric	?	8.2 x 6.3 µm
C. hominis	humans	enteric	acute-chronic	4.9 x 4.3 µm
C. macropodum	eastern grey kangaroo	enteric	?	5.4 x 4.9 µm
C. meleagridis	turkeys, parrots, humans	enteric	acute	5.2 x 4.6 µm
C. molnari	fish	gastro-enteric	chronic	4.7 x 5.4 µm
C. muris	mammals (mice, cats, humans)	gastro-enteric	chronic	7.4 x 5.6 µm
C. nasorum	fish	gastro-enteric	chronic	4.3 x 3.2 µm
C. parvum	mammals (humans, cattle, sheep, goats, horses, pigs, mice)	enteric	acute-chronic	5.0 x 4.5 µm
C. ryanae	cattle	enteric	?	3.7 x 3.2 µm
C. saurophilum	lizards	gastric	chronic	5.0 x 4.7 µm
C. serpentis	snakes, lizards	gastric	chronic	6.2 x 5.3 µm
C. suis	pigs	enteric	acute	4.6 x 4.2 µm
C. wrairi	guinea pigs	enteric	chronic	5.4 x 4.6 µm

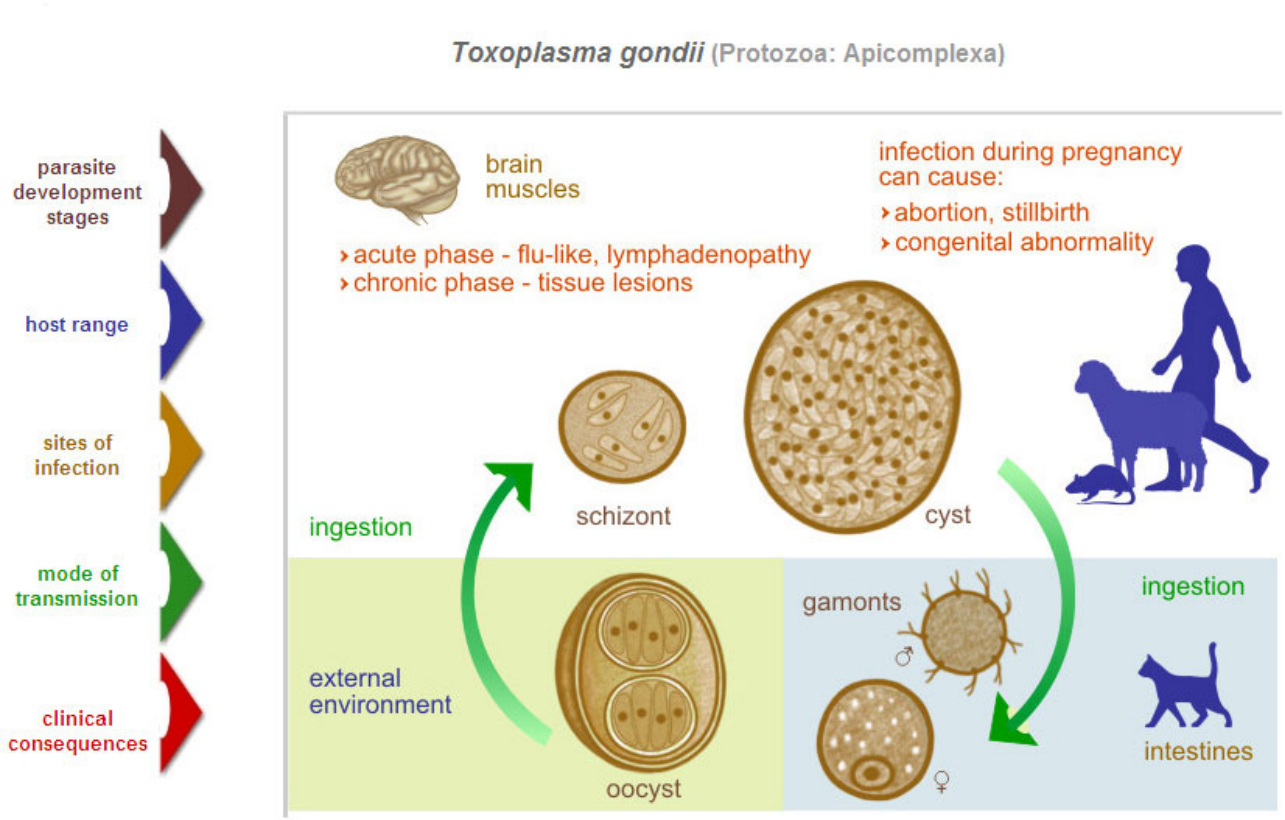
Toxoplasma

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Coccidea	(gamonts small and intracellular, form small resistant spores called oocysts)
Eimeriida	(gametes develop independently without syzygy; known as coccidian parasites)

Family: Toxoplasmatidae

This family belongs to the tissue cyst-forming coccidia: heteroxenous (two-host) parasites cycling between predator and prey hosts (transmission to predator via carnivorism of tissue cysts, and to prey via faecal-oral transmission of spores). Parasites undergo sexual reproduction termed gamogony (♂ microgametes fertilize ♀ macrogametes) in the gut of the predator (= definitive host) resulting in the formation of small spores (oocysts). The oocysts undergo endogenous sporogony (forming sporocysts and sporozoites) and are shed in host faeces. When ingested by prey (= intermediate hosts), the parasites multiply by asexual merogony (schizogony) and then form cysts within host tissues (especially striated muscles and brain). The cysts may remain dormant in the tissues for months or years until eaten by a predator.



Toxoplasma gondii [this species causes toxoplasmosis in numerous vertebrate species]

Parasite morphology: Four developmental stages are formed; schizonts, tissue cysts, gamonts and oocysts. Schizonts appear as small basophilic intracellular bodies which divide rapidly to form small collections of tachyzoites (measuring 4-5 x 1-2 µm). Tissue cysts (measuring 10-100 µm in diameter) are surrounded by a thin primary cyst wall (<0.5 µm thick) and contain hundreds of basophilic bradyzoites (measuring 3-4 by 1-2 µm). Gamonts exhibit sexual differentiation, with microgamonts (♂) apparent as multinucleate basophilic stages ultimately shedding small biflagellated microgametes; and macrogamonts (♀) evident as uninucleate eosinophilic cells with a single ovoid nucleus. Oocysts are small ovoid stages (10-13 x 9-11 µm) and contain two round sporocysts, each containing four elongate sporozoites (isosporid-like 1:2:4 configuration).

Host range: Infections have been detected worldwide in a diverse range of vertebrate hosts; carnivores, herbivores, insectivores, rodents, pigs, primates (including humans) and occasionally birds. Sexual development and oocyst formation only occurs, however, in feline hosts. Only one parasite species is considered valid due to the lack of intermediate host specificity. Various strains, however, are recognized on the basis of their variable infectivity, growth, virulence and gene expression. Recent genetic studies indicate that *T. gondii* propagates primarily by clonal, asexual or uniparental clonal reproduction, and various strains have been allocated to three clonal lineages (Types I, II and III) on the basis of analyses of multiple independent single-copy loci as well as microsatellite markers. Type I strains are most often associated with disease in immunocompetent adults and in congenital infections, type II strains with immunocompromised individuals, and type III strains with patients with ocular toxoplasmosis. The prevalence of infections varies according to host populations and geographic location but seroprevalence estimates range from 5-75% in many countries.

Site of infection: In cats, parasites undergo asexual and sexual multiplication in intestinal epithelial cells culminating in the formation of oocysts 3-5 days after infection. In all other vertebrate hosts, parasites undergo asexual multiplication in a wide range of extra-intestinal locations (cells of the lymphatic and circulatory systems, nervous tissue, skeletal musculature, etc.). During the acute phase of infection, the parasites divide rapidly forming small groups of 8-32 tachyzoites which lyse the host cells. As infections become chronic, the parasites divide more slowly forming large accumulations of bradyzoites particularly within the brain, heart and skeletal muscle. These tissue cysts are surrounded by a thin cyst wall and they persist for months or even years after infection. Cyst formation coincides with the development of host immunity (not sterile immunity but rather a state of premunition).

Pathogenesis: Many host species exhibit an age-related resistance to disease therefore most infections in adults and weaned individuals are asymptomatic. In susceptible hosts, symptomatic infections may be acute, subacute or chronic. Acute infections by proliferating tachyzoites cause flu-like symptoms, including lymphadenitis, fever, headache, muscle pain and anaemia. Symptoms generally subside with the development of immunity, but may sometimes persist producing subacute disease, characterized by extensive lesions in the lung, liver, heart, brain or eyes. Postnatal infections often involve lymphadenitis, myocarditis, central nervous system involvement and retinochoroiditis. Chronic infections by encysted bradyzoites usually cause few clinical signs, although degenerating cysts have been associated with hypersensitive inflammatory reactions, resulting in, for example, encephalitis, myocarditis and/or chorioretinitis. The tissue cysts lay quiescent (dormant) in the tissues for some time, occupying little space and apparently causing few functional deficits, although there is contradictory evidence that infections may be associated with some learning disabilities, slower reflexes and altered behaviour in intermediate hosts. Latent cyst infections may be reactivated in immunocompromised patients (i.e. those undergoing immunosuppressive therapy or with acquired immunodeficiencies) resulting in cell lysis, expanding focal lesions, rapid dissemination, encephalopathy and meningoencephalitis. Infections may also be transmitted transplacentally. If the mother/dam contracts infection during pregnancy, parasites may cross the placenta and infect the foetus causing spontaneous abortion, stillbirth or congenital abnormalities, such as hydrocephalus, brain calcification, chorioretinitis and mental retardation. Nonetheless, if the mother/dam is infected prior to pregnancy, her immunity is transferred to her foetus which is consequently protected. Infections in cats by enteric sexual developmental stages are generally subclinical, transient and leave the cat with a solid protective immunity against subsequent oocyst production.

Mode of transmission: Infections are transmitted horizontally between hosts by the ingestion of oocysts excreted by cats, and vertically between mother and offspring by transplacental or even transmammary

transmission of proliferative tachyzoites. Infections may also be transferred between intermediate hosts through the food chain via carnivorism, the ingestion of fresh or undercooked meat containing viable cysts. Bradyzoites released during digestive processes are resistant to enzymatic digestion and revert back to tachyzoite stages which infect the host, multiply, spread and lead to new cyst formation. Infections are more prevalent in human populations which have traditional cultural practices involving the consumption of raw or partially cooked meat (e.g. steak tartare, partly cured smallgoods). Oocysts excreted by cats take 1-5 days to sporulate before they become infective and they are resistant to external environmental conditions and may remain viable in contaminated soil and water for some time.

Differential diagnosis: Parasites may be detected in autopsy or biopsy material by histology, immunolabelling or *in vivo* culture following inoculation into laboratory rodents. Zoites in smears stain well with Giemsa and other Romanowsky stains while cysts in sections have silver-positive walls and the bradyzoites are strongly PAS (periodic acid-Schiff) positive. Monoclonal and polyclonal antibody labels have also been used to detect parasites in tissue sections, and molecular studies using polymerase chain reaction (PCR) amplification techniques have detected parasite DNA in host tissues. Most infections, however, are diagnosed serologically and a range of immunoassays (fluorescence, agglutination and enzyme-based) are commercially available. Recent/acute infection is indicated by a 4-16 fold increase in specific antibody titre over a two-week period, or by the detection of specific IgM antibody titres.

Treatment and control: Chemotherapy is successful when pyrimethamine and sulphonamides are given together as they act synergistically. The toxic side-effects of bone marrow depression can be relieved by the administration of folinic acid. Clindamycin and spiramycin have also been reported to be effective. The risk of transmission can be reduced by maintaining high standards of hygiene (particularly where cats are involved), by thoroughly cooking or deep-freezing meat prior to consumption and washing potentially contaminated foodstuffs. Molecular vaccines are currently being developed for high risk patient groups, and a live vaccine using a low-virulent non-persistent strain has been marketed to protect sheep against toxoplasmosis.

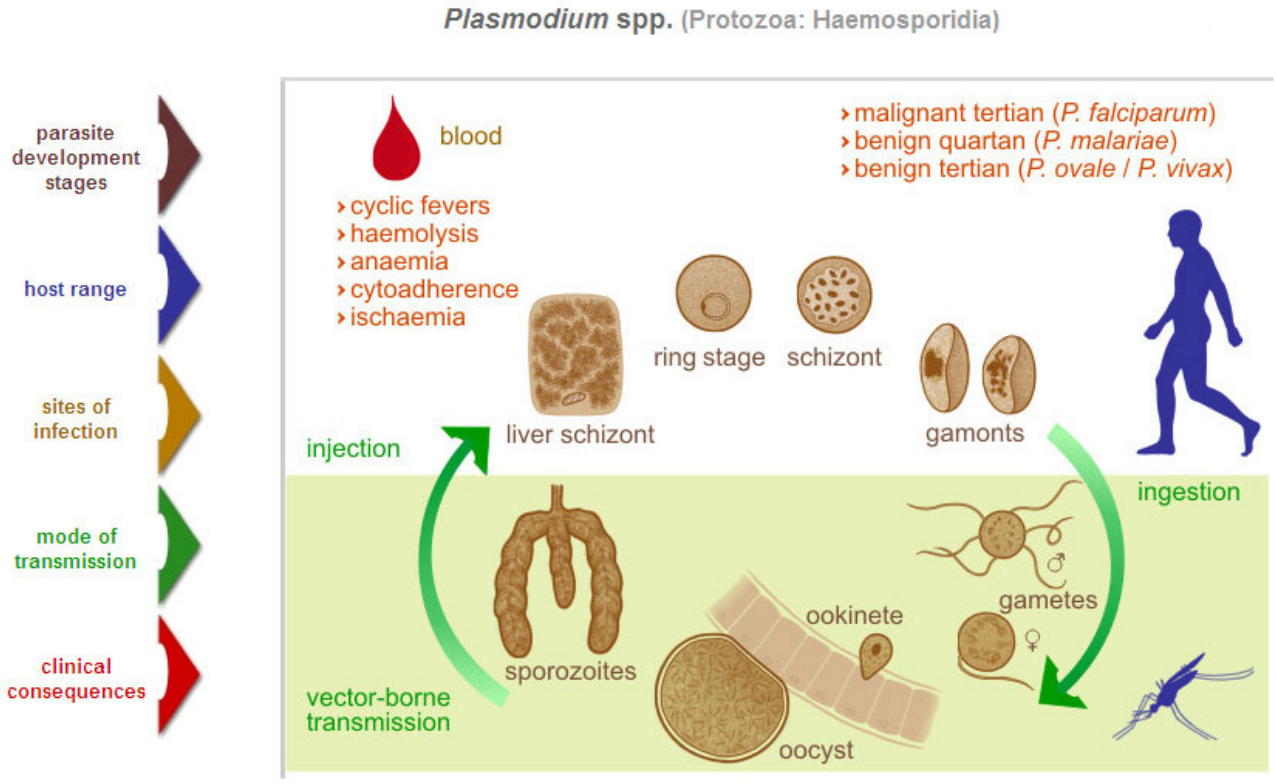
Plasmodium

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Haematozoea	(vector-borne parasites infecting blood cells of vertebrates)
Haemosporidia	(blood-dwelling spore-formers, insect vectors)

Family: Plasmodidae

These parasites are transmitted to vertebrate hosts by insect (notably mosquito) vectors. In vertebrates, they form amorphous developmental stages (plasmodia) in blood cells (mostly erythrocytes). All stages have a reduced apical complex (lacking a conoid). Hundreds of species have been described in mammals, birds and reptiles; most causing no apparent harm but those infecting humans causing one of the worst fever scourges of mankind, malaria. Parasites undergo exoerythrocytic schizogony in hepatocytes of vertebrates then repeated cycles of intraerythrocytic schizogony with some stages subsequently undergoing gametogony. Many species produce haemozoin pigment granules as a byproduct of haemoglobin metabolism. Gametes ingested by insect vectors undergo fertilization in the gut forming motile zygotes (ookinetes) which form oocysts on the outer gut wall. The oocysts produce thousands of sporozoites which infect the salivary glands and are injected into vertebrate hosts during feeding.



Plasmodium spp. [these species cause malaria in humans]

Parasite morphology: Malarial parasites form four developmental stages in humans (hepatic schizonts and then intraerythrocytic trophozoites, schizonts and gamonts) and three developmental stages in mosquitoes (ookinetes, oocysts and sporozoites). Liver schizonts appear as clusters of small basophilic bodies (merozoite nuclei) located within host hepatocytes, measuring 40-80 µm in diameter when mature. Intraerythrocytic stages consist of small rounded trophozoites (ring forms) measuring 1-2 µm in diameter, amorphous multinucleate schizonts measuring up to 7-8 µm in length, and micro – (♂) and macro- (♀) gametocytes ranging in length from 7-14 µm. The morphological characteristics (size, shape and appearance) of the blood stages are characteristic for each *Plasmodium* spp. Microgametocytes have a larger more diffuse nucleus (ready for gamete production) while macrogametocytes have darker-staining cytoplasm (plentiful ribosomes for protein synthesis). In the mosquito, long slender microgametes (15-25 µm in length) produced by exflagellation fertilize the rounded macrogametes to form motile ookinetes (15-20 x 2-5 µm) which migrate through the gut wall to form ovoid oocysts (up to 50 µm in diameter) on the exterior surface. The oocysts produce thousands of thin elongate sporozoites (~15 µm long) which ultimately infect the salivary glands.

Host range: Some 130 *Plasmodium* species have been classified into several subgenera which occur in mammals (primates and rodents), birds (wild and domestic species) and reptiles (lizards and snake). Humans are hosts for four main species, although they can occasionally be infected by other species from nonhuman primates. Most species are confined to tropical and subtropical areas depending on the distribution of their insect vectors. On a global basis, ~40% of infections are due to *P. falciparum*, ~10% are due to *P. malariae*, ~50% to *P. vivax* and <1% to *P. ovale.*

Plasmodium spp.	Vertebrate hosts	Periodicity	Vectors	Pathogenicity
P. falciparum	humans	48 hours + irregular	*Anopheles*	moderate
P. ovale	humans	48 hours	*Anopheles*	moderate
P. vivax	humans	48 hours	*Anopheles*	low
P. malariae	humans, monkeys	72 hours	*Anopheles*	low
P. knowlesi	Asian monkeys, humans	24 hours	*Anopheles*	moderate
P. coatneyi	Asian monkeys, humans	48 hours	*Anopheles*	low
P. cynomolgi	Asian monkeys, humans	48 hours	*Anopheles*	moderate
P. simium	New World monkeys, humans	48 hours	*Anopheles*	low
P. gallinaceum	chickens	irregular	*Aedes, Culex*	moderate
P. juxtanucleare	chickens	irregular	*Culex*	low
P. relictum	pigeons	12-36 hours	*Culex, Aedes, Anopheles*	moderate
P. cathemerium	sparrows, canaries	24/48 hours	*Culex, Aedes, Anopheles*	low
P. berghei	rodents	24 hours	*Anopheles*	moderate
P. wenyoni	snakes	irregular	*Culex*	low
P. agamae	lizards	irregular	*Lutzomyia, Culicoides*	moderate

Site of infection: Sporozoites injected by mosquitos first undergo massive amplification by asexual exoerythrocytic schizogony in liver cells. Some sporozoites of *P. vivax* and *P. ovale* may also exhibit arrested development in the liver forming hypnozoites (dormozoites) which are quiescent stages responsible for malaria relapses. Merozoites released from the liver then invade erythrocytes and transform into trophozoites which undergo schizogonous division. This cycle of asexual multiplication in the red blood cells occurs with regular periodicity. Ultimately, intraerythrocytic gametocytes are formed which do not divide further in the human host. When ingested by mosquitoes during feeding, the gametocytes mature

and undergo fertilization in the gut forming motile ookinetes which migrate through the gut wall to form oocysts. The oocyst then produces hundreds of sporozoites which migrate into the salivary glands (once infected, mosquitos remain infected for life).

Pathogenesis: The disease malaria is characterized by its long persistence in infected individuals in endemic areas, with characteristic recrudescences or relapses, sometimes after years of subclinical infection. However, infections in highly susceptible individuals, such as children, pregnant women and travellers, can produce acute severe and even fatal disease. Clinical expression is characterized by cyclic paroxysms of fever/chills (produced by host inflammatory responses), haemolysis and erythrophagocytosis (resulting in anaemia), and organ hypoperfusion due to ischaemia (arising through cytoadherence of infected cells to vascular endothelia, disseminated intravascular coagulation, erythrocyte rosetting, and haemozoin pigment accumulation). Vague prodromal signs may first develop prior to parasitaemia, including headache, anorexia and mild fever. Thereafter, characteristic febrile paroxysms and haemolytic anaemia develop and become progressively worse. Depending on the parasite species involved, severe complications may arise, including splenic rupture, cerebral signs, haemolytic anaemia, cardiac, pulmonary and renal failure. Paroxysms coincide with intraerythrocytic parasite developmental cycles (tertian = 2 day cycle, quartan = 3 day cycle) and may be accompanied by dizziness, nausea, vomiting, delirium, hepato/splenomegaly, leucopenia and thrombocytopenia. Infected cells are removed from the circulation by erythrophagocytosis during passage through the spleen. Some uninfected cells may also be removed if damaged or coated with debris or parasite antigens, thus exacerbating anaemic conditions. As the parasites grow within erythrocytes, they ingest and digest haemoglobin leaving behind characteristic dark pigment deposits, termed haemozoin (metabolic byproducts containing the indigestible iron-containing part of the haemoglobin molecule). Haemozoin may accumulate in organs and tissues resulting in impaired function. Infected erythrocytes (especially by *P. falciparum*) develop sticky protrusions by which they adhere to vascular endothelial cells, or clump together, resulting in restricted blood flow, ischaemia and end-organ anoxia.

Characteristic	*P. falciparum*	*P. malariae*	*P. ovale*	*P. vivax*
Type of malaria:	malignant tertian	benign quartan	benign quartan	benign quartan
Erythrocytic cycle:	48 hours	72 hours	48 hours	48 hours
Exoerythrocytic cycle:	9 days	14-15 days	9 days	8 days
Gametocytes:	crescent	ovoid	ovoid	ovoid
Distribution:	worldwide in tropics, subtropics & temperate regions	scattered in tropics and subtropics	mainly tropical Africa	worldwide in tropics and subtropics
	recrudescent malaria		relapsing malaria	
	(continuance of infection by persistent erythrocytic forms)		(persistent exoerythrocytic schizogony and occurrence of hypnozoites)	

P. falciparum causes malignant tertian malaria (sometimes known as malaria tropica), a severe disease with high parasitaemia because the parasites infect both young and mature erythrocytes. Symptoms appear 8-12 days after infection, being vague for 3-4 days (aches, pains, headache, fatigue, anorexia) then becoming acute in onset (fever, severe headache, nausea, vomiting, epigastric pain) with paroxysms exhibiting a periodicity of <48 hours. Schizogony often occurs in vessels in organs so disease severity may not correlate with parasitaemia. Various complications may arise due to ischaemic changes, including cerebral malaria (comatose), bilious remittent fever (hepatomegaly), dysentery (malabsorption diarrhoea), algid malaria (circulatory collapse) and blackwater fever (haemoglobinuria). Cerebral malaria occurs when capillaries are blocked by infected erythrocytes causing small haemorrhages which rapidly increase in size (conspicuous in retina). Symptoms include abnormal behaviour, fits, change in level of consciousness, coma, elevated cerebrospinal fluid (CSF) pressure, and classic decerebrate rigidity associated with hypoglycaemia. There are often neurological sequelae, such as hemiparesis, cerebral ataxia, cortical blindness, hypotonia, mental retardation, generalized spasticity, or aphasia.

P. malariae causes benign quartan malaria, a moderately severe disease with reduced parasitaemia because parasites only infect mature erythrocytes. The incubation period ranges from 27-40 days, with vague symptoms developing for 3-4 days (headache, photophobia, muscle aches, anorexia) followed by

severe paroxysms of chills and fevers every 72 hours (long chill stage, more severe symptoms during fever stage). Proteinuria is common in infected individuals and a nephrotic syndrome may develop in children.

P. vivax and ***P. ovale*** cause benign tertian malaria, a moderately severe disease with high parasitaemia as both species preferentially infect reticulocytes (young erythrocytes). *P. vivax* infections are clinically similar to those of *P. ovale*, but they are more severe and relapses occur more frequently. Symptoms appear 7-10 days after infection and are vague for 3-4 days (headache, photophobia, muscle aches, anorexia), developing to steady or irregular low-grade fever then paroxysms with a regular 48 hour cycle. Many patients exhibit slow irregular recovery over 3-8 weeks but relapses may occur after weeks/months/years. Splenomegaly is evident during the first few weeks of infection and leukopenia is usually present. Severe complications are rare but *P. vivax* infections can sometimes include cerebral malaria with neurological signs, haemolytic anaemia, renal failure and pulmonary failure.

Mode of transmission: Infections are vector-borne, being transmitted by female mosquitos, mainly *Anopheles* spp. Although 390 mosquito species are found worldwide, only a few are considered to be important vectors. Only the female mosquitoes feed on blood as they require high protein diets in order to reproduce and lay rafts of eggs. The mosquito is not simply a vector, it acts as the definitive host in which sexual reproduction of the parasite occurs. Gametocytes ingested during feeding undergo fertilization forming an ookinete then an oocyst which produces numerous sporozoites eventually infecting the salivary glands. Sporozoites are injected into new hosts when the mosquito next feeds as saliva has anticoagulant properties and prevents blood from clotting in the mouthparts. Once a mosquito is infected, it is infected for life and continues to transmit infections.

Differential diagnosis: Diagnosis is conventionally made by a combination of clinical symptomatology and the detection of parasites in thick or thin peripheral blood smears stained with one of the Romanowsky's stains, usually Giemsa's, Leishman's or Field's stains. Fluorochrome stains have also been used to detect parasites in blood samples, but the morphological features of the stages detected are often obscure. It is important that infections by individual parasite species be differentiated as it impacts on treatment and prognosis. All infections should be considered to be immediately life-threatening, and a complete clinical history should be taken (symptoms/signs), including history of travel, transfusions, recreational drug use, and previous medications (especially anti-malarials). Immunoserological tests have also been developed and several fluorescence, haemagglutination and enzyme immunoassays are being used, particularly for mass screening. Molecular biological techniques using polymerase chain reaction (PCR) amplification of gene fragments have also been developed and have shown great potential for the detection of drug resistance in *Plasmodium*.

Treatment and control: A variety of drugs have been developed for therapeutic (treatment) and prophylactic (preventive) use. While most enjoyed years of efficacy, there are now widespread problems with drug resistance amongst the parasites. Early explorers noticed that Peruvian Indians used brews from 'fever bark' (Cinchona) trees to stave off fevers. The active drug quinine was isolated from the bark around 1820 and this become the mainstay for malaria treatment throughout the world, essentially based on Cinchona tree plantations in tropical colonies. Supply shortages due to the World Wars prompted research on synthetic drugs. Pamaquine, mepacrine and chloroquine were developed in the 1930s, proguanil in the 1940s, and pyrimethamine in the 1950s. Chloroquine, in particular, was found to be highly effective, cheap to produce and had low toxicity. However, resistance to chloroquine emerged in the 1960s and soon spread around the world. Sulphonamides were developed in the 1960s, mefloquine and a series of related drugs in the 1970s, and artemisinin was discovered in a Chinese herbal remedy in the 1980s. A holistic and strategic approach to the treatment of infected individuals is required based on whether suppressive, radical or preventive treatment is required, and the level of drug resistance present. Antimalarial drugs of choice are primaquine, chloroquine (despite the emergence of chloroquine-resistant strains), sulfadoxine, pyrimethamine, mefloquine, quinine and tetracycline. Preventive measures based on vector control programmes had many early successes (including those using DDT), but the rapid emergence of insecticide resistance (and the recognition of the toxicity of DDT and its prohibition) have led to the resurgence of malaria in many countries. At present, the best protection is the avoidance of mosquito bites, using screens, bed nets, insect repellants, and residual insecticide sprays.

Drug	TISSUE STAGES		BLOOD STAGES	
	primary	latent	schizonts	gametocytes
quinine	-	-	+++	++
chloroquine	-	-	+++	++
proguanil	++	-	++	++
pyrimethamine	++	+	++	+++
sulphadoxine/dapsone	?	-	+	-
primaquine	++	+++	++	+++
doxycycline	+	?	++	-
mefloquine	-	-	+++	-
halofantrine	-	-	+++	-
artemisinin	-	-	+++	+
	causal prophylaxis	antirelapse radical cure	suppression clinical cure	prevent spread

	Clinical target	Drug	Main effect
Non-resistant malaria	Attack	chloroquine	blood schizonts
-	Recrudescence (*P.f.*/*P.m.*)	chloroquine	blood schizonts
-	Recurrence (*P.v.*/*P.o.*)	primaquine	tissue zoites
-	Prophylaxis	pyrimethamine	tissue/blood schizonts
-	-	combinations	tissue/blood schizonts
Drug-resistant malaria	Attack	quinine	blood schizonts
-	-	combinations	blood schizonts
-	Prophylaxis	mefloquine	febrile reaction

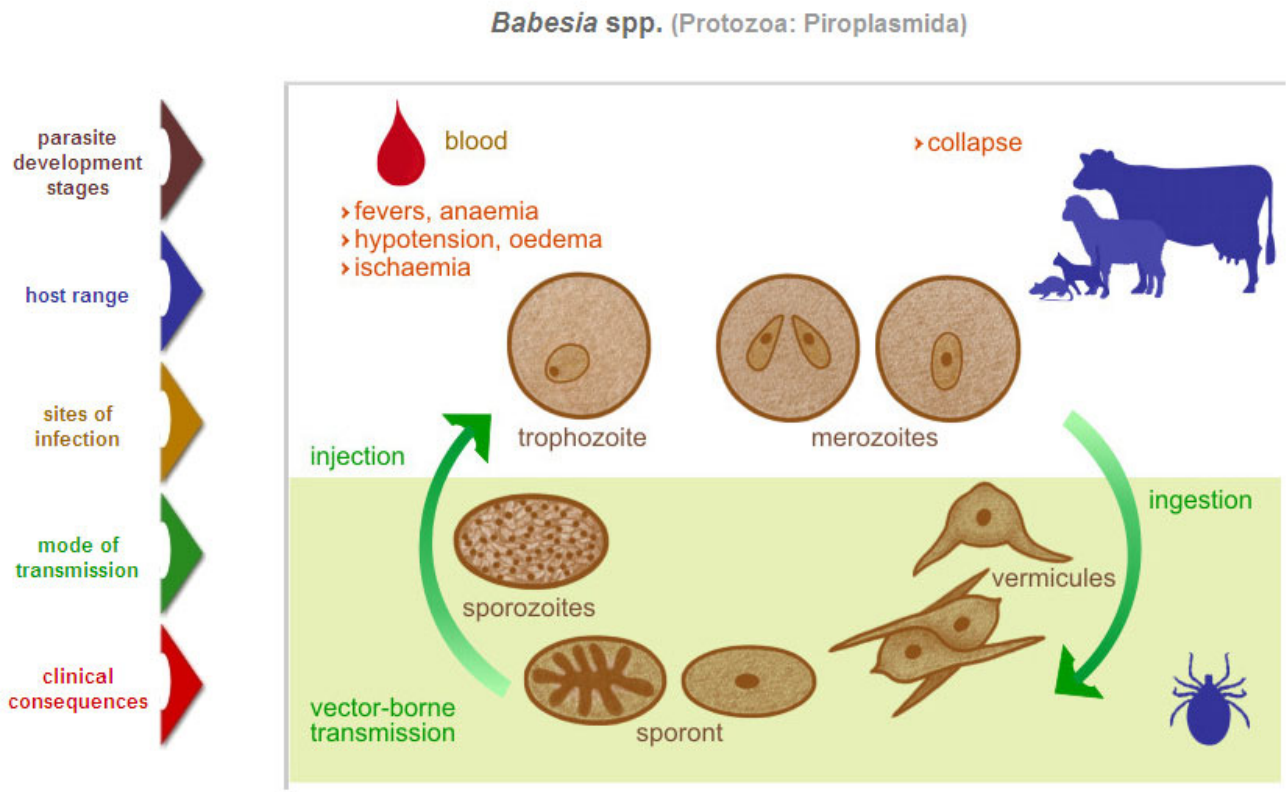
Babesia

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Apicomplexa	(cells with cluster of organelles known as apical complex)
Haematozoea	(vector-borne parasites infecting blood cells of vertebrates)
Piroplasmorida	(form pear-shaped bodies in blood cells, tick vectors)

Family: Babesiidae

This group of parasites is transmitted to mammalian hosts by arachnid (tick) vectors. They do not produce spores, flagella, cilia or pseudopodia but move by body flexion or gliding. The apical complex is reduced (conoid absent) and no stages produce haemozoin pigment. In mammals, the parasites do not undergo exoerythrocytic schizogony but multiply by binary fission and schizogony forming small characteristic pear-shaped (piroplasm) stages in blood cells. When ingested by ticks, the parasites form unique paired bodies (strahlenkorper) which give rise to numerous schizonts leading to the production of numerous sporozoites in the salivary glands. Infections persist in ticks during metamorphosis (trans-stadial transmission) and are passed by female ticks to their progeny (trans-ovarian transmission). Many babesial species have been associated with severe disease syndromes.



***Babesia* spp**. [these species cause babesiosis (tick fever) in domestic and wild animals]

Parasite morphology: Intraerythrocytic stages appear singly as small round, ovoid or elongate trophozoites (2-4 µm), in pairs as pear-shaped (= pyriform, hence piroplasm) merozoites, or in tetrads as cruciform merozoites.

Host range: Infections have been detected in most domestic animals (cattle, sheep, goats, horses, pigs, dogs, cats) and numerous wild animals (over 70 species) and humans. Three species cause tick fever in cattle, *B. bovis* (*B. argentina*), *B. bigemina*, and *B. divergens*. Some parasite species are not host specific and can be transmitted among different mammals; some are zoonotic. Infections in humans have been attributed to *B. microti* from rodents in North America and *B. divergens* from cattle in Europe. All parasite species are limited in their distribution in accordance with that of their tick vectors.

Parasite species	Vertebrate hosts	Disease	Pathogenicity	Vectors	Distribution
B. bovis (argentina)	cattle, deer	redwater fever	high	*Ixodes, Rhipicephalus (Boophilus)*	Europe, Africa, Australia, South & Central America
B. bigemina	cattle, deer	redwater fever	moderate	*Haemaphysalis, Rhipicephalus (Boophilus)*	Europe, Africa, Australia, South & Central America
B. divergens	cattle	redwater fever	moderate	*Ixodes*	Western & Central Europe
B. major	cattle	-	low	*Rhipicephalus (Boophilus)*	Europe, Russia
B. equi	horses, zebra	biliary fever	high	*Dermacentor, Hyalomma, Rhipicephalus (Boophilus)*	Southern Europe, Africa, Asia, South America
B. caballi	horses	-	moderate	*Dermacentor, Hyalomma, Rhipicephalus (Boophilus)*	Dermacentor, Hyalomma, Rhipicephalus (Boophilus) Southern Europe, Russia, Africa, Asia
B. ovis	sheep, goats	-	low	*Rhipicephalus (Boophilus), Ixodes*	Southern Europe, Africa, Asia, tropical America
B. motasi	sheep, goats	-	moderate	*Rhipicephalus (Boophilus), Haemaphysalis, Dermacentor*	Southern Europe, Africa, Asia, tropical America
B. trautmanni	pig		moderate	*Rhipicephalus*	Southern Europe, Africa
B. canis	canids	tick fever	high	*Rhipicephalus, Dermacentor, Haemaphysalis*	Southern Europe, Africa, Asia, South & North America
B. gibsoni	canids	tick fever	high	*Rhipicephalus, Haemaphysalis*	India, Ceylon, China
B. felis	cats, lion, leopard	-	moderate	*Haemaphysalis*	Africa, India
B. microti	rodents	-	low	*Ixodes*	worldwide
B. rodhaini	rodents	-	low	*unknown*	Africa

Site of infection: Parasites infecting host erythrocytes undergo transformation to form trophozoites which divide by binary schizogony and undergo differentiation to form merozoites. The host cell is ultimately lysed and the merozoites infect new cells, repeating the cycle of development.

Pathogenesis: Infected animals develop a high persistent fever becoming dull, listless and anorexic. Parasites cause extensive intravascular haemolysis (erythrocyte rupture) producing progressive signs of anaemia. Erythrocyte destruction may be as high as 75% in fatal cases and even milder infections produce severe anaemia. Haemoglobin clearance mechanisms become overloaded, resulting in jaundice and haemoglobinuria (red discolouration of the urine, 'red water' in bovine babesiosis). Haemolysis involves the release of many pharmacologically active agents (e.g. proteolytic enzymes) which affect microcirculation (vasodilatation, increased permeability) leading to hypotension and oedema, and affect blood (viscosity, coagulation, cytoadherence) leading to ischaemia (congestion and degenerative changes in tissues/organs). Infected animals may exhibit diarrhoea, abortion if pregnant, cerebral signs, muscle tremors, wasting, coma and death. Chronically infected animals remain weak, thin and out of condition for several weeks before recovery. Animals that recover are usually immune for life, sometimes thought to be due to complete cure (sterile immunity) but more often associated with the persistence of small numbers of parasites (premunitive immunity). There is an inverse age-resistance to infection and disease, with young cattle being less susceptible than older cattle. There is also a genetic component to resistance, with *Bos taurus* cattle being more susceptible than *Bos indicus* (zebu) cattle. Infections in humans have proven severe and fatal in asplenic individuals, with symptoms appearing 10-20 days after tick bite and presenting as a fulminant febrile haemolytic disease, characterized by general malaise, then fever, shaking chills, sweating, arthralgias, myalgias, fatigue, weakness, occasional hepatosplenomegaly, and jaundice.

Mode of transmission: Infections are transmitted by ixodid (hard-bodied) ticks which may be one-, two- or three-host ticks. Ingested parasites develop into large motile vermicules which migrate through the body of the tick and then undergo sporogony. Parasites undergo trans-stadial transmission, whereby infections persist during metamorphosis from larvae to nymphs to adults. They also undergo transovarian transmission, where parasites infect developing eggs in engorged female ticks, so nearly all the progeny are born already infected. Eventually, hundreds of small pyriform bodies (sporozoites) are formed within salivary cells and are injected into mammalian hosts during feeding.

Differential diagnosis: Infections are conventionally diagnosed by the detection of intraerythrocytic stages in smears of peripheral blood stained with any of the Romanowsky's stains, notably Giemsa. However, once the acute febrile phase has passed, parasites may be difficult to find as they are rapidly removed from the circulation. Recourse has therefore been made to immunoserological tests to detect specific host antibodies against the parasites. Molecular biological techniques have also been developed to parasite DNA following the polymerase chain reaction (PCR) amplification of specific gene sequences.

Treatment and control: Timely chemotherapy is generally effective, although the small virulent species (such as *B. bovis*) are usually more difficult to treat than other less aggressive species. One of the first successful treatments for bovine babesiosis was the azonaphthalene dye, trypan blue, but it was not very effective against *B. bovis*. The most commonly used compounds are the diamidines (diminazene diaceturate, imidocarb, amicarbalide), and quinuronium and acridine derivatives. Macrolide antibiotics (clindamycin) and tetracyclines (oxytetracycline, chlortetracycline) have shown variable effects against human infections. Treatment can facilitate recovery, leaving latent infections or complete cure. However, elimination of all parasites may also eliminate premunitive immunity. Because young animals in endemic areas develop infection-immunity (premunition), this has been exploited for immunological control either through premunization/chemoimmunization (infect animals then treat them) or vaccination using whole parasites (attenuated strains) or subcellular (subunit) fractions. Several commercially available preparations have proven effective in regional areas, but a universal vaccine is not yet available. Prevention strategies involving tick control programmes have been relatively effective in several countries in controlling or eliminating infections in domestic stock.

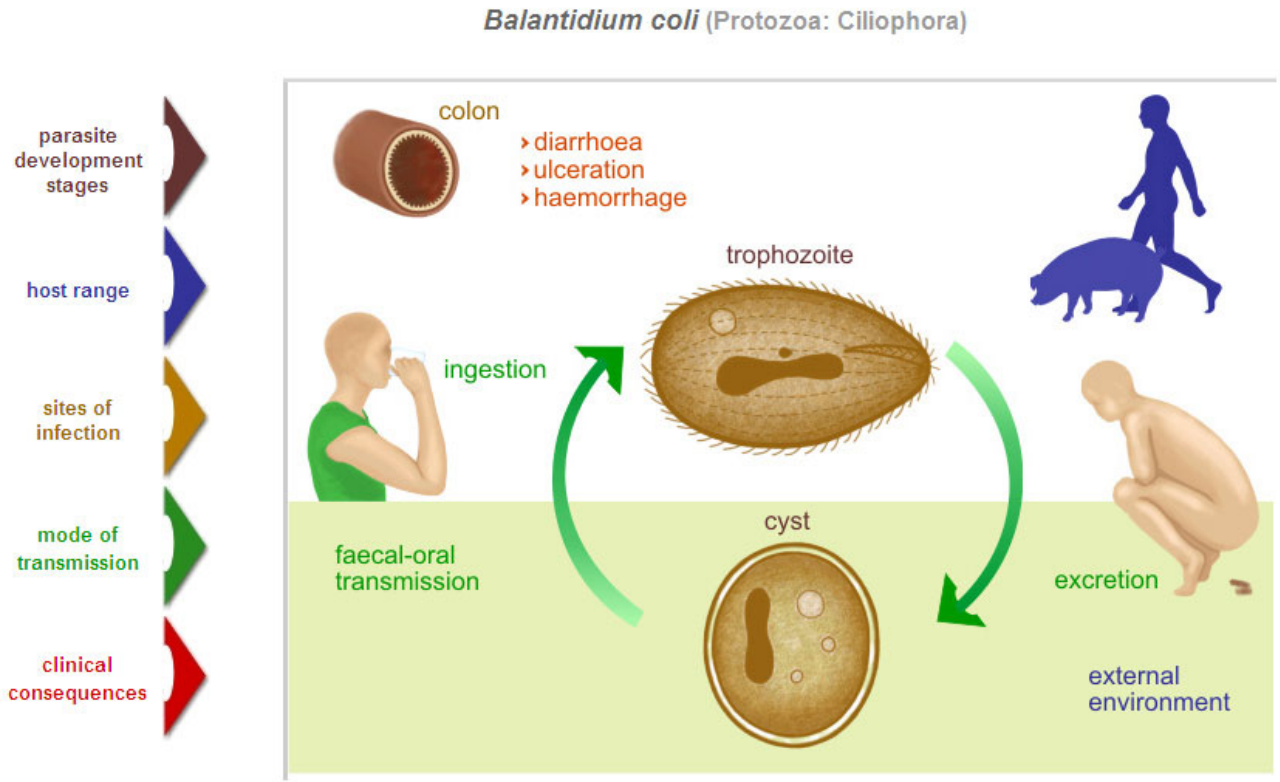
Balantidium

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Ciliophora	(with cilia, nuclear dualism, pellicular alveoli, reproductive conjugation)
Kinetofragminophorea	('lower holotrichs', little distinction between oral and body ciliature)
Rhabdophora	(noncurved tubular cytopharyngeal apparatus = rhabdos)
Litostomatea	('simple mouths', special somatic kineties)
Trichostomatia	(endosymbionts)
Vestibulifera	(distict oral depression = vestibulum)

Family: Balantidiidae

These ciliates are monoxenous (one-host) endocommensals in vertebrates, some species of which can become histophagous parasites. The trophozoites have a uniform covering of somatic ciliary rows and a cytostome at the base of an anterior vestibulum.



Balantidium coli [this species causes balantidiasis in vertebrates, esp. pigs and humans

Parasite morphology: Two developmental stages are formed: trophozoites and cysts. Trophozoites are variable in size ranging from 30-120 µm in length. They are oblong-spherical in shape and are covered by longitudinal kineties (rows of cilia). At the anterior end there is a depression (vestibulum) leading to the cytostome (mouth). Internally, they contain a single large kidney-shaped macronucleus and single small micronucleus. The cysts appear as membrane-bound ovoid bodies ranging from 40-60 µm in diameter

Host range: Several *Balantidium* spp. have been recorded throughout the world in various species of crustacea, insects, fish, amphibia and mammals (including humans). Infections by *B. coli* are particularly prevalent in pigs, monkeys and humans, especially in the tropics, with zoonotic transmission frequently implicated by epidemiological studies.

Site of infection: Ciliates are found in the large intestines of their hosts. They are actively swimming organisms and they reproduce asexually (by transverse fission) and sexually (by conjugation).

Pathogenesis: Infections are usually not associated with any changes in the colonic mucosa. Healthy individuals often exhibit spontaneous recovery or become symptomless carriers. However, under certain conditions, the organisms produce proteolytic enzymes which digest away the epithelium producing flask-shaped ulcers. This stimulates inflammatory changes with lymphocytic infiltration and haemorrhage and secondary bacterial invasion may follow. Infections may cause a dysentery-like syndrome, involving diarrhoea, tenesmus, nausea, vomiting, anorexia, headache, insomnia and weakness. Colonic ulceration involves mucosal sloughing, necrosis, fluid loss, haemorrhage, occasional abscess formation and sometimes perforation of the bowel.

Mode of transmission: Infections are passed horizontally between hosts by faecal-oral transmission. Cysts passed in the faeces of infected hosts contaminate the environment. When ingested with contaminated food or water, the cysts excyst releasing trophozoites in the digestive tract.

Differential diagnosis: Infections are diagnosed by coprological examination and the detection of characteristic cysts in faecal material or trophozoites in colonic biopsy material.

Treatment and control: Clinical infections may be treated with metronidazole, di-iodohydroxyquin, tetracycline or carbarsone. Prevention and control depends on strict hygiene to prevent the contamination of food and water supplies, particularly by pig faeces. Effluent from intensive piggeries should not be used to fertilize vegetable gardens or edible crops. In developing countries, pigs should not be left to roam free in rural villages, but are best confined to pens and stys where proper waste disposal can be practiced.

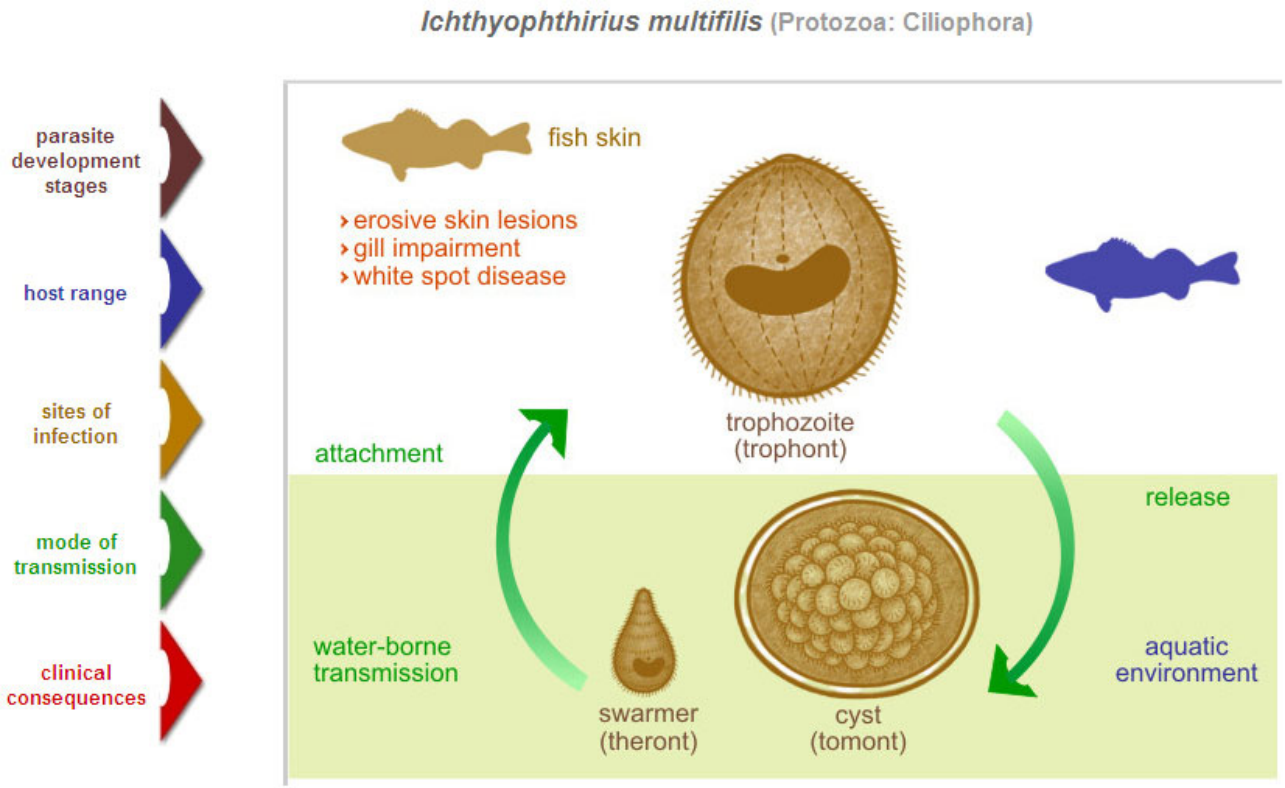
Ichthyophthirius

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Ciliophora	(with cilia, nuclear dualism, pellicular alveoli, reproductive conjugation)
Olighymenophorea	(conspicuous oral and body ciliature, membranelle-bearing 'holotrichs')
Cyrtophora	(curved tubular cytopharyngeal apparatus = cyrtos)
Hymenostomatida	(oral ciliature = paroral membrane and adoral zone of membranelles)

Family: Ichthyophthiriidae

These ciliates are monoxenous (one-host) ectoparasites of fishes. Trophonts infect epithelial tissues, often causing visible lesions evident as white spots. When replete, they leave the host and form encysted stages (tomonts) in the external environment. These cysts produce hundreds of infective stages (tomites) which are released as swarmers (theronts) which actively seek new hosts.



Ichthyophthirius multifiliis [this species causes whitespot disease ('ich') in freshwater fishes]

Parasite morphology: The parasite forms three developmental stages: trophonts, tomonts and theronts. Trophonts variable in size (up to 1 mm), horseshoe-shaped macronucleus encircling single micronucleus; subapical vestibulum with weakly developed buccal ciliature tomonts encysted on substrate, repeatedly divides to form numerous small tomites which break through cyst wall to become theronts (25-70 x 15-22 µm) covered with 36-48 meridional (longitudinal) kineties (ciliary rows) converging around the pre- and post-oral sutures, ellipsoidal macronucleus and subspherical micronucleus

Host range: Infections have been detected in numerous species of aquarium and wild freshwater fish throughout the world. There is some conjecture about the existence of different parasite races, which may have different temperature tolerances, being adapted to hosts with specific temperature preferences, or they may be geographic races varying in virulence in introduced and/or endemic fish species.

Site of infection: Trophonts infect the epidermis, cornea and gill filaments.

Pathogenesis: Theronts use an elevated pointed ridge (perforatorium) to penetrate host tissues and they discharge their pellicular mucocysts to form a stick envelope glued to the host's epithelium. Within minutes, the parasites penetrate deeper into epithelial or epidermal tissues where they feed and grow (increasing their volume up to 3,000 times). The trophonts form greyish pustules in the skin of their hosts where they feed by ingesting host cell debris. Infected fish produce excess mucus to combat the irritation but many epidermal cells are destroyed and are sloughed. Heavy infections of the gill filaments interfere with gas exchange and may prove fatal. Lesions containing engorging trophonts appear as visible white spots covering infected fish. Fish surviving infection exhibit some protective immunity against subsequent infections.

Mode of transmission: Engorged trophonts are liberated from ruptured pustules into the water column where they settle on convenient substrates or on the bottom. They form a gelatinous cyst and undergo a series of divisions producing from 250 to 2,000 tomites which are subsequently released and actively search for new hosts. The number, size and duration of the life-cycle stages depends prevailing environmental condition, particularly temperature (no development occurs below 2°C or above 30°C). The whole life-cycle may be completed in as little as 3-8 days at 23-24°C, but it progressively takes longer at lower temperatures (up to 3 months at 4-5°C).

Differential diagnosis: Infections are diagnosed by the detection of characteristic pustules containing feeding trophonts.

Treatment and control: Aquarium fish have been successfully treated with dilute concentrations of formaldehyde, malachite green or methylene blue. Closed culture systems are particularly at risk of sustained contamination and outbreaks. Periodic flushing of tanks and ponds with clean fresh water helps to reduce contamination levels. Avoiding overstocking also reduces stress.

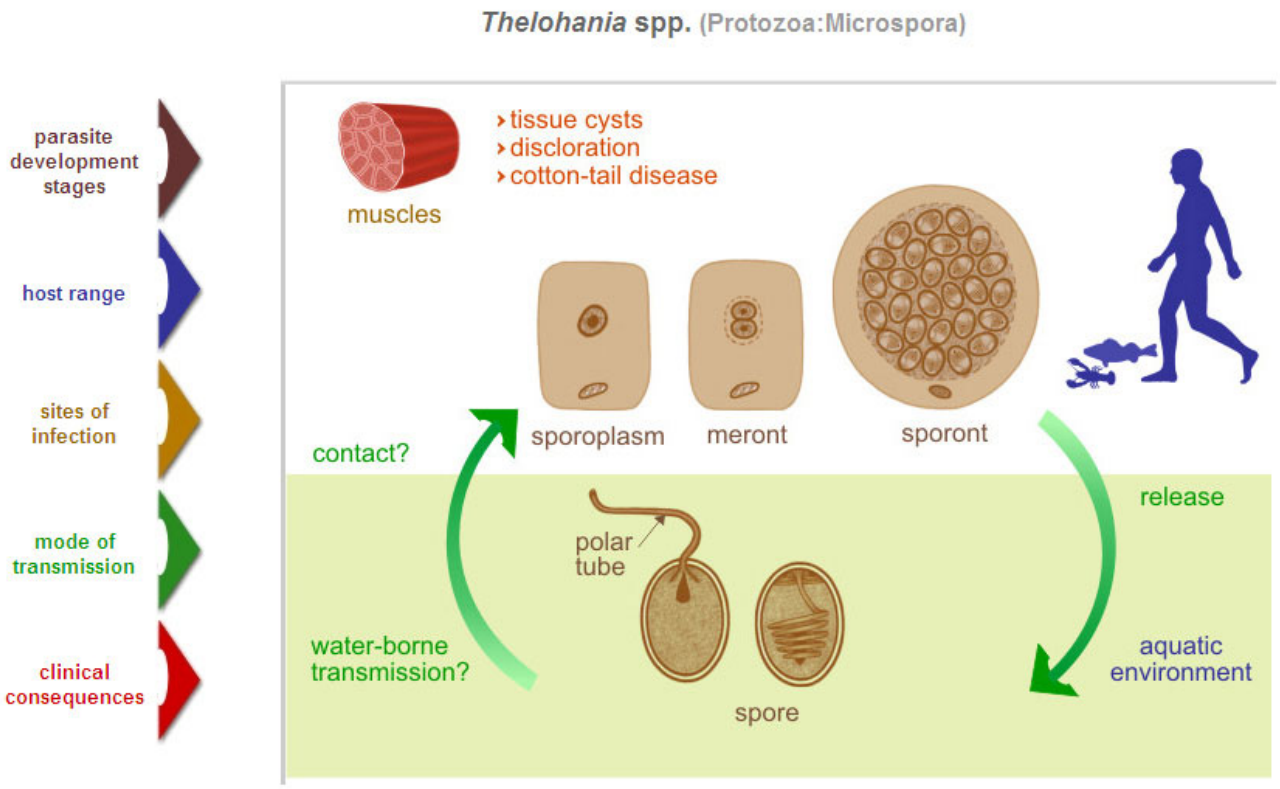
Thelohania

Classification: Taxonomic ranks under review (cf. Illustrated Guide to Protozoa, 2000. Allen Press)

Protista	(unicellular eukaryotes)
Microspora	(form unicellular spores containing coiled polar tubes)
Microsporea	(oval-tubular spores, well-developed polar tube opening terminally)
Pansporoblastina	(spore formed in sporophorous vesicles bounded by pansporoblast membrane)

Family: Thelohaniidae

These microsporans (microsporidia) proliferate in host tissues by merogony (asexual division) followed by sporoblastogenesis and sporogony (spore formation). The meronts are diplokaryotic (containing 2 identical nuclei) while mature spores are unikaryotic. Eight spores are formed within each sporophorous vesicle. Mature spores contain a coiled polar tube which everts forcibly to inject the infective sporoplasm into pierced host cells. Most thelohaniid species are parasitic in insects and crustaceans.



***Thelohania* spp.** [these species cause cotton-tail disease in aquatic crustaceans]

Parasite morphology: The parasites form monomorphic ovoid spores (5 x 4 µm) bound by a dense membranous exospore wall overlaying a thick lucent endospore wall. Mature spores are unikaryotic and contain an isofilar polar tube arranged in 17-19 coils in two layers. The spores divide in rosette formation from a sporogonial plasmodium to produce 8 sporoblasts bound by a sporophorous vesicle.

Host range: Infections have been detected in most freshwater crayfish species, both wild and cultured animals (marron, yabbies, redclaw). The prevalence of infections can be so high in some streams and ponds that no commercial return for wild or cultured crayfish is possible. Microsporidia are common histozoic parasites of fish and arthropods, although clinical infections are now being detected in humans, especially immunocompromised individuals. Some infections in humans are similar to species found in animals (suggesting their zoonotic origin), but others are unique and only found in humans.

Site of infection: Parasites are usually found at all stages of development within the muscles, although other tissues and organs can be infected.

Pathogenesis: The parasites undergo obligate intracellular development resulting in cell lysis (subacute presentation) and tissue cyst (xenoma) formation (chronic presentation). Mature spores are very refractile and heavily infected muscles become porcelain white in appearance (hence the term cotton-tail). The muscles are unpalatable and are rejected from human consumption. Mildly infected individuals may be stunted in growth and exhibit weak tail-flick responses, while heavy infections may be fatal. Other microsporidia in fish have been associated with respiratory distress (*Loma*), anaemia (*Nucleospora*), myeloencephalitis (*Microsporidium*) and lesions/xenomas (*Glugea*), while some species in arthropods have been associated with bee dysentery (*Nosema*) and silkworm disease (*Loma*?). Infections in humans involving pansporoblastic (*Pleistophora, Trachipleistophora, Brachiola, Thelohania* and *Vavraia*) and apansporoblastic genera (*Nosema, Enterocytozoon, Septata, Encephalitozoon* and *Vittaforma*) have variously been associated with neurologic (convulsions, vomiting, headaches, fever, coma), ocular (keratoconjunctivitis, chronic sinusitis), muscular (atrophy, muscle fibre degeneration), enteric (diarrhoea, fever, malaise, weight loss) and pulmonary (respiratory) signs.

Mode of transmission: While the developmental cycle within the host has been well studied, the route of spore transmission between hosts remains speculative. Transmission has been assumed to be direct via water-borne carriage of infective spores or their ingestion by carnivorism, but neither has been substantiated by experimental studies. It is known that mature spores contain a coiled polar tube which is forcibly everted to penetrate adjacent cells and inject the infective sporoplasm which subsequently divides and ultimately forms new spores.

Differential diagnosis: Heavy infections can be detected macroscopically by visual examination of crayfish tails which are opaque and chalky in appearance, rather than translucent and clear. Most infections, however, are diagnosed by the microscopic detection of cysts and spores in squash preparations or histological sections of musculature. Mature spores are best visualized using phase-contrast or interference-contrast microscopy, as they have a phase-bright refractile appearance due to the chitinous nature of the spore wall.

Treatment and control: No drug treatments have proven totally effective, but some successes have been reported when treating human infections with albendazole (ocular, intestinal and disseminated infections), metronidazole (intestinal infections) and trimethoprim-sulfamethoxazole (disseminated infections). Recent studies have shown that the coccidiostat toltrazuril may be effective against microsporidial infections in fish, insects and decapod crustacea. Various forms of control have been attempted in aquaculture systems, the most successful being to drain culture ponds and lime them or bake them over summer before restocking.

Helminth Parasites

The word ‘helminth’ is a general term meaning ‘worm’, but there are many different types of worms. Prefixes are therefore used to designate types: platy-helminths for flat-worms and nemat-helminths for round-worms. All helminths are multicellular eukaryotic invertebrates with tube-like or flattened bodies exhibiting bilateral symmetry. They are triploblastic (with endo-, meso- and ecto-dermal tissues) but the flatworms are acoelomate (do not have body cavities) while the roundworms are pseudocoelomate (with body cavities not enclosed by mesoderm). In contrast, segmented annelids (such as earthworms) are coelomate (with body cavities enclosed by mesoderm).

Many helminths are free-living organisms in aquatic and terrestrial environments whereas others occur as parasites in most animals and some plants. Parasitic helminths are an almost universal feature of vertebrate animals; most species have worms in them somewhere.

Biodiversity

Three major assemblages of parasitic helminths are recognized: the Nemathelminthes (nematodes) and the Platyhelminthes (flatworms), the latter being subdivided into the Cestoda (tapeworms) and the Trematoda (flukes):

nematode

cestode

trematode

> Nematodes (roundworms) have long thin unsegmented tube-like bodies with anterior mouths and longitudinal digestive tracts. They have a fluid-filled internal body cavity (pseudocoelum) which acts as a hydrostatic skeleton providing rigidity (so-called ‘tubes under pressure’). Worms use longitudinal muscles to produce a sideways thrashing motion. Adult worms form separate sexes with well-developed reproductive systems.

> Cestodes (tapeworms) have long flat ribbon-like bodies with a single anterior holdfast organ (scolex) and numerous segments. They do not have a gut and all nutrients are taken up through the tegument. They do not have a body cavity (acoelomate) and are flattened to facilitate perfusion to all tissues. Segments exhibit slow body flexion produced by longitudinal and transverse muscles. All tapeworms are hermaphroditic and each segment contains both male and female organs.

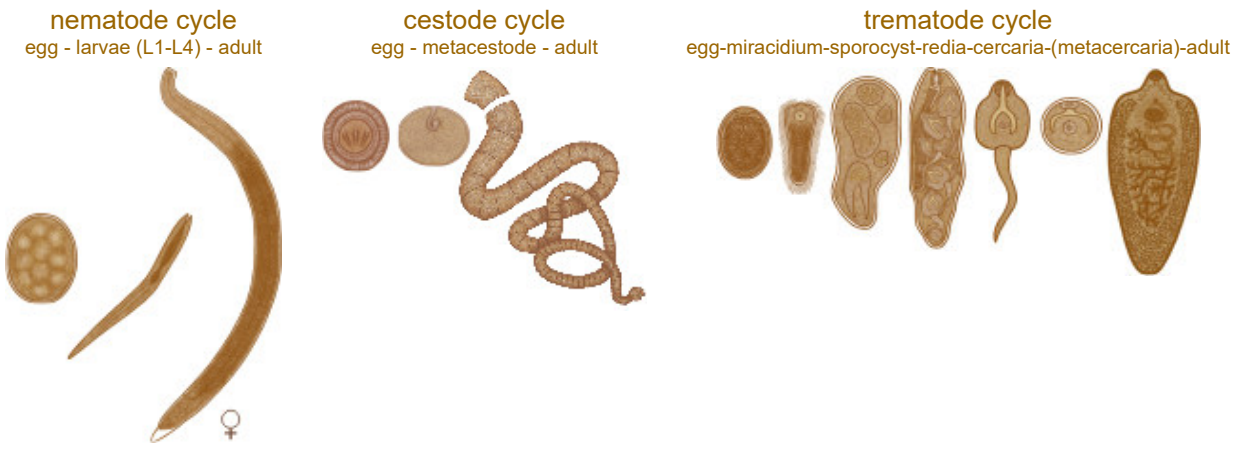
> Trematodes (flukes) have small flat leaf-like bodies with oral and ventral suckers and a blind sac-like gut. They do not have a body cavity (acoelomate) and are dorsoventrally flattened with bilateral symmetry. They exhibit elaborate gliding or creeping motion over substrates using compact 3-D arrays of muscles. Most species are hermaphroditic (individuals with male and female reproductive systems) although some blood flukes form separate male and female adults.

Life-cycles

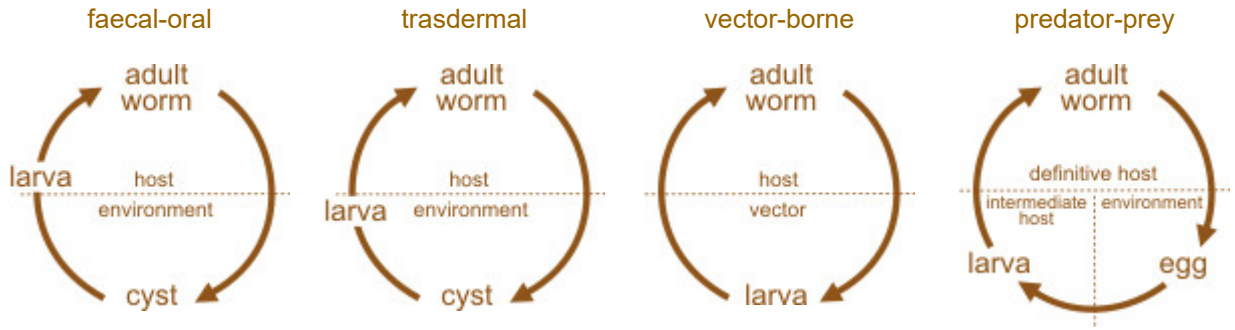
Unlike other pathogens (viruses, bacteria, protozoa and fungi), helminths do not proliferate within their hosts. Worms grow, moult, mature and then produce offspring which are voided from the host to infect new hosts. Worm burdens in individual hosts (and often the severity of infection) are therefore dependent on intake (number of infective stages taken up). Worms develop slowly compared to other infectious pathogens so any resultant diseases are slow in onset and chronic in nature. Although most helminth infections are well tolerated by their hosts and are often asymptomatic, subclinical infections have been associated with significant loss of condition in infected hosts. Other helminths cause serious clinical diseases characterized by high morbidity and mortality. Clinical signs of infection vary considerably depending on the site and duration of infection. Larval and adult nematodes lodge, migrate or encyst within tissues resulting in obstruction, inflammation, oedema, anaemia, lesions and granuloma formation. Infections by adult cestodes are generally benign as they are not invasive, but the larval stages penetrate and encyst within tissues leading to inflammation, space-occupying lesions and organ malfunction. Adult flukes usually cause obstruction, inflammation and fibrosis in tubular organs, but the eggs of blood flukes can lodge in tissues causing extensive granulomatous reactions and hypertension.

Helminths form three main life-cycle stages: eggs, larvae and adults. Adult worms infect definitive hosts (those in which sexual development occurs) whereas larval stages may be free-living or parasitize invertebrate vectors, intermediate or paratenic hosts.

- Nematodes produce eggs that embryonate in utero or outside the host. The emergent larvae undergo 4 metamorphoses (moults) before they mature as adult male or female worms.
- Cestode eggs released from gravid segments embryonate to produce 6-hooked embryos (hexacanth oncospheres) which are ingested by intermediate hosts. The oncospheres penetrate host tissues and become metacestodes (encysted larvae). When eaten by definitive hosts, they excyst and form adult tapeworms.
- Trematodes have more complex life-cycles where ‘larval’ stages undergo asexual amplification in snail intermediate hosts. Eggs hatch to release free-swimming miracidia which actively infect snails and multiply in sac-like sporocysts to produce numerous rediae. These stages mature to cercariae which are released from the snails and either actively infect new definitive hosts or form encysted metacercariae on aquatic vegetation which is eaten by definitive hosts.



Helminth eggs have tough resistant walls to protect the embryo while it develops. Mature eggs hatch to release larvae either within a host or into the external environment. The four main modes of transmission by which the larvae infect new hosts are faecal-oral, transdermal, vector-borne and predator-prey transmission:



> faecal-oral transmission of eggs or larvae passed in the faeces of one host and ingested with food/water by another (e.g. ingestion of *Trichuris* eggs leads directly to gut infections in humans, while the ingestion of *Ascaris* eggs and *Strongyloides* larvae leads to a pulmonary migration phase before gut infection in humans).

> transdermal transmission of infective larvae in the soil (geo-helminths) actively penetrating the skin and migrating through the tissues to the gut where adults develop and produce eggs that are voided in host faeces (e.g. larval hookworms penetrating the skin, undergoing pulmonary migration and infecting the gut where they feed on blood causing iron-deficient anaemia in humans).

> vector-borne transmission of larval stages taken up by blood-sucking arthropods or undergoing amplification in aquatic molluscs (e.g. *Onchocerca* microfilariae ingested by blackflies and injected into new human hosts, *Schistosoma* eggs release miracidia to infect snails where they multiply and form cercariae which are released to infect new hosts).

> predator-prey transmission of encysted larvae within prey animals (vertebrate or invertebrate) being eaten by predators where adult worms develop and produce eggs (e.g. *Dracunculus* larvae in copepods ingested by humans leading to guinea worm infection, *Taenia* cysticerci in beef and pork being eaten by humans, *Echinococcus* hydatid cysts in offal being eaten by dogs).

Taxonomic overview

Two classes of nematodes are recognized on the basis of the presence or absence of special chemoreceptors known as phasmids: Secernentea (Phasmidea) and Adenophorea (Aphasmidea). While many different orders are recognized within these classes, the main parasitic assemblages infecting humans and domestic animals include one aphasmid order (Trichocephalida) and 6 phasmid orders (Oxyurida, Ascaridida, Strongylida, Rhabditida, Camallanida, and Spirurida).

Trichocephalid 'whip-worms' have long thin anterior ends which they embed in the intestinal mucosa of their hosts. They have simple life-cycles where infections are acquired by the ingestion of eggs and emergent larvae moult and mature to adults in the gut. *Trichuris* infections in humans may cause inflammation, tenesmus, straining and rectal prolapse.

Oxyurid 'pin-worms' have small thin bodies with blunt anterior ends. They have simple life-cycles, but with an unusual modification. Female worms emerge from the anus of their hosts at night and attach eggs to the skin. This causes peri-anal itching and eggs are transferred by hand to mouth. Infections by *Enterobius* cause irritability and sleeplessness in humans, especially children.

Strongyle 'hookworms' have dorsally curved mouths armed with ventral cutting plates or teeth which they embed in host tissues to feed on blood. They have complex life-cycles where larvae develop in the external environment (as 'geo-helminths') before infecting hosts by penetrating the skin. Once inside, they undergo pulmonary migration before settling in the gut to feed. Heavy infections by *Ancylostoma* and *Necator* cause severe iron-deficient anaemia in humans, especially children.

Rhabditid 'thread-worms' have tiny bodies which become embedded in the host mucosa. Their life-cycle includes parasitic parthenogenetic females producing eggs which may hatch internally (leading to auto-infection) or externally (leading to transmission of infection or formation of free-living male and female adults). Super-infections by *Strongyloides* may cause severe haemorrhagic enteritis in humans.

Ascarid 'roundworms' have large bodies with 3 prominent anterior lips. Their life-cycles involve a stage of pulmonary migration where larvae released from ingested eggs invade the tissues and migrate through the lungs before returning to the gut to mature as adults. *Ascaris* infections in humans cause gastroenteritis, protein depletion and malnutrition and heavy infections can cause gut obstruction.

Spirurid 'filarial worms'occur as long thread-like adults in blood vessels or connective tissues of their hosts. The large female worms release live larvae (microfilariae) into the blood or tissues which are taken up by blood-sucking mosquitoes or pool-feeding flies and transmitted to new hosts. *Onchocerca* infections cause nodules, skin lesions and blindness in humans, while those of *Wuchereria* cause elephantitis.

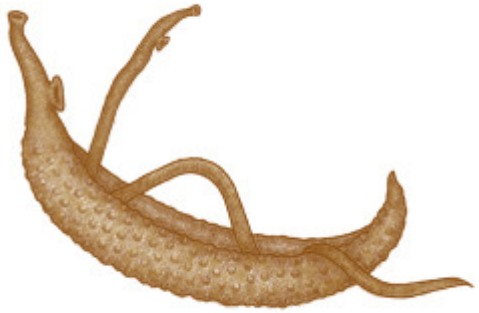
Camallanid 'guinea worms' infect host tissues where the large females cause painful blisters on the feet and legs. When hosts seek relief by immersion in water, the blisters rupture releasing live larvae which infect copepods that are subsequently ingested with contaminated drinking water. The 'fiery serpents' mentioned in historical texts are thought to refer to *Dracunculus* infections.

Two subclasses of cestodes are differentiated on the basis of the numbers of larval hooks, the Cestodaria being decacanth (10 hooks) and the Eucestoda being hexacanth (6 hooks). Collectively, 14 orders of cestodes have been identified according to differences in parasite morphology and developmental cycles. Two orders have particular significance as parasites of medical and veterinary importance.

Cyclophyllidean cestodes have terrestrial 2-host life-cycles where adult tapeworms develop in carnivores (scolex with 4 suckers and sometimes hooks) while larval metacestodes form bladder-like cysts in the tissues of herbivores. The larvae of *Taenia* spp. cause cysticercosis in cattle, pigs and humans, while those of *Echinococcus* cause hydatid disease in humans, domestic and wild animals.

Pseudophyllidean cestodes have aquatic 3-host life-cycles, involving the sequential formation of adult tapeworms in fish-eating animals (scolex with 2 longitudinal bothria), procercoid larval stages in aquatic invertebrates (copepods) and then plerocercoid (spargana) stages in fish e.g. *Diphyllobothrium* in humans, dogs and cats being transmitted through copepods and fish.

Two major groups of trematodes are recognized on the basis of their structure and development: monogenean trematodes with complex posterior adhesive organs and direct life-cycles involving larvae called oncomiracidia; and digenean trematodes with oral and posterior suckers and heteroxenous life-cycles where adult worms infect vertebrates and larval miracidia infect molluscs to proliferate and produce free-swimming cercariae. Monogenea are almost exclusively ectoparasites of fishes while Digenea are endoparasites in many vertebrate hosts and have snails as vectors. Some 10 digenean orders are recognized on the basis of morphologic and biologic differences, two orders are of particular medical and veterinary significance.



Echinostomatid fasciolids (liver flukes) live as adults in hepatic bile ducts of mammals where they cause fibrotic ‘pipestem’ disease. The parasites proliferate in freshwater snails and mammals become infected by ingesting metacercariae attached to aquatic vegetation. Several *Fasciola* spp. cause hepatic disease in domestic ruminants and occasionally in humans.

Strigeatid schistosomes (blood flukes) are unusual in that the adults are not hermaphroditic but form separate sexes which live conjoined in mesenteric veins in mammals. Female worms lay eggs which actively penetrate tissues to be excreted in urine/faeces or they become trapped in organs where they cause granuloma formation. Miracidia released from eggs infect aquatic snails and produce fork-tailed cerceriae which actively penetrate the skin of their hosts. Several *Schistosoma* spp. cause schistosomiasis/bilharzia in humans.

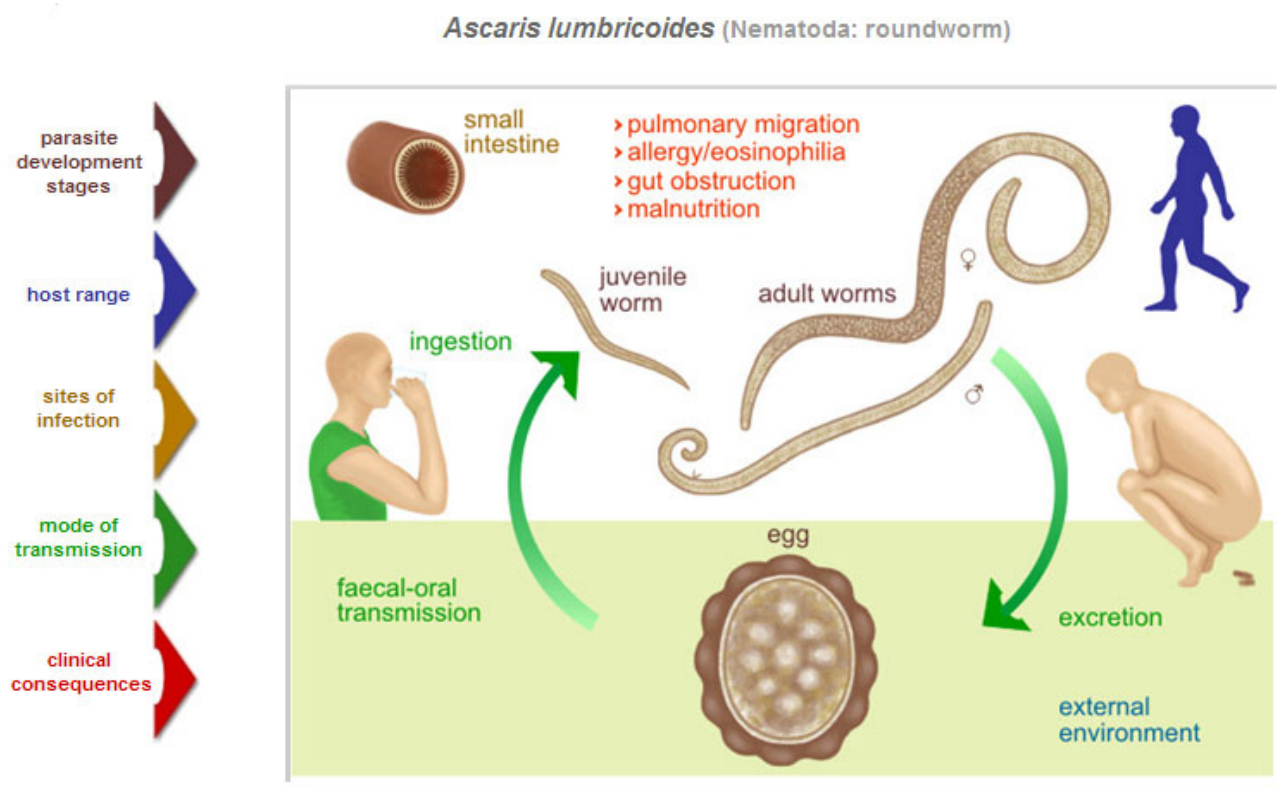
Ascaris

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Ascaridida	(intestinal roundworms)
Ascaridoidea	(large worms, three prominent lips)

Family: Ascarididae

The ascaridoids are "round-worms" of the small intestine of many animals, including humans. They are characterized by their large size, three prominent anterior lips and the absence of a bursa. Round-worms have simple direct life-cycles involving faecal-oral transmission of infective eggs. Female worms produce numerous eggs which are excreted with host faces and must undergo embryonation before becoming infective. Larvae hatch from ingested eggs and undergo pulmonary migration before developing into adult worms in the small intestines. Adult worms generally eat the food of their hosts, but heavy infections cause tangles of worms which can obstruct the gut. Clinical infections are typically found in young individuals, although older individuals may serve as sources of infection.



Ascaris lumbricoides [this species may cause gut obstruction in humans]

Parasite morphology: The parasite forms several different developmental stages: eggs, larvae [moult from first-stage (L1) through to fourth-stage (L4)], and adults (male and female). Fertilized eggs appear as round-oval tan-coloured stages (45-75 µm long by 35-50 µm wide) surrounded by a thick albuminous mamillated (lumpy) outer coat. Before insemination or in early stages of oviposition, female worms may also excrete unfertilized eggs which are more elongate (85-95 x 45 µm) and decorticated (not mamillated). Fertilized eggs are excreted unembryonated, but then develop first-stage then second-stage infective larvae. When hatched in the host, these small larvae (1.2-1.8 mm long) invade host tissues and undertake pulmonary migration. Large adult worms develop in the gut, female worms measuring 20-50 cm long by 3-6 mm wide, while males are smaller, measuring 15-30 cm long by 2-4 mm wide with two simple spicules 2.0-3.5 mm long. Adults have a striated cuticle and three small, but conspicuous, lips around the apical mouth.

Host range: *A. lumbricoides* is common in many human populations around the world, particularly in tropical and subtropical countries with high rainfall, as well as in temperate regions with warm summers. Infections are particularly prevalent in countries where nightsoil (human faeces) is used to fertilize vegetable crops. It is estimated that almost one quarter of world population (1 billion people) may be infected. Infections are over-dispersed in local populations, where large numbers of parasites occur in a small number of individuals. Children are most susceptible to clinical infection; although a range of predisposition factors have been reported, involving various combinations of environmental, social, behavioural and genetic factors. A similar species, *A. suum*, occurs in pigs, especially in developing countries with free-ranging village or feral pigs. Modern husbandry practices in developed countries have resulted in a significant decline in the incidence of infections in pigs. There is considerable biological and epidemiological evidence to suggest zoonotic transmission of *A. suum* to humans, although recent molecular studies have shown limited gene flow between human and pig ascarid populations. While the whole life-cycle of *A. suum* may not be completed in non-porcine hosts, their larvae can undergo extensive migration in a number of hosts (humans, cattle, sheep, etc) leading to allergic manifestations.

Site of infection: Adult worms live in the lumen of the small intestine, where the females lay numerous eggs which are shed in host faeces. Prior to the development of adult worms, the infective larvae undertake a curious circuitous migration through the lungs, ending up in the gut from where they started. This pulmonary migration phenomenon is considered an evolutionary relict behaviour preserved from ancestral forms. The larvae migrate through the gut wall into blood/lymph and are carried to the lungs where they penetrate into air spaces and move up the respiratory tree to the epiglottis where they are swallowed.

Pathogenesis: Infections by small numbers of worms may remain asymptomatic, although some individuals may develop allergic reactions (urticaria, eosinophilia). Larger numbers of worms, however, can cause significant health problems for the host. Following infection, pulmonary migration by larvae may cause petechial haemorrhages, oedema, inflammation, and pulmonary congestion (pneumonitis, or Loeffler's pneumonia) with cough, chest pain and difficulty breathing. Migrating larvae lost or trapped in other tissues often die causing focal inflammation and vague symptoms difficult to diagnose. Adult worms developing in the gut feed on luminal content, they steal liquid nourishment from the host contributing to protein energy malnutrition and impaired carbohydrate absorption. Moderate-heavy infections may cause a variety of digestive disorders, poor growth and development in small children, abdominal pains, restlessness, insomnia and allergic responses (rashes, asthma). Heavy infections may also cause life-threatening gut obstructions where tangles of worms form a bolus mechanically blocking the gut. To the great consternation of their hosts, worms may also occasionally wander upstream (obstructing biliary or pancreatic ducts, sometimes even being regurgitated) or downstream (infecting the appendix, or being passed in faeces).

Mode of transmission: Infections are passed between hosts by the faecal-oral transmission of eggs containing infective larvae. Freshly-excreted eggs require 9-40 days for embryonation before they become infective. Embryonation occurs faster in warm moist soil (especially clay) and water (~10 days at 30°C). The eggs are very resistant to external environmental conditions and can survive high temperatures (up to 45°C) and dry conditions (down to 6% humidity). Experimental studies have shown that eggs may remain viable in soil for several years. They are also dispersed in the environment by wind, water, earthworms and insects (cockroaches). Eggs in soil/water may be transferred to the mouth by contaminated hands or ingested with foods (uncooked vegetables, washed salads and fruits) or soil (pica = dirt-eating, especially by young children). Once ingested, the eggs hatch releasing infective larvae which invade the gut and migrate via the blood/lymph to the lungs over 8-10 days. They break into the airspaces (alveoli) of the lungs

and move up the bronchi and trachea to the pharynx where they are swallowed. They moult in the small intestines and mature to adult worms. Females begin egg production 60-65 days after infection and produce huge numbers of eggs (up to 200,000 per day). The adult worms may live for 6 months to 2 years, so the entire parasite life-cycle can range from 2 months up to 5-10 years.

Differential diagnosis: Established infections are diagnosed by the microscopic detection of eggs in faecal material, often using sedimentation and/or flotation concentration techniques. Imaging techniques have been used to examine gut obstructions and masses of worms appear as filling defects in X-rays. Differential diagnosis of infections during the larval migration stage is difficult due to non-specific nature of any clinical signs. Larvae have sometimes been detected in sputum samples but are difficult to identify by untrained personnel.

Treatment and control: Various anthelmintic drugs have proven effective for the treatment of infections. Mebendazole appears to be the drug of choice, although it sometimes may cause some worms to wander. Suitable alternatives include pyrantel and levamisole, while albendazole has also been used. Once diagnosed, infections can be successfully treated, but the individual often returns to the heavily contaminated environment and quickly becomes re-infected. Environmental decontamination is difficult because the eggs are very resistant to chemicals; they can embryonate in dilute formalin, potassium dichromate, acid solutions and many commercial disinfectants. Because infections accumulate in their hosts (worms do not multiply in hosts), control measures involve avoiding behaviours conducive to the uptake of eggs; such as improving personal hygiene, maintaining sanitary conditions, and proper disposal of excreta. Fresh faecal material should not be used to fertilize edible crops, but it can be processed by microbial biocomposting before use (high temperature processing destroys egg viability).

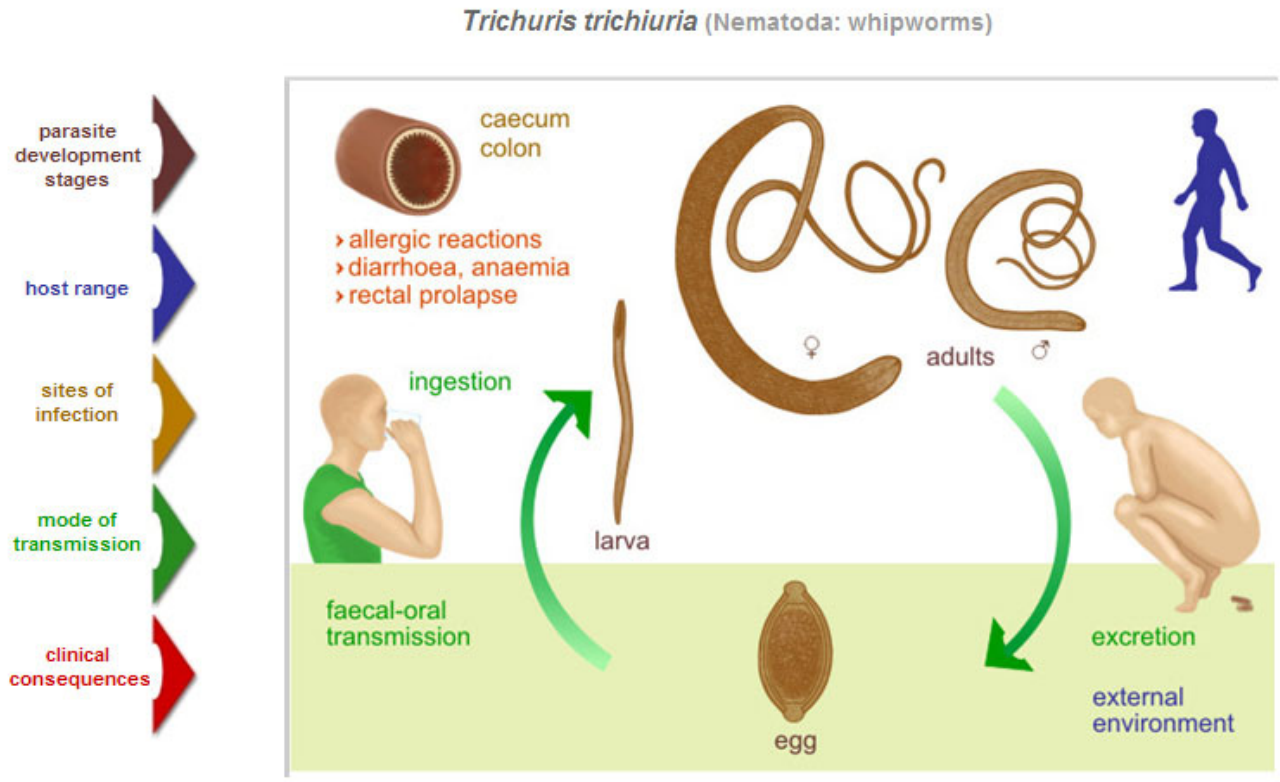
Trichuris

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Adenophorea (Aphasmidea)	(without chemoreceptors known as phasmids)
Trichocephalida (Enoplida)	(thread-head)
Trichuroidea	(whipworms, anterior end long and narrow, stichosome pharynx)

Family: Trichuridae

Trichurid worms are known as "whip-worms" because they have a broad short posterior end and a very long narrow whip-like anterior end (with a stichosome pharynx) which is embedded in the mucosa of the lower intestines of humans and domestic animals. Heavy infections may cause dysentery, anaemia, malnutrition, and occasionally rectal prolapse. They have simple direct life-cycles involving the faecal-oral transmission of eggs containing infective larvae. Eggs excreted with host faeces contaminate soil, food and water supplies and have a characteristic barrel-shape with mucoid polar plugs at each end.



Trichuris spp. [these species cause trichuriasis in humans and animals]

Parasite morphology: Whipworms form three different developmental stages; eggs, larvae and adults. The eggs are ellipsoidal to barrel-shaped, measuring 50-70 µm in length by 25-35 µm in width and have two distinct mucoid polar plugs. They are typically unembryonated in faecal samples and develop infective larvae in the external environment. Adult worms have elongate whip-like bodies (3-7 cm long), with a long thin anterior end that suddenly becomes thick at the posterior end. The mouth is a simple opening without lips and the oesophagus is thin, tubular and surrounded by glandular stichocytes (whole structure referred to as stichosome pharynx). Adult female worms measure up to 7 cm in length and the uterus contains many lemon-shaped eggs. Adult male worms are smaller measuring up to 5 cm in length and they have a tightly coiled posterior end and a single spicule with a spiny, eversible sheath.

Host range: The species *T. trichiura* is found in human populations throughout the world, mainly in tropical and subtropical regions. It is estimated that around 10% of the world population (800 million people) may be infected. Parasites are very prevalent in regions where human excrement (nightsoil) is used to fertilize vegetable gardens. Infections are typically over-dispersed, where a few individuals harbour most of the worms. Other whipworm species occur in a range of domestic and wild animals, including *T. ovis*, *T. skrjabini*, *T. discolor* and *T. globulosa* in ruminants, *T. vulpis*, *T. campanula* and *T. serrata* in dogs and cats, *T. suis* in pigs and *T. muris* in rodents. Zoonotic transmission of *T. vulpis* to humans has occasionally been reported.

Site of infection: Juvenile worms develop in glands of the caecal and colonic mucosa where they moult and grow. Adult worms have their anterior ends embedded in the mucosa with their posterior ends dangling into the lumen.

Pathogenesis: Small worm burdens rarely cause disease, while heavier infections may produce a variety of conditions, ranging from local enteric disturbances to systemic conditions and occasionally death. The anterior ends of the adult worms are embedded in the mucosa where they feed on fluids, digested tissues and possibly blood. They may cause significant trauma to the mucosa with chronic haemorrhage leading to dysentery and anaemia. Pathogenesis has been related to host inflammatory responses, involving markedly reduced cell-mediated responses and elevated IgE responses, characteristic of local tissue anaphylactic responses. Persistent infections have been associated with malnutrition, growth retardation, and reduced cognitive function in children. Chronic infections may also cause finger (and occasionally toe) clubbing evident as odd thickening of the ends of the digits. Heavy infections may produce tenesmus (urgency) causing the host to strain and possibly suffer rectal prolapse.

Mode of transmission: Whipworms have a direct developmental cycle whereby embryonated eggs are directly infective to the definitive host. Infections are transmitted by the faecal-oral route, involving the ingestion of eggs with contaminated food, water or soil. Fertilized female worms produce numerous eggs (3,000-10,000 per day) which are excreted with host faecal material. The eggs embryonate in around 10 days and develop infective larvae in about three weeks in moist shady soil (or up to 4 months in cold conditions). Eggs are dispersed in the environment by anthropogenic activities as well as by wind, water and insects (houseflies can act as mechanical vectors). When ingested, infective larvae emerge from the eggs and invade the mucosa of the lower intestines where they tunnel, grow and moult to form adults. Patent infections may develop in 8-12 weeks and can persist for 1-4 years. Infections may also accumulate in hosts as they are constantly re-infected from their heavily-contaminated environments.

Differential diagnosis: Infections are routinely diagnosed by coprological examination of faecal samples, usually following concentration, and the microscopic detection of the characteristic eggs. In individuals with rectal prolapse, worms can be seen macroscopically attached to the mucosa. Colon endoscopy has also been used to reveal the presence of worms.

Treatment and control: Whipworms are resistant to many anthelmintic treatments due to their relative inaccessibility. Mebendazole and albendazole have proven effective, and pyrantel/oxantel pamoate and flubendazole have some activity. Thiabendazole is also effective but has unpleasant side-effects. Prevention of infections is best achieved by thorough washing of vegetables, salads and fruits with clean water prior to consumption. Control measures include education programmes to improve personal hygiene and sanitary conditions, prohibiting the use of excrement as fertilizer (or ensuring it is processed by suitable microbial biocomposting prior to use) and regular deworming campaigns.

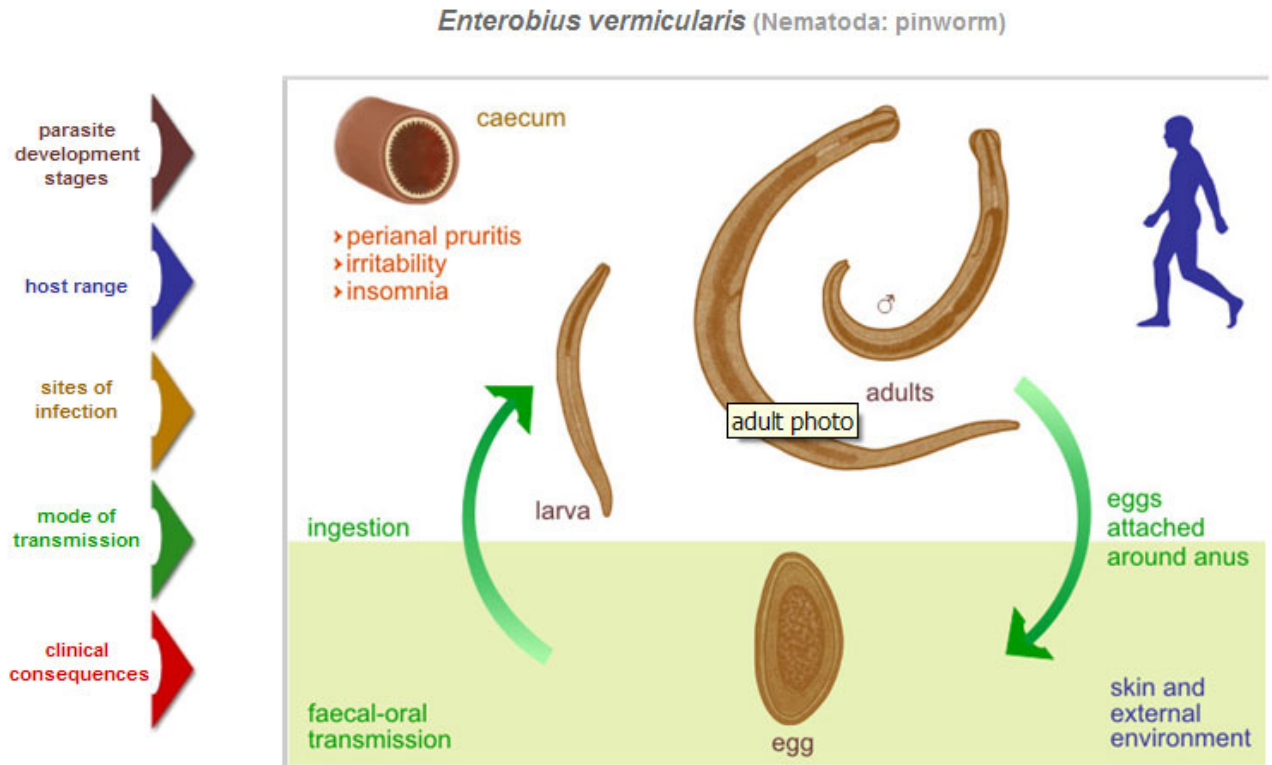
Enterobius

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Oxyurida	(pinworms; pointed tails)
Oxyuroidea	(eggs attached around anus of host)

Family: Oxyuridae

Oxyurid worms are commonly called “pin-worms” because of their characteristic tapering shape and pointed tails. They have simple direct life-cycles involving faecal-oral transmission of eggs containing infective larvae. The eggs, however, are oviposited around the anus (perineum) where they are subsequently dislodged and ingested by their hosts. Pinworms are common in many animal species, and infections in humans may cause intense pruritis (itching), irritability, insomnia and sometimes diarrhoea



Enterobius vermicularis [this species causes perianal pruritis (enterobiasis) in humans]

Parasite morphology: These worms form three developmental stages: eggs, larvae and adults. The eggs are elongate-oval in shape, measure 50-60 µm in length by 20-30 µm in width, and are characteristically asymmetric about the long axis being distinctly flattened on one side. Infective larvae develop rapidly within the eggs. Adult worms appear as elongate whitish tubes with pointed tails. They have three lips surrounding the anterior mouth, a large oesophageal bulb, and a conspicuous anterior cuticular inflation (swollen head). Male worms are 1-4 x 0.2-0.4 mm in size, have a single spicule 100-140 µm long, and their posterior ends are strongly curved ventrally. Female worms are 8-13 x 0.3-0.6 mm in size and have pronounced slender pointed tails.

Host range: The species *E. vermicularis* is the most common worm found in humans worldwide, particularly in temperate regions. They are commonly found as group infections in children, in families and in institutions (where contact between individuals is high and hygiene may be low). They are estimated to infect some 400 million people, but few countries consider them to be of public health significance due to their low pathogenicity. Infections are more irritating than debilitating, causing embarrassment, low morbidity and rarely mortality. However, individual families often spend considerable time and money trying to rid themselves of infections. Numerous pin-worm species have been described from a range of mammals, birds, reptiles, amphibians, insects and millipedes, but they appear to be highly host-specific. Curiously, dogs and cats do not become infected with pin-worms so companion animals should never be considered as sources of human infection.

Site of infection: Adult worms tend to congregate in the ileocaecal region of the gut where they attach to the mucosa, but they may wander throughout the intestines from the stomach to the rectum. Fertilized female worms migrate out through the anus and deposit eggs of the perianal skin.

Pathogenesis: While many infections remain asymptomatic, worm burdens may increase with time resulting in damage to the intestines by adult worms and/or damage to the perineum resulting from egg deposition. Adult worms attach to the mucosa and feed on intestinal content, bacteria and possibly epithelial cells, causing minute ulcerations which may lead to mild catarrhal inflammation with diarrhoea, eosinophilia and bacterial infection. More commonly, however, infections are characterized by intense perianal itching (*pruritis ani*) caused by host sensations and reactions to female worms depositing sticky eggs on the skin. Patients vigorously scratch themselves attempting to relieve the itching, but in doing so, often cause skin damage, bleeding, bacterial infection and intensified itching. Heavy infections in children may cause restlessness, irritability, anorexia, insomnia, nightmares, bed-wetting, nausea and vomiting. Occasionally, wandering worms have been associated with appendicitis, vaginitis, and rarely, extra-intestinal granulomas in ectopic sites.

Mode of transmission: Pinworms have direct life-cycles involving the oral ingestion of eggs containing infective larvae. The eggs, however, are not excreted with faecal material, but are attached to the perianal skin. Such transmission is therefore not strictly faecal-oral, but rather contaminative, involving the transfer of eggs to the mouth via host behaviours or inanimate objects. Gravid females migrate out through the anus onto the perineum, particularly during the night, and leave trails of eggs (up to 10,000) as they crawl about. After oviposition, the females die whereas the males die soon after copulation. Larvae develop within the eggs within six hours and become infective. The eggs are dislodged by host scratching and contaminate hands, bedding, clothing, toys, and furniture. They are very light and easily disseminated with house dust by the slightest of air currents. They remain viable in cool moist conditions for up to one week. Following ingestion, the eggs hatch in the small intestine and the larvae migrate to the large intestine and mature over 2-6 weeks. Alternatively, eggs trapped in perianal folds may hatch and the larvae may enter the intestines directly via the anus (process called retro-infection). Occasionally, larvae may enter the vulva and infect the vagina of women. The parasite may complete its whole life-cycle in 2-13 weeks, and infections may become progressively heavier due to continual parasite uptake (through auto-infection, re-infection and retro-infection).

Differential diagnosis: Worm eggs are rarely found in faeces so conventional coprological examination techniques are not used. Instead, infections are best diagnosed by the macroscopic detection of adult worms or the microscopic detection of eggs on the perineum. Motile worms may be seen on perianal skin glistening under bright light when close visual examinations are conducted during the night or early in the morning. Adult worms may sometimes be observed on the surface of fresh stool samples. Alternatively, sticky-tape may be quickly applied to the perianal skin first thing in the morning and then stuck onto a glass

slide for microscopic examination of adherent eggs (aptly-named perianal sticky-tape test). Parents of infected children should be trained to collect appropriate samples to respect patient rights and privacy (especially involving minors) and alleviate any shame or embarrassment.

Treatment and control: Anthelmintic treatment for pin-worm infections is readily available from most pharmacies. The drug of choice is mebendazole, although albendazole, levamisole and pyrantel pamoate are also effective. Piperazine has been used for many years but requires a longer course of treatment. Treatment should be repeated after about 10 days to kill any newly-acquired worms. It is advisable to institute whole group treatment where appropriate, so that other group, cohort or family members do not continue to act as sources of infection. To avoid constant re-infection, it is imperative that strict personal hygienic precautions are introduced, particularly frequent hand-washing. Household decontamination is difficult as infective eggs can survive for many days in cool moist house dust and for a few days on toys or furniture. Nonetheless, clothes, bed linen and towels should be laundered in hot water, dusty areas should be well vacuumed and potentially contaminated surfaces should be cleaned. While the eggs are very resistant to many disinfectants, they are susceptible to desiccation in dry conditions.

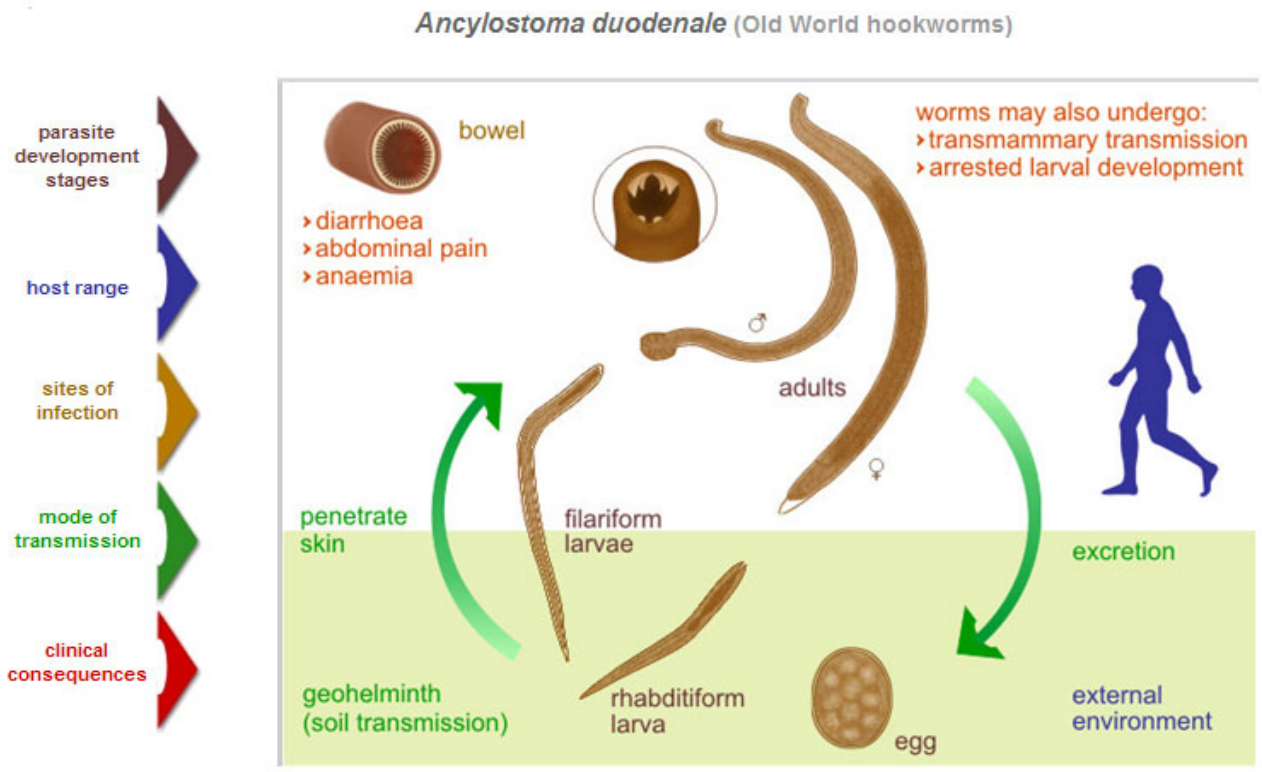
Ancylostoma/Necator

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Strongylida	(strongyles, bursate nematodes)
Ancylostomatoidea	(hookworms, with cutting plates/teeth)

Family: Ancylostomatidae

These worms are characterized by their bent mouths, the anterior ends being bent dorsally, hence the common name of “hook-worms". They have a well-developed buccal capsule with cutting plates or teeth, and are voracious blood-feeders in the small intestines of mammals, including humans, dogs, cats, sheep and cattle. Male worms have a well-developed bursa (copulatory clasping organ) at their posterior ends. Hook-worms have direct life-cycles, involving a geo-helminth phase. Eggs voided with faeces hatch releasing free-living rhabditiform larvae which subsequently develop into infective filariform larvae that are ingested or actively penetrate the skin of their hosts (causing cutaneous larval migrans). Juvenile worms migrate through the lungs (causing pneumonitis) before developing into adults in the small intestines (causing iron-deficiency anaemia and growth retardation).



Ancylostoma duodenale [this species causes Old World hookworm disease in humans]
Necator americanus [this species causes New World hookworm disease in humans]

Parasite morphology: Hook-worm developmental stages include eggs, four larval stages and adult worms. Eggs appear as oval thin-shelled bodies, measuring 55-77 µm in length by 35-42 µm in width. Freshly-excreted eggs contain a developing embryo in the early stages of cleavage (2-8 cells). The first two larval stages (L1 and L2) are rhabditiform (free-living) and characterized by a long narrow buccal chamber and flask-shaped muscular oesophagus. Third stage larvae (L3) measure up to 0.6 mm in length and are filariform, non-feeding infective stages characterized by a closed mouth, elongate oesophagus with posterior bulb (strongyliform) and pointed non-notched tail. Fourth-stage larvae (L4) migrate and live in host tissues. Adult hook-worms have a creamy-white tough cuticle, a prominent anterior hook and a large oval buccal capsule with specialized structures to aid in feeding, *Ancylostoma* spp. having 2 pairs of fused ventral teeth, and Necator having two ventral cutting plates. Ancylostoma females measure 10-13 x 0.6 mm, while males measure 8-11 x 0.4 mm. The adults of *Necator* are slightly smaller. All male worms have a pronounced posterior copulatory bursa, consisting of two broad lateral lobes and a smaller dorsal lobe, all supported by fleshy rays

Host range: Hook-worms infections have been reported in numerous mammalian species throughout the world, mainly in tropical and subtropical regions because the larvae cannot develop below 22°C. They are most common in rural areas with high annual rainfall and shaded sandy or loam soils ideal for larval development (not clay or gravel). *Ancylostoma* can survive at lower temperatures than *Necator* and were a common finding in miners and tunnel builders in Europe. It is estimated that around 800 million people are infected with hook-worms worldwide, with 1.6 million suffering from anaemia and 55,000 deaths annually. *A. duodenale* is the Old World human hookworm and is entrenched on most continents. *N. americanus* is the New World human hookworm, although it probably came to such areas with the slave trade. Similar hook-worms species occur in domestic and wild carnivores, and they vary in their host specificity. *A. ceylanicum* normally occurs in carnivores but has been reported from humans in the Philippines. *A. braziliense* has also been found in humans from several countries, but some infections may have been confused with *A. ceylanicum*. The larvae of many species can undergo partial development in humans, and the dog hookworm *A. caninum* can almost complete its development in humans.

Parasite species	Hosts	Oral structures	Geographic distribution
Necator americanus	humans	2 cutting plates	Africa, India, Asia, China, central America
Ancylostoma duodenale	humans	2 pairs teeth	Europe, Africa, India, China, Asia, patchy distribution in North and South America
Ancylostoma ceylanicum	cats, dogs, humans	2 pairs teeth	Sri Lanka, India, Asia, Philippines
Ancylostoma braziliense	dogs, cats (humans?)	2 pairs teeth	Brazil, Africa, India, Sri Lanka, Indonesia, Philippines
Ancylostoma caninum	dogs, humans	3 pairs teeth	worldwide
Ancylostoma tubaeforme	cats	3 pairs teeth	worldwide

Site of infection: Adult hook-worms use their bent mouths to attach to the small intestinal mucosa. Infective larvae invade dermal tissues, particularly in sites which have come into close contact with the ground (feet, hands and buttocks). Migrating larvae move through the lungs (pulmonary migration) and some may undergo arrested development deeper in the gut tissues or in muscles (hypobiotic larvae of *A. duodenale*)

Pathogenesis: Many people may be infected with hook-worms but remain asymptomatic. In general, disease development depends on the parasite species involved, the intensity of infection, and the nutritional condition of the individual. Sequential parasite development causes three phases of disease; a

cutaneous phase where invading larvae may cause dermatitis, a pulmonary phase where migrating larvae may cause pneumonitis, and an intestinal phase where adult worms may cause anaemia. Infective larvae penetrate the skin and invade blood vessels in the dermis, moderate to heavy infections giving rise to an allergic dermatitis with papular, and sometimes vesicular, focal rash and pruritis (condition known as ground itch). Larvae from animal hook-worms (especially *A. caninum* and *A. braziliense*) can also penetrate human skin but do not complete their development. Instead, they aimlessly tunnel through the skin for several days or weeks leaving red itchy wounds that may become secondarily infected. The resultant condition is known as cutaneous *larval migrans* (or creeping eruption) and is characterized by local dermatitis, pruritis (itching) and inflammation (oedema, erythema). The next phase of disease occurs when larvae undergo pulmonary migration, having been carried to the lungs where they break out into airspaces (alveoli) causing focal haemorrhages and allergic pneumonia (severity dependent on numbers). Once worms reach the small intestines, they attach to the mucosa by ingesting a tissue plug into their mouths and commence feeding on blood. They have voracious appetites and individual adult *Necator* worms may consume 0.03 ml blood per day, while those of *Ancylostoma* may take up to 0.26 ml blood per day. Blood loss from the host may result in a profound iron-deficiency anaemia and hypoproteinaemia. The worms appear to be wasteful feeders as not all blood ingested is digested, some is apparently used for respiration and passes through the worm but degrades in the intestines resulting in black tarry faeces (melena). Blood loss is further exacerbated by intestinal lacerations as worms move to new feeding sites from time to time, secreting proteolytic enzymes and anticoagulants, and leaving microscopic ulcers. Infections involving <100 *Necator* are frequently mild whereas >100 worms produce more damage and >1,000 may be fatal. Fewer *Ancylostoma* cause greater disease because they suck more blood, 100 worms may cause severe disease. Patients with heavy infections have severe protein deficiency, dry skin and hair, oedema, and potbelly in children with delayed puberty, mental dullness, heart failure and death. Disease is intensified by malnourishment and immunological impairment.

Mode of transmission: Hook-worms have direct life-cycles involving a geo-helminth stage where infective larvae in the soil actively penetrate the skin or oral mucosa of their hosts. Female worms produce numerous eggs (up to 9,000 eggs per day for Necator and 30,000 eggs per day for *Ancylostoma*) which are excreted with host faeces. The eggs embryonate rapidly in warm moist conditions and hatch within 1-2 days releasing free-living rhabditiform larvae which feed on bacteria and organic debris. The larvae moult once after ~3 days and then transform 2-5 days later into non-feeding ensheathed filariform larvae (L3) which are the infective stages. They remain viable for several weeks in light sandy soils under warm moist conditions. The larvae also exhibit short vertical migration, moving to the surface in moist conditions and host-seeking by rhythmically waving back and forth, but retreating back into the soil in dry conditions. *Necator* larvae must penetrate the skin to infect humans (transdermal or percutaneous transmission), but *Ancylostoma* can penetrate the skin or oral mucosa, be passed in mother's milk (transmammary transmission) and even cross the placenta to infect the foetus (transplacental transmission). Some evidence suggests that *A. duodenale* larvae may survive in paratenic hosts and lead to human infection through the ingestion of undercooked meat, including rabbit, lamb, beef and pork. Ingested larvae may undertake pulmonary migration, but most undergo a histotrophic stage by penetrating mucosal glands before returning to the lumen and maturing into adults. Larvae which penetrate the skin actively secrete collagenase to break down basement membranes and dermal ground substances. The larvae enter the circulation and migrate over 2-7 days to the lungs where they break into respiratory alveoli and move up the trachea to be swallowed. Once they reach the small intestines, they moult, attach to mucosa and become sexually differentiated, moult again and grow into adult worms. The prepatent period (from infection to egg excretion) ranges from 4-7 weeks, although *A. duodenale* may undergo arrested larval developmental for up to 38 weeks. Hypobiotic larvae remain dormant in gut or muscles and recommence their development later coinciding with the seasonal return of environmental conditions more favourable to transmission. Infections may persist for years, as *Ancylostoma* adults have been found to live for up 5 years, and *Necator* adults for up to 15 years.

Differential diagnosis: The diagnosis of hookworm disease on the basis of clinical symptomatology (notably chronic anaemia and debility) is highly suggestive, but requires confirmation by the detection of parasite eggs in faecal samples by microscopy, preferably after concentration. Because the eggs of hookworms (*Ancylostoma* and *Necator*) and thread-worms (*Strongyloides*) are virtually identical, faeces should be kept for larval cultures (on moistened filter paper in a closed tube for a few days) to differentiate infections (hook-worm larvae have a larger buccal cavity and smaller genital primordium), since treatment options are quite different. Several immunoserological tests have been developed to detect host antibodies against hookworm antigens, but they generally do not discriminate between patent or previous infections. Radiographic findings include intestinal hypermotility, proximal jejunal dilatation and coarsening of the mucosal folds.

Treatment and control: Various anthelmintic drugs have been used to cure infections, and are best used in conjunction with dietary supplementation, especially iron replacement. The most effective drugs are mebendazole, albendazole and pyrantel pamoate. Levamisole is less effective and treatment has adverse side-effects. Older drugs, such as bephenium and tetrachlorethylene, are still used in many areas throughout the world because they are cheap. Salicylanilides have also proven effective against animal *Ancylostoma* infections. While chemotherapy works, mass treatment programmes are only partly effective as most cured individuals return to heavily contaminated areas and rapidly become re-infected. Infection appears to stimulate little protective immunity. Control programmes must include prophylaxis to prevent infections as well as environmental management to reduce soil contamination. People should be encouraged to wear solid shoes in endemic regions and to thoroughly wash salad vegetables. Building and education campaigns should be introduced to improve sanitary conditions, as promiscuous defaecation, associated with poverty and ignorance, keeps soil contamination high. Nightsoil (faecal waste) should not be used to fertilize gardens or vegetable crops. Dog faeces should not be left on lawns or parks (especially well-watered ones) where people congregate. Several countries have successfully controlled infections, mainly through regular periodic mass treatment, the provision of latrines and institutionalized public education.

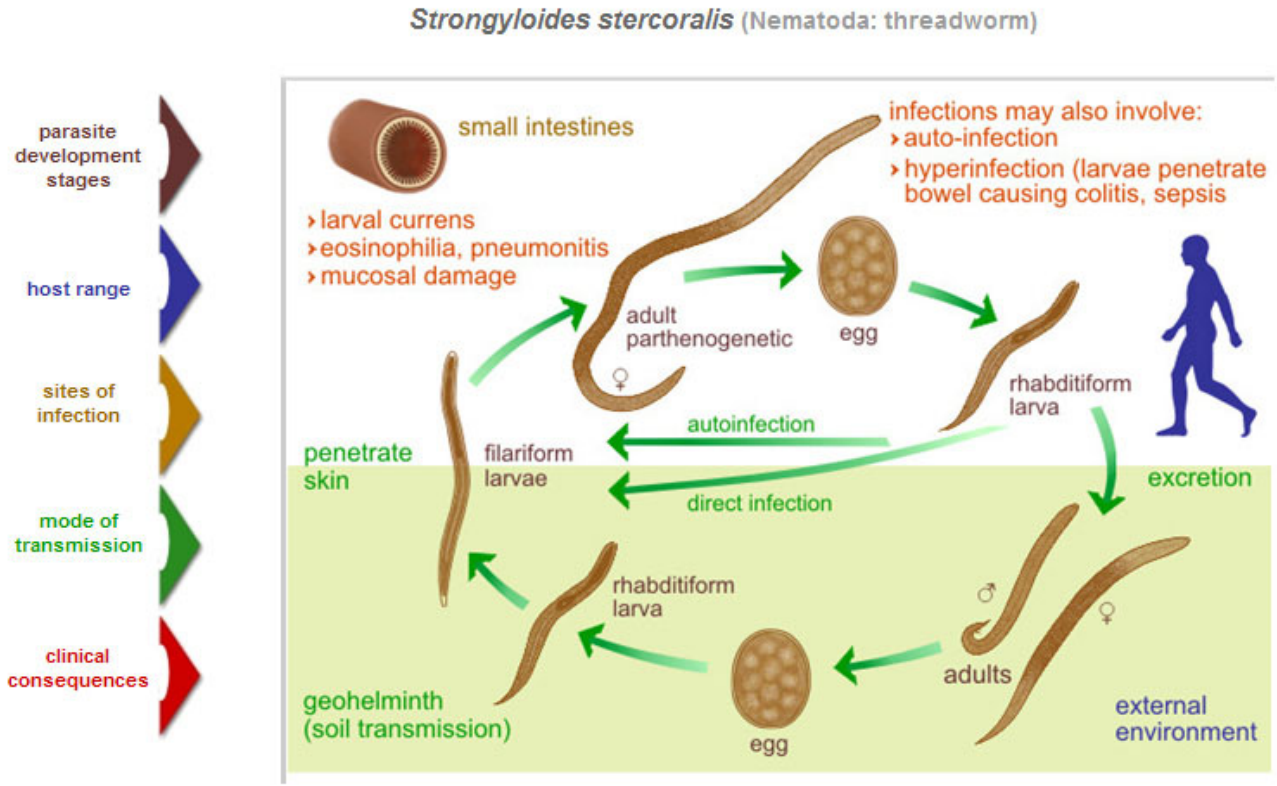
Strongyloides

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Rhabditida	(early-stage larvae with rhabditiform pharynx)
Rhabdiasoidea	(threadworms, parthenogenetic females embedded in mucosa)

Family: Strongyloididae

These slender cylindrical worms have a long oesophagus and uterus intertwined, giving the appearance of a twisted thread, hence their common name of 'thread-worms'. They are unique amongst nematodes, being capable of both parasitic and free-living reproductive cycles. Only parthenogenetic female worms are parasitic, living in the small intestinal mucosa of various mammals, birds, reptiles and amphibians. Transmission involves a geo-helminth phase, where rhabditiform larvae in the soil form infective filariform larvae which penetrate the skin of their hosts. Sometimes, however, larvae develop into male and female worms which undergo one or more free-living cycles in the soil before producing infective larvae again



Strongyloides stercoralis [this species causes Cochin diarrhoea, larval currens in humans]

Parasite morphology: The parasite has an unusual developmental cycle involving the formation of eggs, free-living and parasitic larvae, free-living male and female adult worms, as well as parasitic parthenogenetic female worms. Eggs appear as small oval thin-shelled bodies, measuring 50-58 µm in length by 30-34 µm in width, and are partially embryonated at the 2-8 cell stage of development. Free-living larvae (L1 and L2) measure up to 350 µm in length and have a rhabditiform pharynx (with a muscular oesophagus for feeding on particulate material). Infective third-stage larvae (L3) measure up to 600 µm in length and have a filariform pharynx (with a long fine oesophagus for sucking fluids after penetrating host tissues). These larvae do not feed in the soil and are ensheathed with a closed mouth and a pointed notched tail. Parasitic worms are all parthenogenetic females, measuring from 2-3 mm in length and characterized by the presence of an extremely long filariform pharynx (one third of body length) and a blunt pointed tail. Free-living male and female worms have a rhabditiform pharynx and are smaller in size, measuring up to 1 mm in length. Males have two simple spicules and a gubernaculum, and a pointed tail curved ventrally. Females are stout with the vulva located around the middle of the body.

Host range: Thread-worm infections occur in a range of mammalian species throughout the world, particularly in tropical and temperate regions with warmer climates favouring the survival of parasite developmental stages in soil. Different species vary in their host-specificity, the species *S. stercoralis* being found in humans and companion animals, and thus should be considered zoonotic.

***Strongyloides* species**	**Hosts**	**Location**	**Clinical signs**	**Geographic distribution**
S. stercoralis	humans, primates, dogs, cats	small intestine	bloody diarrhoea	worldwide, esp. warmer regions in South America and southeast Asia
S. fuelleborni	apes, humans	small intestine	bloody diarrhoea	Africa, Asia
S. ransomi	pigs	small intestine	bloody diarrhoea	worldwide
S. planiceps	cats	small intestine	non-pathogenic	worldwide
S. cati (felis)	cats	small intestine	non-pathogenic	worldwide
S. tumefaciens	cats	large intestines	mucosal tumours	worldwide
S. papillosus	sheep, cattle	small intestine	diarrhoea, anorexia	worldwide
S. westeri	horses, donkeys, zebra, pigs	small intestine	diarrhoea	worldwide

Site of infection: Parasitic female worms become embedded in the small intestinal mucosa, forming tunnels in the epithelium at the bases of villi in the small intestines. Eggs and first-stage larvae are passed with host faeces. Infective third-stage larvae penetrate the skin and undergo pulmonary migration before forming parthenogenetic females in the intestines.

Pathogenesis: Light thread-worm infections remain asymptomatic, even though they may persist for years due to auto-infection or re-infection. Heavier infections, however, can cause several forms of disease in humans; including dermal, pulmonary, enteric and disseminated disease. Migrating larvae can race through the skin (up to 10 mm per hour) causing *larval currens*, characterized by urticaria, pruritis, eosinophilia, dermatitis, and inflammation. Pulmonary migration may cause a mild transient pneumonia, with coughing, wheezing, shortness of breath, and transient pulmonary infiltrates (Loeffler's syndrome). Lesions caused by adult worms generally consist of catarrhal inflammation, although severe infections may result in necrosis

and sloughing of the mucosa, haemorrhage, epigastric pain (may mimic peptic ulcer or Crohn's disease), vomiting, abdominal distention, diarrhoea with voluminous stools and a malabsortion syndrome with dehydration and electrolyte disturbance, peripheral eosinophilia, and possibly reactive arthritis. Hyper-infections can develop when individuals are stressed or immuno-compromised resulting in the production of large numbers of filariform larvae which can penetrate the bowel and disseminate, causing colitis, polymicrobial sepsis, pneumonitis or neurological manifestations, such as meningitis and cerebral or cerebellar abscesses.

Mode of transmission: Even though thread-worms may form parasitic or free-living adults, they all have direct life-cycles involving a geo-helminth phase where infective larvae in soil penetrate the skin of their hosts. Parasitic parthenogenetic females produce partially embryonated eggs (several dozen per day) which hatch prior to excretion with host faeces. The emergent rhabditiform larvae (L1) feed on bacteria and organic debris, moult to second-stage larvae (L2) which feed and then develop either as parasitic or free-living stages. Homogonic strains develop directly into infective third-stage filariform larvae (L3) which can live in moist soil for several weeks. Heterogonic strains moult twice to form a generation of free-living males and females which feed on bacteria with a rhabditiform pharynx before producing unembryonated eggs which grow and moult twice to form infective filariform larvae. All filariform larvae penetrate the skin (or oral mucosa) of their hosts where they enter the circulation. Most larvae are carried to the lungs where they undergo pulmonary migration by penetrating alveoli and moving up the trachea to be swallowed (other routes of larval migration have been shown in experimental animal models). Parthenogenetic female worms parasitize the small intestines and only live for a few months, yet infections can continue indefinitely because hosts undergo self-infection (auto-infection). This occurs when eggs hatch in the intestines and develop into infective larvae which directly penetrate the lower gut or peri-anal region, thus leading to a new cycle of infection.

Differential diagnosis: Infections are diagnosed by the detection of larvae in faecal samples, as most eggs hatch internally within the host releasing rhabditiform larvae. Filariform larvae may occasionally be detected, especially during hyper-infection, and they can be identified by their notched tails. Although eggs are rarely detected in faeces, they are similar in size, shape and appearance to hook-worm eggs. Faecal culture can increase the sensitivity of microscopic diagnosis, by either concentrating larvae (Harada Mori technique) or amplifying populations through a generation of free-living males and females. Larval cultures also differentiate between thread-worm (*Strongyloides*) and hook-worm (*Ancylostoma* and *Necator*) infections, an important undertaking as treatment options differ (thread-worm larvae have a smaller buccal cavity and a larger genital primordium). Non-nutrient agar plate cultures of faeces have also been used to detect motile larvae. Several immunoserological tests have also been developed to detect host antibodies against thread-worm antigens, but they have difficulty in distinguishing between past and active infections.

Treatment and control: Several anthelmintics are reasonably effective against threadworm infections, but none are entirely satisfactory. Thiabendazole has been widely used but it has unpleasant side-effects, including nausea, vomiting, dizziness, malaise and smelly urine. Albendazole and levamisole have also shown some activity, but infections are not responsive to mebendazole or pyrantel. Treatment should be repeated after a week because of difficulty in confirming cure. Immuno-suppressive treatments should be avoided as they can result in rampant auto-infection. Preventive measures include the wearing of solid shoes in endemic areas, thoroughly washing salad vegetables, prohibiting the use of nightsoil to fertilize gardens, the sanitary disposal of faeces, the provision of latrines in poor areas, and public education campaigns.

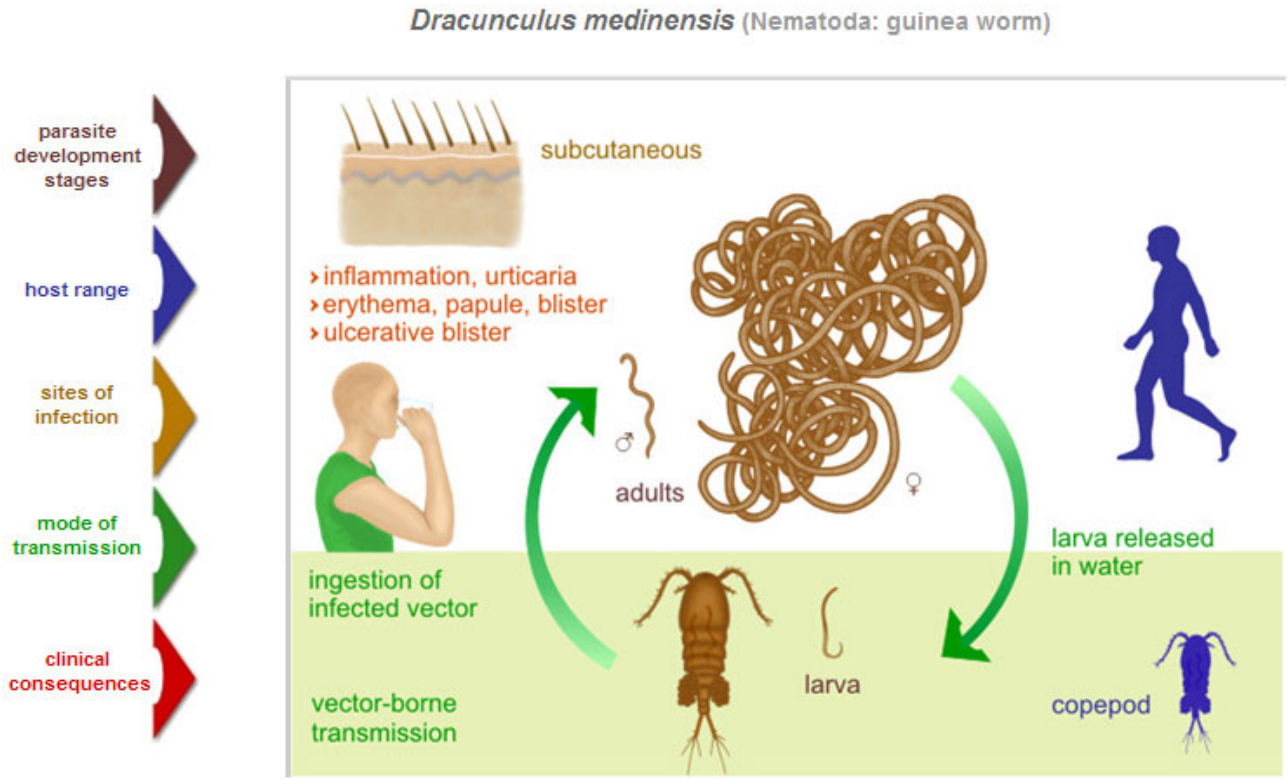
Dracunculus

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Camallanida	(copepod intermediate hosts)
Dracunculoidea	(weakly-developed buccal cavity, large guinea worms)

Family: Dracunculidae

These worms include some of the largest known nematodes, several species measuring up to 80cm long. They have heteroxenous (two-host) life-cycles involving vertebrate definitive hosts (in which tissue-dwelling worms develop) ingesting aquatic copepodid intermediate hosts (in which infective larvae develop). Female worms do not lay eggs but birth live larvae (ovoviviparous). Infections in humans cause painful blisters through which larvae are released. Infections have been described throughout human history; the iconic 'staff-with-serpent' adopted as the official symbol of medicine may depict the traditional means of worm removal by winding it onto a stick.



Dracunculus medinensis [this species causes dracunculiasis in humans]

Parasite morphology: Guinea-worms develop through four larval stages prior to the formation of large adult worms; eggs are not produced. First-stage larvae appear as thin white tubular stages measuring up to 400 µm in length and having a rhabditiform pharynx. The third-stage larvae are longer, measuring up to 600 µm in length, and they have a filariform pharynx. Adult worms exhibit marked sexual dimorphism; males measuring from 2-4 cm in length with unequal spicules, while creamy-white females grow up to 80 cm in length by 2 mm in width and contain thousands of embryos. In young females, the vulva is located around the midbody but it becomes atrophied and non-functional in adults, as does the intestine due to the high internal pressure generated by the gravid uterus. Although the worms are very long and thin, they are not true filarial worms and are grouped separately.

Host range: Infections of humans by *D. medinensis* have been recorded many times in history, being described as 'little snakes' by Greek and Roman scholars, 'fiery serpents' in Biblical texts (Numbers 21:4-8), and colloquially named Medina-worms, guinea-worms or dragon-worms. Infections occur throughout semi-desert areas of sub-Saharan Africa, India, the Middle-East and Brazil, mainly in rural areas where water is drawn from wells or shallow ponds during the rainy season. It has been estimated that the prevalence of infections has decreased markedly (from 15 million in 1980 to 4 million in 1986 and 60,000 in 1997) due mainly to systematic preventive campaigns fostered by the World Health Organization. *D. medinensis* infections have occasionally been reported in dogs, cats, cattle, horses and other mammals. Other dracunculid species have been described from snakes, turtles, crocodiles and aquatic birds. The species *D. insignis* has been found in muskrats, opossums, raccoons and other carnivores in the Americas, and possibly sometimes in humans.

Site of infection: Ingested infective larvae penetrate the gut and invade subcutaneous connective tissues, migrating mainly to the axillary and inguinal regions. Maturing female worms migrate from deep connective tissues to peripheral subsurface locations, particularly in the extremities of limbs (legs and arms) although they can occur elsewhere.

Pathogenesis: Despite their eventual enormous size, infections by guinea-worms usually do not produce any clinical signs until the mature female worms migrate to the skin and provoke the formation of a papule then a blister. Migration may sometimes produce vague allergic reactions, including nausea, dizziness, diarrhoea, rash and local oedema. Infections generally produce two types of lesions: subcutaneous or deep abscesses around dead worms (involving many inflammatory cell types) that tend to calcify; or cutaneous papules which rapidly become blisters through which females release live larvae. Skin lesions may involve local erythema, urticaria, inflammation, ulceration and intense burning pain (fiery serpent of biblical times). Patients seek to relieve symptoms by immersing the affected region in cool water. Lesions are initiated by the deposition of larvae in the tissues and the induction of hypersensitivity reactions which ultimately produce blisters through which larvae, and parts of the adult worm, emerge (a unique means for tissue-dwelling parasites to seek egress from their hosts). In uncomplicated cases, lesions may only last for several weeks until the worm is completely expelled. However, many cases involve secondary bacterial infection of the worm track with persistence of the lesion, chronic ulceration and possible sequelae, involving disseminated infections, phlegma of limbs, contractures of tendons, fibrous ankylosis or arthritis in the joints, or even tetanus.

Mode of transmission: The parasites have a unique indirect life-cycle, involving copepods (*Cyclops*, water fleas) as intermediate hosts. Adult female worms cause skin blisters which eventually rupture, thus releasing any larvae deposited in the tissues and also exposing the anterior portion of the adult worm. The exposed portion may rupture, or the gravid uterus may prolapse from the worm. Muscular contractions of the body wall force thousands of larvae out in periodic spurts (half a million per day); the contractions often being instigated by contact with water. Females usually die within 2-6 weeks of penetrating the skin. Liberated larvae are infective for less than a week and they actively move about in water attracting copepodid crustaceans which ingest them. Copepods breed best in standing waters such as ponds and open wells, so infections are common in remote rural areas reliant on such water supplies. The larvae penetrate into the haemocoel of the copepods, especially dorsal to the gut, and develop into infective third-stage larvae over 12-15 days (at 25°C). Humans become infected by swallowing infected copepods with drinking water. The infective larvae penetrate the intestinal wall and migrate for about 3 months through connective tissues where male and female worms develop and mate. The males die after mating, while the fertilized females migrate to subcutaneous sites and grow to essentially become non-feeding bags full of larvae. Gravid females begin to emerge from the skin around 10-14 months after infection.

Differential diagnosis: Infections become obvious once a blister forms and part of the female worm emerges. Milky clouds of larvae can also be seen under low magnification when the lesion is placed in water. Immunoserological tests have been developed to detect host antibodies formed against parasite antigens during the pre-patent period of infection.

Treatment and control: The traditional means of curing infections involves the slow extraction of worms by winding them onto a stick a few centimetres a day for several weeks. Excessive force should not be used to avoid breaking the worm and complicating lesions and reactions. Surgical removal may be successful when worms are restricted to superficial sites, but can be difficult when worms are threaded through tendons or deep fascia. Chemotherapy with conventional anthelmintics has not proven effective, but various compounds, such as albendazole, mebendazole, niridazole, thiabendazole and metronidazole, appear to act as anti-inflammatory agents, thus allowing worms to be extracted more easily. Preventive measures involve breaking the cycle of transmission by reducing contamination of water supplies and eliminating copepod hosts. Public education programmes have been developed to discourage infected persons from entering ponds or wells to collect drinking water or to bath. Local water supplies can be treated with temephos (Abate, cyanamid) which kills copepods for several weeks. Drinking water can also be purified by boiling or filtering through fine-meshed cloth (<0.15 mm). The World Health Organization has accredited the global decline in the prevalence of infections to the adoption of many of these simple preventive measures.

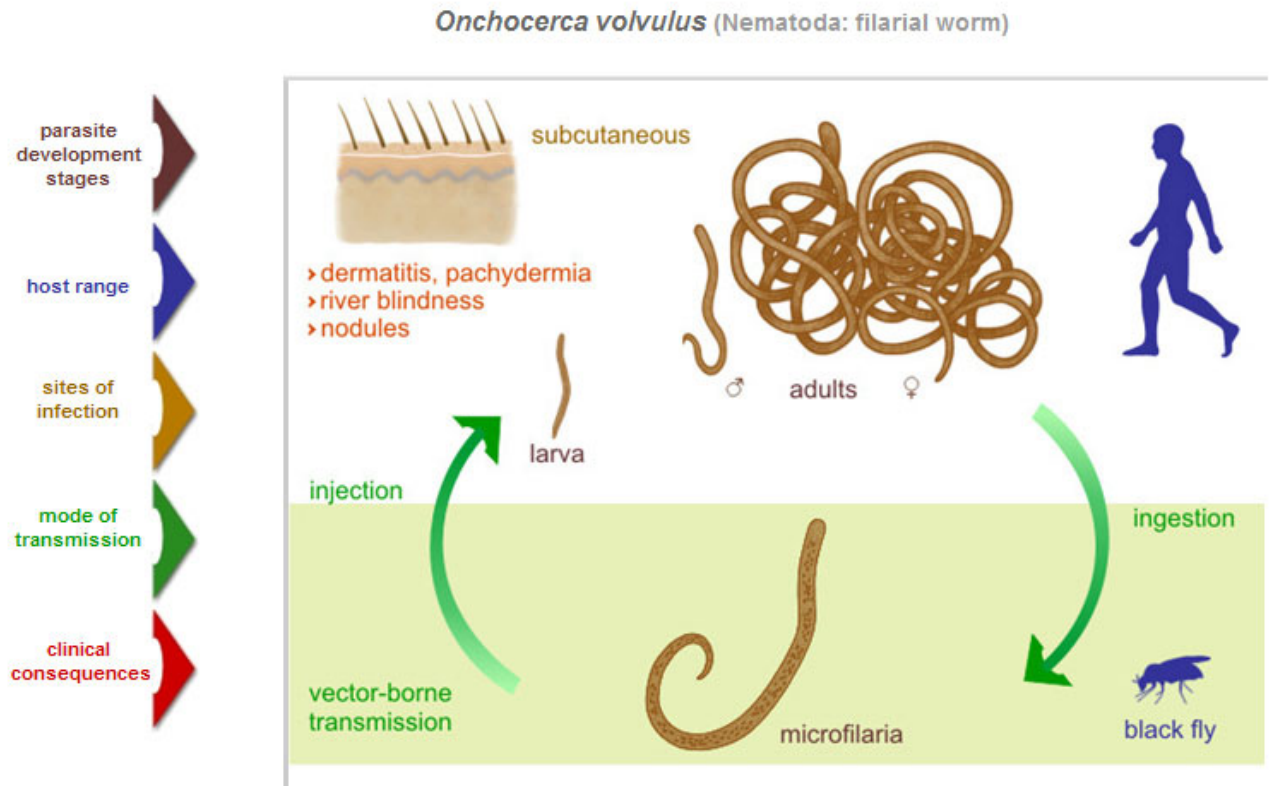
Onchocerca

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Nemathelminthes	(nematodes)
Secernentea (Phasmidea)	(with chemoreceptors known as phasmids)
Spirurida	(indirect life-cycles, arthropod intermediate hosts)
Filarioidea	(filarial worms, microfilariae transmitted by vectors)

Family: Filariidae

These long thin 'filarial' worms are tissue-dwelling nematode parasites that live as adults in the circulatory system or connective tissues of vertebrate hosts. Female worms do not lay eggs but produce live microfilariae (pre-larvae). The parasites have indirect life-cycles involving the transmission of larvae by arthropod intermediate hosts (blood or tissue feeding insect vectors). Infections are common in wild animals and birds, but several species cause serious diseases in humans and domestic animals, involving skin lesions, blindness, and gross deformities, such as nodules and elephantiasis.



Onchocerca volvulus [this species causes skin lesions, nodules and river blindness in humans]

Parasite morphology: Filarial worms form adults and microfilariae in vertebrates while larval development occurs in the arthropod vectors. Adult worms have distinctive cross-striations (regularly spaced annulations) of their cuticle and they exhibit marked sexual dimorphism. Female worms are large, measuring 25-50 cm by 0.3-0.4 mm, while male worms are smaller, measuring 2-4 cm by 0.2 mm. Gravid females produce small microfilariae (pre-larvae), measuring 220-360 µm by 5-9 µm, which are released into host tissues. The microfilariae of various filarial worms can be differentiated on the basis of their morphology, those of *Onchocerca* not being sheathed and possessing nuclei which do not extend to the tip of the tail (compared to those of *Wuchereria*, *Brugia* and *Loa* which are ensheathed by a thin flexible 'egg-shell' membrane).

Host range: The species *O. volvulus* infects humans throughout central Africa, Central America and northern South America. It is thought to have originated in Africa and was taken to Central America by the slave trade. Infections are transmitted by black-fly vectors. It is estimated that some 30 million people in Africa suffer from onchocerciasis, up to 1 million being blind. Infections have also been recorded in higher primates, chimpanzees and gorillas. Other *Onchocerca* spp. infect domestic animals, eight species having been described in cattle and two in horses. These species are transmitted either by black-flies or midges. Other filarial worms infect humans causing severe disease and disfigurement, most being restricted to tropical regions, and involving mosquitoes or other flies as vectors.

Parasite genus	Disease	Geographic distribution	Location of adult worms	Location of microfilariae	Vector
Onchocerca	river blindness, skin lesions	Africa, Central America	subcutaneous	tissues	black-fly
Wuchereria	Bancroftian filariasis (elephantiasis)	Africa, Asia, South America	lymphatics	blood	mosquito
Brugia	Malayan/Timorian filariasis (elephantiasis)	Malaya/Timor	lymphatics	blood	mosquito
Loa	Calabar swellings	Central/West Africa	subcutaneous	blood	tabanids
Mansonella	skin lesions	Central America	dermis	blood	sand-fly, black-fly
Dirofilaria	pulmonary lesions	widespread	heart	blood	mosquito

Site of infection: Adult female worms live in the connective tissues of the skin, where they become encapsulated forming distinctive nodules containing tangled pairs of groups of worms. Live microfilariae are released directly into adjacent host tissues (or blood for other filarial worms).

Pathogenesis: *Onchocerca* causes the disease onchocerciasis which has three principal manifestations; subcutaneous nodule formation; dermatitis; and blindness. Adult female worms become surrounded by fibrous nodules (onchocercomas), usually over bony prominences (especially the pelvis in Africa and the head in Mexico). The most pathogenic effects, however, are caused by the release of numerous microfilariae into host tissues. Early stage infections are often associated with pruritis, rash and lymphadenopathy in the groin or axilla. Over time (months to years), chronic inflammatory responses manifest as dermatitis, intradermal oedema, and pachydermia (thickened wrinkled skin colloquially known as crocodile or elephant skin). There is progressive loss of elastic fibres causing hernias or hanging groin (hanging lymph glands) and atrophy of the skin giving a premature aged appearance. In Africa, skin depigmentation resembling leprosy may occur, whereas hyperpigmentation ('Sowda') is common in Yemen. Ocular infections by microfilariae may result in blindness due to anterior (corneal) lesions causing

a sclerosing keratitis and corneal opacities, or posterior (retinal) lesions resulting in marked sclerosis (hardening) of choroidal vessels and retinochoroiditis. People are afflicted more in savannah than forest regions, and the common name 'river blindness' actually indicates an association between the distribution of infections and suitable habitats for the insect vector. Infections in animals by other *Onchocerca* spp. do not result in severe diseases; infections in cattle may lead to devaluation of carcasses and blemished hides, although there is some evidence of ocular inflammatory reactions in horses.

Mode of transmission: All filarial worms have indirect life-cycles, involving vector-borne transmission. *O. volvulus* infections are transmitted by small black-flies (sometimes called buffalo gnats) of the genus *Simulium*. The flies are pool-feeders with coarse mouthparts that rasp and tear host tissues. They feed on a variety of mammals and birds, and their painful bites cause considerable annoyance. Microfilariae ingested during feeding migrate to the flight muscles of the fly and moult twice over 1 week. They then migrate to the proboscis and develop into infective third-stage larvae which are transmitted to vertebrate hosts during feeding. Larvae injected into subcutaneous tissues moult and develop into mature worms over 1-2 years before the females start producing microfilariae. Adult worms may live for as long as 12 years and produce billions of microfilariae. Many studies have demonstrated differences in the temporal and spatial distribution of microfilariae; many species exhibit a daily periodicity or tissue tropism which is attuned to the feeding habits of the vector species; e.g. microfilariae of *Onchocerca* in Africa normally concentrates in lower body to maximize transmission to low-biting *Simulium damnosum* but infections in Guatemala concentrate in the upper body where the vector is the high-biting *Simulium ochraceum*.

Differential diagnosis: The diagnosis of early stage infections on the basis of the appearance of a pruritic rash is not distinctive enough as other conditions may cause similar conditions. Infections are generally diagnosed after they have become patent and worms have formed characteristic palpable nodules under the skin. Portions of worms can be obtained by biopsy to confirm diagnosis. Infections can also be detected by examining skin-snip biopsies for active microfilariae after incubation in saline for 30 mins. *Onchocerca* microfilariae are rarely found in blood whereas those of other filarial worms are commonly found in peripheral blood samples (taken at different times of the day to account for any differences in periodicity). Microfilariae may be concentrated from blood samples using Knott's technique to lyse erythrocytes with dilute formalin, or filtering blood through 3-5µm pore-size polycarbonate filters. The morphological characteristics of microfilariae are distinctive enough to differentiate all human filarial worms. A wide variety of immunoserological tests have been developed in attempts to differentially diagnose infections, especially early stage infections, but most tests have lacked sensitivity and specificity. Various molecular biological techniques are currently under development to detect parasite antigens or DNA in host fluids.

Treatment and control: A common therapeutic practice in endemic regions is that of nodulectomy, that is, the surgical removal of detectable nodules from superficial aspects to stop microfilariae production and curb attendant pathology. Some nodules, however, may by non-palpable or the adults may be freely migrating. Chemotherapy is therefore warranted, and a major advance was made with the development of ivermectin which is well tolerated in humans. Single doses were found to eliminate microfilariae from the skin, and to suppress their release from adults for over a year. Multple doses were also found to slowly kill adults. Other microfilaricidal drugs include diethylcarbamazine (DEC), mebendazole, flubendazole and benzimidazole derivatives, but they have little or no effect on adult worms. DEC treatment may also precipitate serious dermal, systemic or ocular complications caused by dying microfilariae, although such side-effects can be ameliorated by the use of anti-inflammatory drugs. Suramin does have an effect on adult worms, but it must be administered systemically and it is nephrotoxic. Preventive measures involve vector control and avoiding black-fly bites. Residual insecticides can be used around dwellings to reduce adult fly numbers, but better results are obtained using larvicides to treat rivers and streams where black-flies breed. Unfortunately, there are recurring problems with the development of insecticide resistance in black-fly populations.

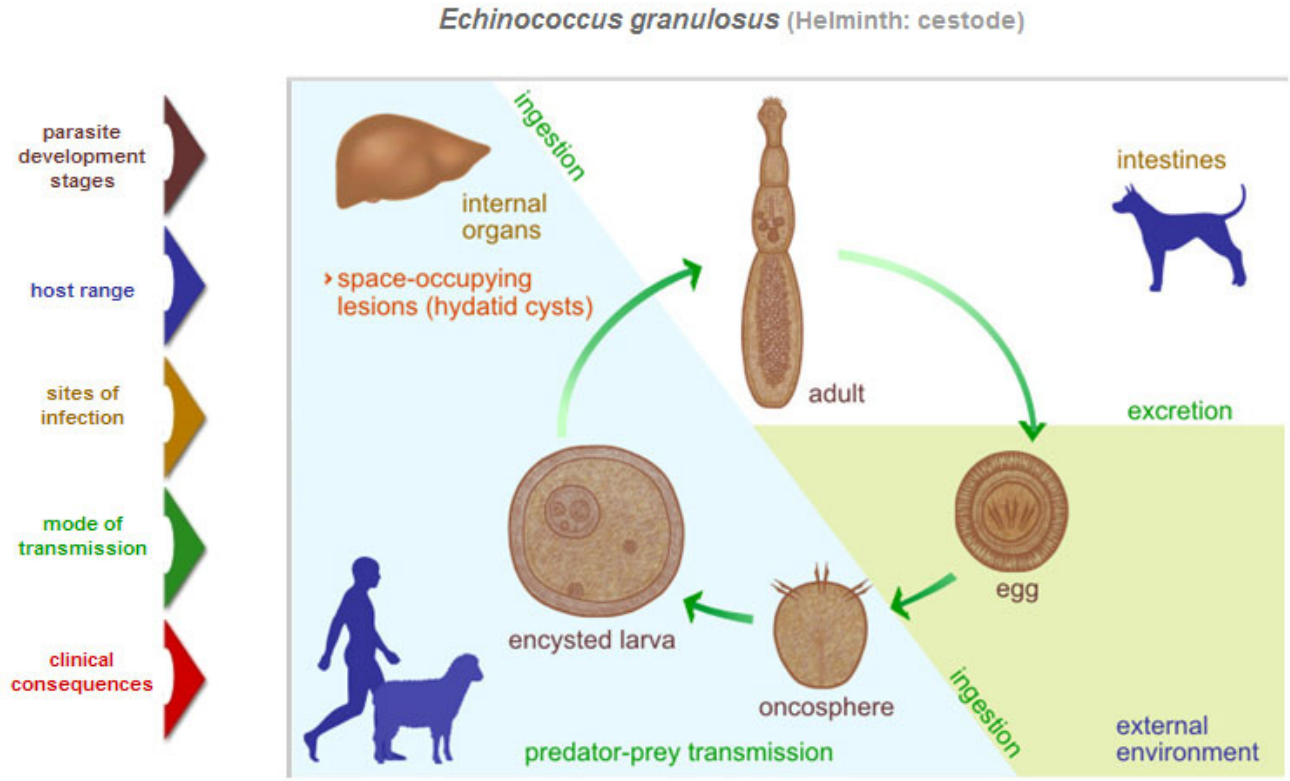
Echinococcus

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Platythelminthes	(flatworms)
Cestoda	(tapeworms)
Eucestoda	(segmented, hermaphroditic)
Cyclophyllidea	(terrestrial cycles, scolex with suckers)

Family: Taeniidae

Cyclophyllidean tape-worms have flat ribbon-like bodies, with an anterior scolex (hold-fast organ with suckers and sometimes hooks) and a posterior tape (strobila) made up of segments (proglottids). Adult worms lack a gut (they absorb nutrients) and they are hermaphroditic (segments containing both male and female reproductive organs). They have indirect life-cycles involving encystment of larvae (metacestodes) in the tissues of intermediate hosts and their transmission to definitive hosts by carnivorism. Various species are parasitic in mammals, birds, reptiles and amphibians. Adult stages are rarely pathogenic, but the encysted larval stages may cause serious space-occupying lesions, including hydatid cysts in humans.



Echinococcus granulosus [this species causes hydatid disease in mammals]

Parasite morphology: Tape-worms form three different developmental stages: eggs; larvae; and adults. Adult *E. granulosus* worms are small (2-6 mm long) and have a scolex with only three attached segments. The scolex has four lateral suckers and the rostellum is non-retractable and armed with a double crown of 28-50 recurved hooks. The anterior segment is immature, the middle segment is mature with functional testes and ovaries, and the posterior segment is gravid with the uterus filled with eggs. The eggs are typical for most taeniid species and are small and round (30-43 µm in diameter), thick-shelled and contain a hexacanth (6-hooked) embryo (oncosphere). The encysted larval (metacestode) stage is known as a bladder-worm or hydatid, and it produces multiple infective stages (protoscoleces, apparent as invaginated scolices already containing suckers and hooks) either directly from the germinal layer of the cyst wall, or by forming brood sacs (hydatid sand) by endogenous (internal) or exogenous (external) budding of the germinal layer. *E. granulosus* forms fluid-filled unilocular cysts with endogenous budding of brood capsules, *E. vogeli* forms fluid-filled polycystic cysts with exogenous budding, and *E. multilocularis* forms fluid-free multilocular or alveolar cysts with exogenous budding.

Host range: *E. granulosus* occurs in most sheep and cattle producing areas around the world, being most prevalent in South America, East Africa, Southeast Asia and China. Canids (dogs, dingoes, wolves, and coyotes) act as definitive hosts for adult worms, while omnivorous/herbivorous mammals (humans, domestic animals and wildlife) serve as intermediate hosts for encysted larval stages.

Parasite species	Definitive host	Intermediate host	Metacestode	Cyst morphology
Echinococcus granulosus	candid	omnivore	unilocular hydatid cyst	fluid-filled sphere with germinal membrane proliferating endogenously to form brood capsules
Echinococcus vogeli	bush dog	paca/rat	polycystic hydatid cyst	fluid-filled with germinal membrane budding exogenously to form new cysts and endogenously to form septae
Echinococcus multilocularis	dog/cat	rodent	multilocular (alveolar) hydatid cyst	no free fluid, germinal membrane budding exogenously to form multiple cysts

Site of infection: The small adult tape-worms attach to the mucosa of the small intestines in dogs, sometimes in their thousands. The larval stages (hydatids) most commonly infect visceral tissues and organs, especially the liver, in their mammalian intermediate hosts, although cysts may be found in many other locations, including the brain and long bones.

Pathogenesis: The adult stages are considered benign and do not cause disease in dogs, as the worms do not invade or feed on host tissues. Encysted larval stages generally do not cause clinical disease in domestic livestock as they are often confined to visceral tissues. However, significant pathological changes occur in humans when the slowly-growing cysts put pressure on surrounding tissues and produce chronic space-occupying lesions.Cysts may grow around 1 mm per month and can become extremely large, up to 30cm in diameter with litres of fluid containing thousands of protoscoleces. Organ enlargement may be accompanied by a variety of clinical signs depending on the size and location of the cysts. Compression of liver may result in jaundice, portal hypertension and abdominal distention. Cysts in the lung may cause haemoptysis (coughing up blood), dyspnoea (difficulty breathing) and chest pain. Cysts in the brain or spinal cord can provoke acute inflammatory responses and numerous neurological sequalae, including epilepsy and blindness. Cyst rupture has been associated with acute clinical signs (such as peritonitis and pneumothorax), and the sudden release of hydatid fluid may cause severe allergic reactions (such as asthma and anaphylactic shock). Protoscoleces released from ruptured cysts can regress and form new hydatid cysts throughout the body.

Mode of transmission: Tape-worms have an indirect life-cycle involving predator-prey transmission between definitive (canid) and intermediate (mammalian) hosts. Mature tape-worms release numerous thick-shelled eggs which are excreted with dog faeces. The eggs are very resistant to external environmental conditions and can survive for months on pasture. Herbivores and omnivores become infected by ingesting eggs; either on herbage, in water, or by hand-to-mouth transfer. Following ingestion, the eggs hatch releasing the oncosphere which uses its three pairs of hooks to penetrate the gut, enter the circulation and settle in various organs and tissues (frequently in the liver after being filtered out by portal capillaries). They form hydatid cysts over many months and eventually produce multiple infective protoscoleces. When mature cysts in offal or carcases are eaten by canids, the cyst wall is digested away freeing the protoscoleces, which evaginate and attach to the small intestinal mucosa. They mature to adult worms in about 8 weeks and may live for 5-20 months. Various strains of *E. granulosus* have been recognized based on differences in parasite morphology, development, biochemistry, genetics and host specificity. Strains are often adapted to particular intermediate host species and do not develop well in other species. Infections are well adapted to pastoral cycles involving farm dogs and domestic livestock (notably sheep and cattle), as well as sylvatic cycles involving wild carnivores (wolves, coyotes, dingoes) and free-ranging herbivores (such as deer, moose and wallabies). Infections in human populations occur more frequently in rural areas, particularly where local traditions are conducive to transmission; e.g. feeding dogs offal, eating dog intestines, not burying the dead, and even using dog faeces to tan hides.

Differential diagnosis: Infections in dogs may be diagnosed by the detection of eggs, and occasionally worms, in faecal samples. Immuno-coprological tests have also been developed to detect parasite antigens in faecal samples. Infections in intermediate hosts are generally diagnosed well after the larvae have encysted. Clinical symptoms of a slow-growing tumour accompanied by eosinophilia are suggestive. Cysts may be visualized by various medical imaging techniques (computerized axial tomography (CAT) scans, X-rays, ultrasound). Several immunoserological tests have been developed to detect host antibodies against crude and purified parasite antigens, and an intradermal (Casoni) test using hydatid fluid has been used in surveys.

Treatment and control: Despite some promising indications, the treatment of hydatid disease with conventional anthelmintic drugs has not proven wholly effective, being complicated by the large size and inaccessible location of cysts and their thick, possibly impenetrable, walls. Variable results have been obtained using praziquantel and mebendazole, while albendazole and niclosamide have been less effective. The only remaining treatment option is for the surgical removal of cysts, provided they are in favourable sites. Surgeons must take care not to rupture cysts as protoscoleces may spread to new sites to form more cysts. Scolicide chemicals, such as cetrimide, may also be used during surgery to sterilize excision sites. In contrast, infections by adult worms in dogs can be successfully treated with praziquantel, and it is advisable to confine dogs and/or use purgatives to facilitate the collection and disposal of infected faeces. Preventing dogs from becoming infected involves eliminating offal and other potentially infected material from their diets, curbing their hunting behaviour, properly disposing of carcases in the field, and culling wild and feral dogs. Several countries have developed highly successful hydatid eradication campaigns based around dog management and treatment. Recently, a recombinant vaccine has been developed to prevent hydatid formation in domestic herbivores, and is undergoing further evaluation. While control may be possible in situations involving pastoral cycles, there will be many problems accessing wildlife involved in sylvatic cycles.

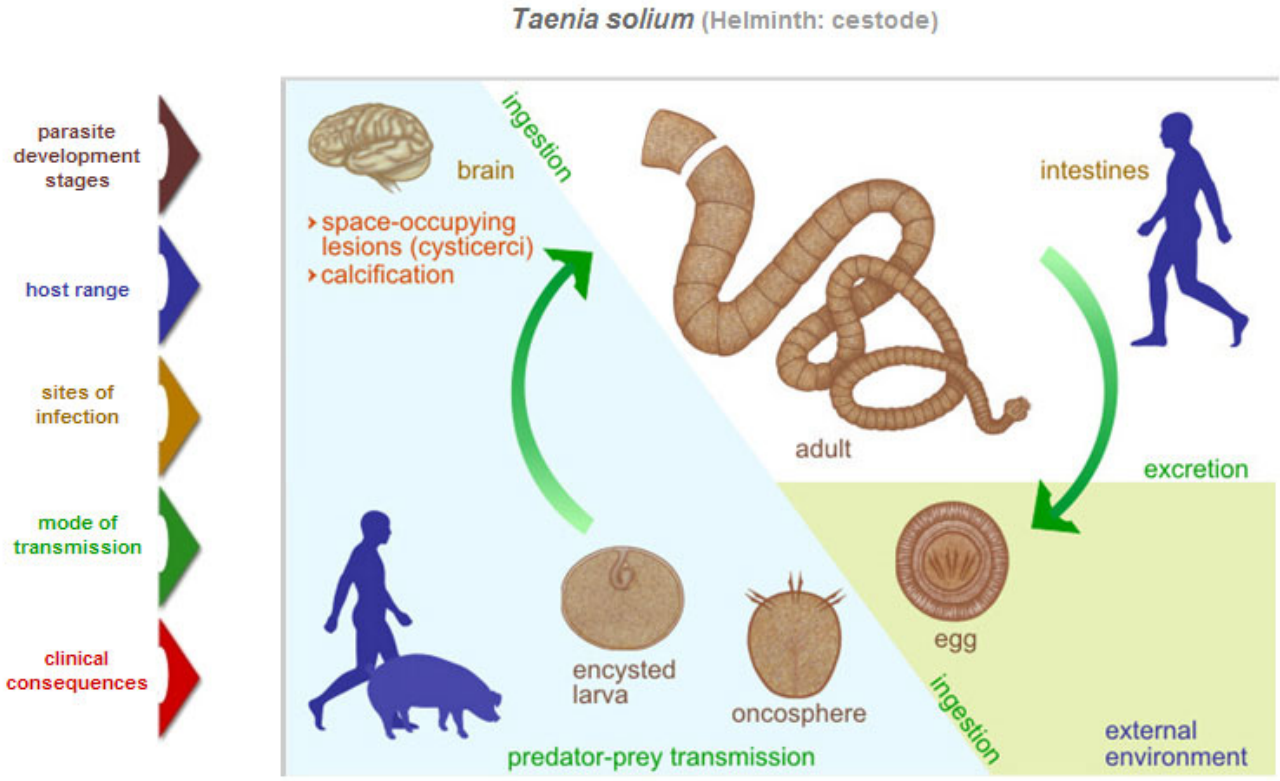
Taenia

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Platythelminthes	(flatworms)
Cestoda	(tapeworms)
Eucestoda	(segmented, hermaphroditic)
Cyclophyllidea	(terrestrial cycles, scolex with suckers)

Family: Taeniidae

Cyclophyllidean tape-worms have flat ribbon-like bodies, with an anterior scolex (hold-fast organ with suckers and sometimes hooks) and a posterior tape (strobila) made up of segments (proglottids). Adult worms lack a gut (they absorb nutrients) and they are hermaphroditic (segments containing both male and female reproductive organs). They have indirect life-cycles involving encystment of larvae (metacestodes) in the tissues of intermediate hosts and their transmission to definitive hosts by carnivorism. Various species are parasitic in mammals, birds, reptiles and amphibians. Adult stages are rarely pathogenic, but the encysted larval stages may cause space-occupying lesions (cysticerci) in domestic animals and humans.



Taenia saginata **[this species causes cysticercosis in cattle]**
Taenia solium **[this species causes cysticercosis in pigs and humans]**

Parasite morphology: These tape-worms form three developmental stages: eggs, larvae and adults. The morphological characteristics of the adults are distinctive; all adults having an anterior scolex (holdfast organ), with four muscular suckers, surmounting a long (up to 10 m) strobila (tape) made up of numerous (as many as 2,000) proglottids (segments). The scolex of *T. solium* is spheroidal, around 1 mm in diameter and is armed with two circles of 22-32 hooks, while that of *T. saginata* is cuboidal, around 2 mm in section and un-armed. Adult worms are hermaphroditic with segments containing both male and female reproductive organs. Anterior segments are usually immature and broader than long, middle segments with fully developed genitalia are square, and posterior segments are gravid (filled with eggs) and longer than broad. The eggs of both species are similar in morphology; being spherical, 40-48 µm in diameter, surrounded by a thick striated wall, and containing a hexacanth (six-hooked) embryo (oncosphere). The larval stages (metacestodes) of *T. saginata* and *T. solium* form distinctive pearly-white cysts (cysticerci) which appear as small (8-10 mm in diameter) fluid-filled bladders (hence the common name of bladder-worms), each containing a single invaginated protoscolex (infective stage). Other *Taenia* spp. form different larval stages; some forming a strobilocercus where the protoscolex is not invaginated, and others forming a larger coenurus containing several invaginated protoscoleces.

Host range: Numerous *Taenia* spp. are found in carnivores and herbivores throughout the world. Many species appear to have two scientific names because the larval stages in herbivores were often named (as *Cysticercus*, *Strobilocercus* or *Coenurus* spp.) before it was realized they were developmental stages of adult *Taenia* tape-worms in carnivores. *T. solium* infections are endemic in humans and pigs in many areas where pork products are common, including regions throughout South and Central America, Eastern Europe, South Africa, China and Indonesia. *T. saginata* infections are cosmopolitan and occur in humans and cattle in most pastoral (beef and dairy) areas throughout the world.

Parasite species	Definitive host	Intermediate host	Metacestode	Cyst morphology
Taenia saginata (beef measles worm)	humans	cattle	(*Cysticercus bovis*)	fluid-filled cyst containing single scolex
Taenia solium (pork measles worm)	humans	pigs, humans	(*Cysticercus cellulosae*)	fluid-filled cyst containing single scolex
Taenia ovis (sheep measles worm)	candids	sheep, goats	(*Cysticercus ovis*)	fluid-filled cyst containing single scolex
Taenia hydatigenea (false hydatid worm)	candids	ungulates	(*Cysticercus tenuicollis*)	fluid-filled cyst containing single scolex
Taenia pisiformis	candids	rabbits, hares	(*Cysticercus pisiformis*)	fluid-filled cyst containing single scolex
Taenia taeniaeformis	cats	rats, mice	(*Strobilocercus fasciolaris*)	fluid-filled cyst containing single scolex
Taenia (Multiceps) serialis	candids	rabbits, hares	(*Coenurus serialis*)	fluid-filled cyst containing several scoleces
Taenia (Multiceps) multiceps	candids	ungulates	(*Coenurus cerebralis*)	fluid-filled cyst containing several scoleces

Site of infection: Adult tape-worms lay in the lumen of the small intestines of their definitive hosts, attached to the mucosa only by their scoleces. Larval stages (metacestodes) may develop in a range of tissues and organs in their intermediate hosts, particularly in muscles, visceral organs and sometimes the brain.

Pathogenesis: Infections in humans by the large adult tape-worms generally only involve 1-2 worms, and often do not involve any distinct symptoms, although there may be vague abdominal pains, with mild intermittent diarrhoea or constipation, and generalized allergic manifestations, including urticaria, anal pruritis, and eosinophilia. Infections by the encysted larval stages (cysticerci) do not appear to cause any severe clinical disease in their normal hosts (cattle and pigs) even when present in relatively high numbers. The cysts often occur in skeletal muscle, connective tissues of the skin and the liver, and while they may occupy space, they generally do not cause organ enlargement, tissue displacement or untoward pressure on surrounding areas. Degenerating cysticerci tend to calcify and are palpable in the tissues. Heavy infections by live and calcified cysts impart a measly appearance to the flesh and may lead to the condemnation of the carcase. Unfortunately, humans may also be infected with *T. solium* cysticerci through the process of self-infection when eggs are accidentally ingested (and possibly by retrofection when eggs carried upwards by reverse peristalsis hatch in the gut). Cysticerci may develop in virtually every organ and tissue of the human body, although they show an affinity for subcutaneous connective tissue, eye, brain, muscles, heart, liver, lungs and coelom. Humans are quite susceptible to pressure necrosis, particularly when cysticerci develop in the brain (neurocysticercosis with cerebral signs, headaches, seizures, and coma) or eyes (ocular signs, pain, and loss of vision). Degenerating cysticerci may elicit severe acute, and even fatal, inflammatory responses before their eventual calcification.

Mode of transmission: These tape-worms have indirect life-cycles: involving predator-prey transmission where carnivores acquire infections by ingesting larval stages in meat. Adult worms produce thousands of eggs which are excreted with host faeces. The eggs are very resistant to desiccation and sewage treatment and can live for weeks on pastures. They are ingested by intermediate hosts with contaminated feed, drinking water, or are physically transferred to the mouth. The eggs hatch releasing the oncospheres which use their hooks to penetrate the gut wall into the circulation where they carried mainly to the skeletal muscles and connective tissues. Over 3 months, they metamorphose into thin-walled cysticerci; each containing a single tiny protoscolex invaginated into the lumen. These encysted larval stages are transmitted to their definitive hosts by carnivorism, when infected meat or offal is consumed. After ingestion, the outer bladder is digested away releasing the protoscolex which evaginates, attachs to the small intestinal mucosa and grows into an adult in about 10 weeks. Adult worms may live for as long as 25 years and they will produce billions of eggs in that time

Differential diagnosis: Intestinal infections in humans are diagnosed by the detection of gravid segments or eggs in faecal samples. The eggs of *T. saginata* and *T. solium* are identical, but the gravid segments of *T. saginata* are more active than those of *T. solium*, and they have more lateral branches of the uterus (15-32 compared to 7-13). Infections by cysticerci can only be seen and felt when in superficial locations. Modern medical imaging techniques (magnetic resonance imaging (MRI) and computerized axial tomography (CAT) scans) may detect cysticerci in soft tissues, while X-rays generally only detect calcified cysticerci. Immunoserological tests have been developed to detect host antibodies against purified antigens and appear to be sensitive and specific.

Treatment and control: Anthelmintic treatment is effective in killing adult tape-worms but does not kill eggs. Single doses of praziquantel or niclosamide can cure infections in definitive hosts, while daily doses of praziquantel given for 1-2 weeks are effective against larval cysticercosis in intermediate hosts. Mebendazole and albendazole also appear to be effective against adult and larval stages. The prevention of infections involves breaking the transmission cycle; through stringent meat inspection for ‘measly’ meat, condemnation of infected carcases for human consumption, proper cooking or freezing of meat (pickling meat often does not kill larvae), sanitary disposal of faeces, prohibiting the use of sewage for fertilizing pastures, washing salad vegetables and strict personal hygiene.

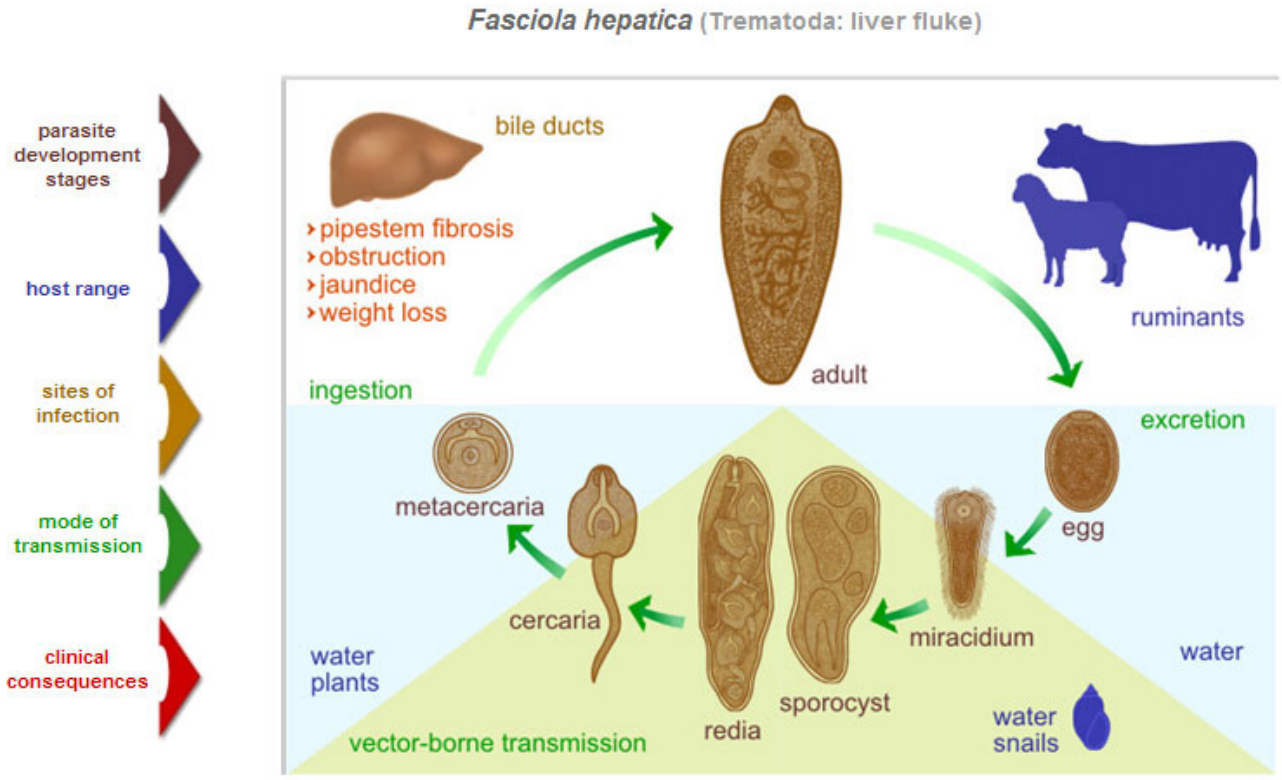
Fasciola

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Platythelminthes	(flatworms)
Cercomeridea	(with oral sucker and bifurcate intestine)
Trematoda	(trematodes, with posterior sucker)
Digenea	(digenetic life-cycle, larval miracidia, snail vectors)
Echinostomatida	(miracidia with one pair protonephridia, simple-tailed cercariae)

Family: Fasciolidae

These worms (known as liver flukes) have soft flat leaf-like bodies with two ventral suckers and a blind gut (mouth but no anus). Adults possess both male and female reproductive organs (hermaphroditic) and they have digenetic life-cycles involving at least two hosts and several developmental stages. Miracidia are released from eggs into water where they infect snails (obligate intermediate hosts) and undergo massive asexual proliferation through sporocyst and redia stages eventually releasing cercariae into the water. Vertebrate (definitive) hosts become infected by the ingestion of encysted stages (metacercariae) on aquatic vegetation. Infections may cause chronic debilitating diseases in domestic animals and humans.



Fasciola hepatica [this species causes hepatic fibrosis in ruminants and humans]

Parasite morphology: These flatworms form seven different developmental stages: eggs, miracidia, sporocysts, rediae, cercariae, metacercariae, and adult flukes. The eggs are operculate ('hatch' at one end), brown and ovoid (130-150µm in length by 65-90µm in width). Miracidia are pyriform motile larval stages (150-200µm long) covered with cilia. Sporocysts are pleomorphic sac-like bodies (0.3-1.5mm in diameter) containing germinal cells which give rise to small rediae (embryos). Mature cercariae (~0.5mm long) are free-swimming gymnocephalous stages with simple elongate club-shaped tails, which are subsequently shed when they encyst on vegetation to form membrane-bound metacercariae (~ 0.2mm in diameter). Mature flukes are leaf-shaped (2.0-3.5cm long by 1.0-1.5cm wide) with a conical apex demarcated by wider 'shoulders'. They are dorsoventrally flattened, the tegument is covered with scaly spines, and they have two suckers (distome arrangement with the oral sucker and acetabulum close together). They have a bifurcate blind gut and each worm is hermaphroditic, possessing both male and female reproductive organs.

Host range: Liver fluke infections are distributed throughout many sheep and cattle producing areas around the world, particularly temperate regions with high rainfall or irrigated pastures where snail vectors are abundant. *F. hepatica* has been reported in sheep, cattle, goats, pigs, macropods, rats, rabbits and many other animals, and occasionally in humans (mainly from western Europe, northern Africa and South America). It has been estimated that some 250 million sheep and 350 million cattle are at risk of fascioliasis.

Site of infection: Immature flukes undergo transient migration through the liver parenchyma and then settle as mature flukes in the bile ducts of their definitive hosts. In some (uncommon) hosts, aberrant flukes may be found encapsulated in lungs, skin or other organs. In snail intermediate hosts, several asexual multiplicative stages are formed; sporocysts first developing in tissues near the site of penetration (foot, antenna, gill), rediae then migrating to glandular tissue (hepatopancreas and gonads) and culminating in the release of tailed cercariae.

Pathogenesis: Infections have been associated with two types of liver disease in domestic animals: acute or subacute necrotic disease due to juvenile flukes; and chronic fibrotic disease due to adult flukes. Penetration of the liver capsule by immature flukes generally does not cause much damage, but their subsequent migration through the liver parenchyma may cause significant necrosis (liver rot). Mass migration of juveniles may produce extensive traumatic tissue damage, coagulative necrosis, haemorrhage, urticaria, eosinophilia, leukocytosis, pallor, anaemia, and can be fatal. Acute infections in sheep can also be complicated by secondary bacterial infection causing clostridial necrotic hepatitis ('black disease'). Chronic infections by the long-lived adults feeding on the lining of the bile ducts may result in progressive loss of condition, biliary epithelial hyperplasia, duct fibrosis, biliary obstruction and cholangitis, jaundice, and eventually a fibrotic hardened liver. Sheep may become anaemic and emaciated, developing submandibular oedema (bottle-jaw) and ascites. In cattle, the bile ducts often become calcified producing a 'clay-pipe' or 'pipe-stem' liver. Chronic fascioliasis causes significant economic losses to many animal industries through mortality, reduced meat, milk and fibre production, condemned livers, secondary infections and expensive treatments.

Mode of transmission: Digenean trematodes have indirect life-cycles, involving mammalian definitive hosts and molluscan intermediate hosts. Transmission between the two hosts occurs within water, via the formation of motile and encysted larval stages. Adult flukes produce numerous eggs (up to 300 per day) which are shed in host faeces. The eggs embryonate in water in a few days to form miracidia which hatch out in 9-10 days in warm weather (longer when colder). Miracidia actively seek snail hosts by chemotaxis, and must penetrate snail tissues within a few hours or die after 24 hours. *F. hepatica* exhibits high intermediate host-specificity and will only develop in freshwater amphibious lymnaeid snails. These snails are pulmonate (with lungs), small (0.5-2.5cm long) and delicate; their shells being thin, fragile, lacking an operculum and the apertures located on the right-hand side (dextral). They live in freshwater and/or wet soils and survive dry periods by burrowing and aestivating. Various *Lymnaea* spp. are suitable intermediate hosts; the most common being *L.* (*Galba*) *truncatula* in most continents, *L. tomentosa* in Australia, *L. viridis* in China, *L. columella* in the Americas, *L. viator* and *L. diaphena* in South America, and *L. bulimoides* in North America. Once the miracidia penetrate a snail, they form mother sporocysts that lack digestive organs but feed by absorption. Sporocysts produce multiple daughter rediae by asexual reproduction (an important amplification mechanism for all trematodes). Rediae have mouths and guts and feed on snail tissues, eventually maturing to single-tailed cercariae which bore their way out of the snail. Cercariae begin

emerging 5-7 weeks after infection and several hundred (sometimes thousands) of cercariae may be produced. Parasites can also survive for months in aestivating snails buried in the soil during dry periods. Emergent cercariae swim to suitable substrates and form encysted metacercariae by shedding their tails and producing thick cyst walls. Metacercariae are quiescent infective stages which can survive on aquatic vegetation or in water for several weeks. Mammals become infected when they ingest metacercariae with food or water (many human infections have been linked to the consumption of watercress). Metacercariae excyst in the small intestines releasing juvenile worms which penetrate the gut wall and migrate around the body cavity for several days. They move to the liver and burrow through the capsule into the parenchyma where they wander for 5-6 weeks before settling in the bile ducts. Worms become sexually mature and begin producing eggs 8-13 weeks after infection. Adult flukes can live for up to 10 years but most infections in domestic animals exhibit marked seasonal variation.

Differential diagnosis: Infections are conventionally diagnosed by coprological examination for fluke eggs in faecal samples, usually following their concentration by sedimentation/flotation techniques. Blood biochemical tests can also be used to show elevated plasma levels of hepatic enzymes, notably glutamate dehydrogenase (GLDH) during acute stages and gamma glutamyl transpeptidase (GGT) during chronic stages. Immunoserological tests have also been developed to detect host antibodies against parasite excretory/secretory antigens in attempts to facilitate early diagnosis. Molecular studies are currently being used to examine parasite strain variation and host reactions to identify virulence factors and protective responses.

Treatment and control: Subacute and chronic infections may be treated with triclabendazole or bithionol, which show excellent trematocidal activity with few side-effects. A range of other anthelmintics show variable activity, including carbon tetrachloride, rafoxanide, niclofolan, closantel and oxyclozanide, but their use may be contra-indicated under certain conditions in certain animals. Preventive measures are based on breaking the cycle of transmission by reducing faecal contamination of water bodies, reducing snail populations using molluscicides (usually copper sulphate) or draining swampy fields, restricting access of livestock to aquatic vegetation, and avoiding watercress. Snail control is often difficult, particularly in high rainfall areas where even temporary pools may harbour large snail populations (they aestivate in the ground during dry conditions). Feral or wild animals (such as rabbits) may also continue to act as reservoirs of infection for domestic livestock.

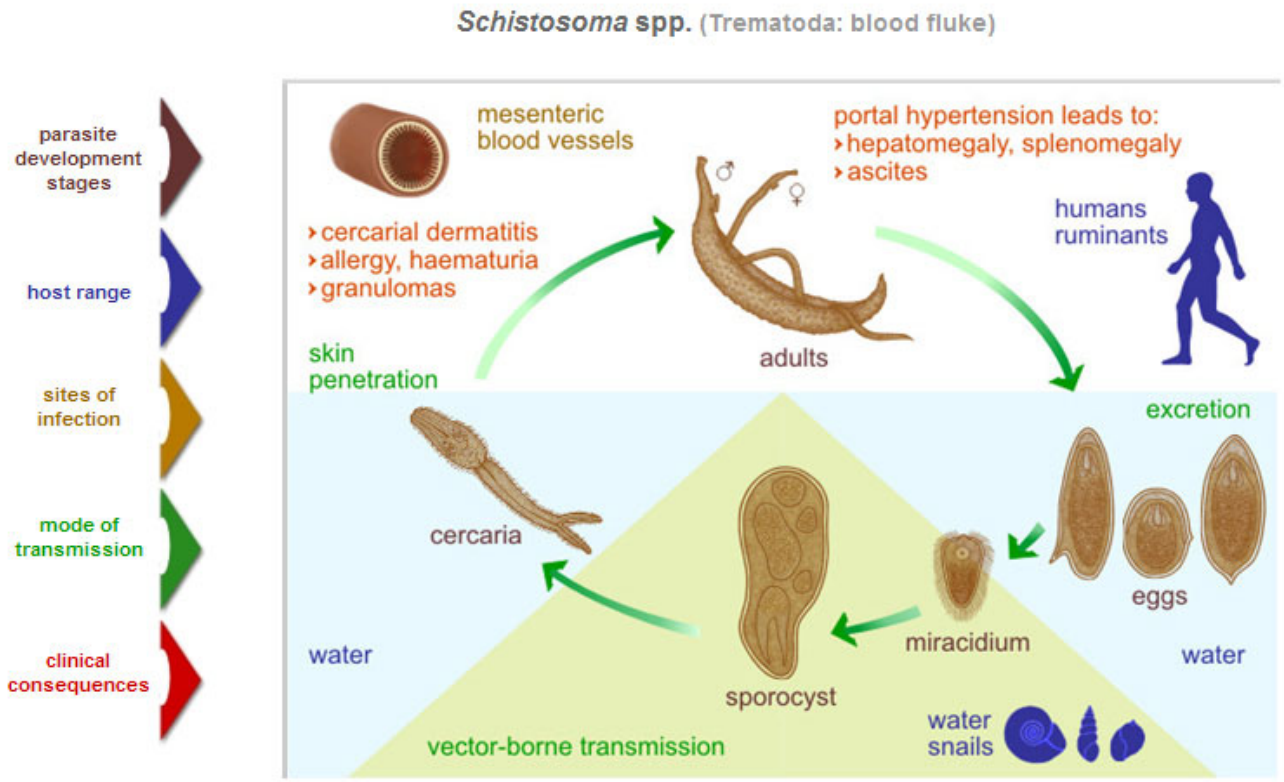
Schistosoma

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Platythelminthes	(flatworms)
Cercomeridea	(with oral sucker and bifurcate intestine)
Trematoda	(trematodes, with posterior sucker)
Digenea	(digenetic life-cycle, larval miracidia, snail vectors)
Strigeatida	(miracidia with 2 pairs protonephridia, fork-tailed cercariae)

Family: Schistosomatidae

Unlike all other trematodes, schistosomes are not hermaphroditic but dioecious, forming separate sexes. Adult worms have elongate tubular bodies, each male having a unique gynecophoral canal (schisto-soma = split body) in which a female worm resides. They live inside visceral blood vessels and are commonly known as blood flukes. They have digenetic life-cycles involving aquatic snails as obligate intermediate hosts. Eggs deposited in the circulation penetrate the gut or bladder to be excreted with faeces or urine. In water, the eggs release miracidia which infect snails and undergo asexual proliferation through sporocyst stages eventually releasing cercariae back into the water. Vertebrate hosts become infected by direct penetration of the skin. Infections may cause chronic debilitating diseases in humans and some domestic animals.



Schistosoma spp. [these species cause schistosomiasis/bilharzia in humans and ruminants]

Parasite morphology: Blood flukes form five different developmental stages: eggs, miracidia, sporocysts, cercariae and adult worms. Eggs are round to oval in shape, operculate (hinged at one end) and contain a developing embryonic larva (miracidium). Differences in egg morphology can be used to distinguish between *Schistosoma* species: *S. mansoni* producing oval eggs (115-175 x 45-7 µm) with a sharp lateral spine, *S. japonicum* forming round eggs (70-100 x 50-70 µm) with a rudimentary lateral spine; and *S. haematobium* producing oval eggs (110-170 x 40-70 µm) with a sharp terminal spine. Miracidia are elliptical free-swimming larval stages (~200 µm long) covered with cilia. Sporocysts appear as pleomorphic sac-like bodies which contain developing cercariae. Mature cercariae are elongate free-swimming larval stages (400-600 µm long) consisting of a tapering head (with prominent penetration glands) and a forked tail (furcocercous). Adult flukes are elongate tubular worms (10-20 mm long), with rudimentary oral and ventral suckers. Males are shorter and stouter than females, and they have a longitudinal cleft (gynecophoral canal or schist) in which the longer slender female lies folded.

Host range: Schistosomes are important human and animal parasites throughout Africa, Asia and South America, predominantly in rural areas supporting agriculture and inland fisheries. Parasite distribution is linked to that of their snail intermediate hosts, which differ in their habitat preferences for slow-flowing or still waters. Many human activities also influence parasite distribution, especially the construction of irrigation channels and dams, and flood irrigation of crops. It has been estimated that over 200 million people may be infected worldwide. Infections have been recorded throughout human history, first being mentioned in ancient Egyptian papyri dated from 2000-1000 BC. Haematuria (bloody urine) became the scourge of Napoleon's army in northern Africa at the turn of the 18th century, and the disease later became known as bilharzia in honour of the discoverer of the causative agent. *Schistosoma* spp. vary in their specificity for intermediate hosts, some only developing in humans (and possibly primates) while others may infect domestic and wild animals, acting as reservoirs for human infection.

Parasite species	Definitive host	Site of infection	Egg excretion	Snail vector	Geographic location
S.haematobium	humans, primates	veins of urogenital system	urine	*Bulinus*	Africa
S. mansoni	humans, rodents	intestinal mesenteric veins	faeces	*Biomphalaria*	Africa, America
S. japonicum	humans, ruminants, carnivores	intestinal mesenteric veins	faeces	*Oncomelania*	SE Asia
S. intercalatum	humans, rodents, cattle	intestinal mesenteric veins	faeces	*Bulinus, Physopsis*	Africa
S. mekongi	dog/cathumans	intestinal mesenteric veins	faeces	*Oncomelania*	SE Asia
S. bovis	ruminants	intestinal mesenteric veins	faeces	*Bulinus*	Africa, SE Asia, Middle East, Europe
S. mattheei	ruminants	intestinal mesenteric veins	faeces	*Bulinus*	Africa, Middle East

Site of infection: Paired adult worms live inside blood vessels in specific sites within the human body. *S. mansoni* lives principally in the portal veins draining the large intestine, *S. japonicum* in the mesenteric veins of the small intestines, and *S. haematobium* infects veins of the urinary bladder plexus. Fluke eggs penetrate into the lumen of the intestines or bladder to be voided with host faeces or urine. Many eggs, however, may be swept away in the host circulation and become trapped in various host tissues and organs.

Pathogenesis: Schistosomiasis (or bilharziasis) is unusual amongst helminth diseases for two reasons: much of the pathogenesis is due to the eggs (rather than larvae or adults); and most of the pathology is caused by host immune responses (delayed-type hypersensitivity and granulomatous reactions). The course of infection is often divided into three phases: migratory, acute and chronic. The migratory phase occurs when cercariae penetrate and migrate through the skin. This is often asymptomatic, but in sensitized patients, it may cause transient dermatitis ('swimmers itch'), and occasionally pulmonary lesions and pneumonitis. The acute phase (sometimes called Katayama fever) is coincident with first egg release and is characterized by allergic responses (serum sickness due to overwhelming immune complex formation), resulting in pyrexia, fatigue, aches, lymphadenopathy, gastrointestinal discomfort and eosinophilia. The chronic phase occurs in response to the cumulative deposition of fluke eggs in tissues and the host reactions that develop against them. Not all the eggs laid by female worms successfully penetrate the gut or bladder walls, many are swept away in the circulation and become trapped in organs where they elicit strong granulomatous responses. Eggs become surrounded by inflammatory cells forming characteristic pseudotubercles, which may coalesce to form larger granulomatous reactions (polyps). The encapsulated eggs die and eventually calcify. The resultant effects on host organs and tissues are manifold, and include intestinal polyposis, abdominal pain, diarrhoea, glumerulonephritis, pulmonary arteritis, cardiovascular problems including heart failure, and periportal (Symmer's clay pipe-stem) fibrosis. Portal hypertension often leads to hepatomegaly, splenomegaly, ascites, and sometimes gross enlargement of oesophageal and gastric veins (varices) which may burst. Cerebral granulomas have been associated with focal epileptic convulsions, while spinal cord granulomas may cause transverse myelitis. Infections by *S. haematobium* often cause haematuria (blood in urine) and progressive disruption of the bladder wall may lead to carcinoma.

Mode of transmission: Schistosomes have indirect digenetic life-cycles, involving sexual reproduction in vertebrate definitive hosts and asexual reproduction in snail intermediate hosts. Parasites are transmitted between hosts by motile aquatic stages which actively seek hosts. Female worms produce numerous eggs (200-3,000 per day) which seek to exit the host by penetrating the gut or bladder wall and being passed with host faeces or urine. When deposited in water, the embryonated eggs hatch releasing free-swimming miracidia which only live for several hours. In that time, they actively seek suitable intermediate hosts (amphibious snails) using chemotaxis and phototaxis (despite absence of eyespots). All *Schistosoma* spp. demonstrate quite narrow host specificity for particular snails: *S. mansoni* infects *Biomphalaria* spp. (large flat spiral snails ~14mm in diameter with ~3 whorls and apical aperture), *S. japonicum* infects *Oncomelania* spp. (small elongate snails ~8mm long with 4-5 whorls and dextral (right-sided) aperture), and *S. haematobium* infects *Bulinus* spp. (medium ovoid snails ~12mm long with 2-3 whorls and sinistral (left-sided) aperture). The miracidia invade the soft tissues of the snail and form a mother sporocyst near the site of penetration. Daughter sporocysts are produced 2-6 weeks after infection and they migrate to other organs in the snail. Schistosomes do not produce redia stages; instead the sporocysts produce cercariae which are released into the water in their thousands beginning 4 weeks after infection. The fork-tailed cercariae are rapid swimmers and they periodically swim to surface of the water and then sink to bottom for up to three days. They are attracted to skin secretions and when they come into contact with a prospective definitive host, they attach and actively penetrate the skin within minutes, losing their tails in the process. Inside the host, the schistosomula (little schistosomes) are carried in blood and/or lymph to the portal vessels in liver, where they develop for 3 weeks. Young worms then pair and migrate to their predilection sites in the veins of the gut or bladder. Egg production begins from 4-8 weeks after infection, and adult worms normally live for 2-5 years, although some may survive much longer.

Differential diagnosis: Infections are conventionally diagnosed by the detection of fluke eggs in faecal or urine samples, often after concentration by sedimentation/flotation or filtration techniques. The eggs are sufficiently characteristic to facilitate specific diagnosis. On occasion, microscopy of rectal biopsies has been used to diagnose *S. haematobium* infections. Immunoserological tests have been developed to detect host antibodies against infection but they have experienced cross-reactivity problems and cannot discriminate between previous and active infection. More recently, molecular techniques have been used to detect parasite antigens or DNA in host samples; some tests showing good correlations with parasite burdens.

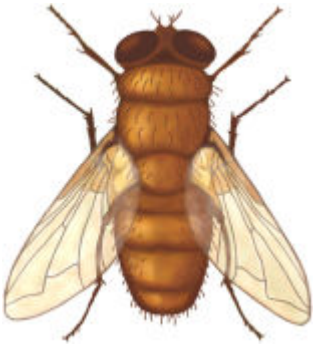
Treatment and control: The drug of choice for the treatment of all *Schistosoma* spp. is praziquantel, a single oral dose being very effective, with low toxicity and good tolerance, even in severe clinical cases. Nitridazole and metrifonate are effective against *S. haematobium*, and oxamniquine against *S. mansoni*, but they have mild side-effects. While timely treatment is effective, cured individuals rapidly become re-infected in endemic areas. Various control programmes have therefore been developed based on mass chemotherapy in conjunction with preventive measures, including improved sanitation, snail vector control, modifying habitats and farming practices, and public education campaigns. Water contamination can be reduced by preventing the ingress of parasite eggs as well as curtailing the asexual amplification cycle in snail hosts. The provision and use of latrines contains sources of infection, and modern biocomposting toilets appear to be effective in killing parasite eggs when used properly. Snail populations may be reduced by the strategic use of molluscicides (niclosamide or copper sulphate), draining marshes and swamps, and clearing channels of vegetation. Irrigation practices can be modified to avoid long-standing still waters, and different or improved crops can be used which are less dependent on lengthy immersion in water. In endemic areas, farmers (and visitors) need to be aware of the dangers of immersion in potentially contaminated waters. Considerable resources have been devoted to the development of cellular, subcellular and recombinant vaccines, and promising results have been obtained with animal models of disease.

Arthropod Parasites

Arthropods form a huge assemblage of small coelomate animals with “jointed limbs” (hence the name arthro-pods). They exhibit segmentation of their bodies (metamerism) which is often masked in adults because their 10-25 body segments are combined into 2-3 functional groups (called tagmata). They exhibit varying degrees of cephalization whereby neural elements, sensory receptors and feeding structures are concentrated in the head region. Arthropods possess a rigid cuticular exoskeleton consisting mainly of tanned proteins and chitin. The exoskeleton is usually hard, insoluble, virtually indigestible and impregnated with calcium salts or covered with wax. The exoskeleton provides physical and physiological protection and serves as a place for muscle attachment. Skeletal plates are joined by flexible articular membranes and the joints are hinges or pivots made from chondyles and sockets.

The main arthropod assemblages include crustaceans (crabs, lobsters, crayfish, shrimp), arachnids (spiders, scorpions, ticks, mites) and insects (beetles, bugs, earwigs, ants, bees, termites, butterflies, moths, crickets, roaches, fleas, flies, mosquitoes, lice). Most parasitic arthropods belong to 2 main classes: the 6-legged insects, and the 8-legged arachnids

insects



arachnids

> Insects have 3 distinct body parts, commonly called the head, thorax and abdomen. The head has 2 antennae and the thorax has 6 legs arranged in 3 bilateral pairs. Many insect species also have 2 pairs of wings attached to the thorax. Parasitic insect species include fleas, flies and lice which actively feed on host tissues and fluids at some stage in their life-cycles.

> Arachnids have 2 body parts known as the prosoma (or cephalothorax) and opisthosoma (or abdomen). The cephalothorax has 8 legs arranged in 4 bilateral pairs and arachnids do not have wings or antennae. Important parasitic assemblages include the ticks and mites which bite into tissues and feed off host fluids.

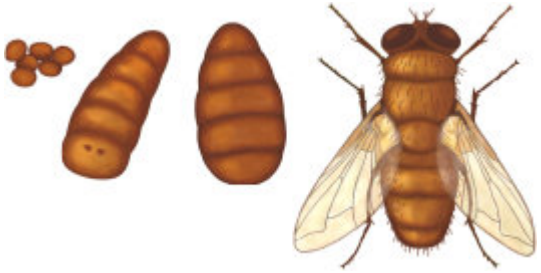
Biodiversity

Collectively, arthropods account for a substantial share of global biodiversity, both in terms of species richness and relative abundance. There are over 1,000,000 species of insects and over 50,000 species of arachnids. They are very successful and adaptable organisms and are capable of forming large populations due to their rapid and fertile reproduction rates. Many species are also able to withstand adverse environmental conditions by undergoing periods of developmental arrest (diapause). The protection afforded by their exoskeletons allows them to colonize many habitats and they overcome the problem of growing larger in a non-expandable exoskeleton by undergoing periodic moulting (or ecdysis) which is mediated by hormones. Developmental stages between moults are referred to as instars. Moulting is a complex process and its timing is mediated by many environmental and physiological cues. It involves detachment of the hypodermis from the procuticle, partial resorption of the old cuticle, production of a new epicuticle, dehiscence (splitting) of the old cuticle, emergence of the animal, stretching and expansion of the new cuticle by air and/or water intake, and then sclerotization of the new cuticle.

Life-cycles

Adult arthropods are generally small in size, most are visible but some remain microscopic. Arthropod sexes are separate and fertilization is internal. A wide range of mating behaviours, insemination and egg production strategies are involved. In most species, the egg develops into a larva: i.e. a life-cycle stage that is structurally distinct from the adult and must undergo metamorphosis (structural reorganization) before becoming an adult. This metamorphosis may be complete (involving major changes during a pupation stage) or incomplete (involving gradual changes in nymph stages). For example, the grub-like larval stages of flies and fleas form cocoon-like pupae where they undergo complete metamorphosis and emerge as radically-different adult insects. In contrast, the larval instars (or nymphs) of lice, ticks and mites undergo incomplete metamorphosis through a series of moults gradually becoming more adult-like in appearance

complete metamorphosis



hatch moult hatch

egg----------larva----------pupa----------adult

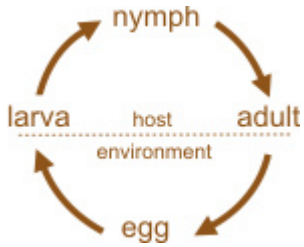
incomplete metamorphosis

hatch moult moult

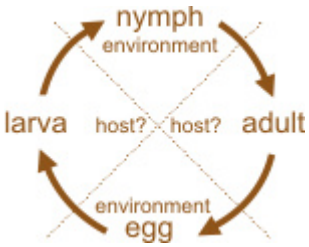
egg----------larva----------nymph----------adult

Arthropods are involved in nearly every kind of parasitic relationship, either as parasites themselves or as hosts/vectors for other micro-organisms (including viruses, bacteria, protozoa and helminths). They are generally ectoparasitic on, or in, the skin of vertebrate hosts. Many species are haematophagous (suck blood) while others are histophagous (tissue-feeders) and bite or burrow in dermal tissues causing trauma, inflammation and hypersensitivity reactions. Infestations are transmitted from host-to-host either by direct contact or by free-living larvae or adults actively seeking hosts.

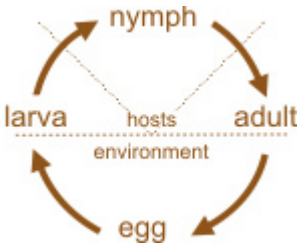
direct



host-seeking
(larva or adult parasitic)



host-seeking
(all feeding stages parasitic)



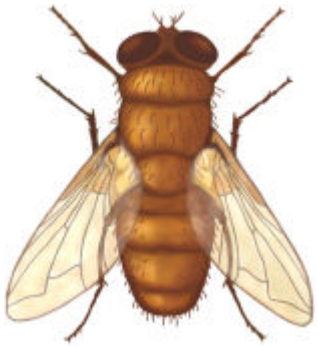
> Direct transmission of infective stages occurs when hosts come into close contact with each other or share quarters, bedding or clothing. Larvae, nymphs or adults may cross from one host to another, while eggs or pupae may contaminate shared environments. Insects (fleas and lice) and arachnids (mites) rely on close contact between hosts.

> Many adult insects actively seek hosts in order to feed or lay eggs. Winged insects (mosquitoes, flies) fly to new hosts to feed while fleas jump onto passing hosts. Some adult flies (botflies) do not feed on their hosts but deposit eggs from which larvae emerge and feed on host tissues and exudates.

> Tick larvae actively seek hosts by climbing vegetation and questing for passing hosts. Some species complete their life-cycle on the same host (one-host ticks) while others detach after feeding and drop to the ground to moult before seeking new hosts as nymphs or adults (two-host or three-host ticks).

Taxonomic overview

Insects exhibit extraordinary biodiversity, both in terms of species richness (numbers of species) and relative abundance (population sizes). Most parasitic species belong to three main groups: the jumping fleas (Siphonaptera); the winged flies (Diptera); and the wingless lice (Phthiraptera).



Fleas are bilaterally-flattened wingless insects with enlarged hindlimbs specially adapted for jumping (up to 100 times their body length). Jumping feats are accomplished using elastic resilin pads which expand explosively when uncocked from the compressed state. Fleas undergo complete metamorphosis whereby grub-like larvae form pupae from which adult fleas emerge. The larvae are not parasitic but feed on debris associated mainly with bedding, den or nest material, whereas the adult stages are parasitic and feed on host blood. There are some 2,500 flea species, most parasitic on mammals (especially rodents) and some on birds. They vary in the time spent on their hosts ranging from transient feeders (rodent fleas) to permanent attachment (sticktight fleas and burrowing chigoes).

Flies and mosquitoes are winged insects with two pairs of wings attached to the thorax and a well-developed head with sensory and feeding organs. They undergo complete metamorphosis involving a pupation stage. Different species vary in their feeding habits, both as adults (parasitic or free-living) and larvae (parasitic or free-living). There are over 120,000 species belonging to 140 families. Two main suborders are recognized on the basis of structural differences, Nematocera (adult stages parasitic, larval stages often free-swimming) and Brachycera (adult stages parasitic or free-living, larvae stages often predaceous).

Lice are small wingless insects, dorsoventrally flattened, with reduced or no eyes and enlarged tarsal claws for clinging. All lice undergo gradual metamorphosis and there are no free-living stages. Eggs are cemented to hair/feathers whereas nymphs and adults cling to hair/feathers. Two orders of lice are recognized on the basis of their mouthparts: the Mallophaga (chewing/biting lice) with some 3,000 species infesting birds and mammals; and the Anoplura (sucking lice) with 500 species found on mammals

Many non-spider arachnids (subclass Acari) are found as parasites on animal or plant hosts. They belong to two main groups: the macroscopic ticks and the microscopic mites. Many species are important in human and animal medicine as causes of disease or as transmission vectors for other pathogens.

Ticks are epidermal parasites of terrestrial vertebrates that may cause anaemia, dermatosis, paralysis, otoacariasis and other infections (transmit viral, bacterial, rickettsial, spirochaete, protozoal and helminth pathogens). They feed mainly on blood and their mouthparts are armed with small backward-facing teeth to aid in attachment. All ticks undergo gradual/incomplete metamorphosis whereby larval and nymphal instars resemble adults. The integument is relatively thick and respiration occurs via spiracles (usually only one pair) and trachea. Two major families of ticks are recognized on the basis of many morphological features: the Ixodidae (hard ticks with a tough cuticle and a large anterodorsal scutum) with some 650 species that infest mammals, birds and reptiles; and the Argasidae (soft ticks with a leathery integument and no scutum) with 160 species that infest mainly birds and some mammals.

Mites are microscopic arachnids which undergo gradual or incomplete metamorphosis. Adults and nymphs have 4 pairs of legs whereas larvae have 3 pairs. Over 30,000 species of mites have been described, many are free-living species, some are plant parasites while others are parasitic on terrestrial and aquatic hosts. Most parasitic species feed on skin debris or suck lymph, some burrow into the skin, some live in hair follicles, and some in the ear canals. Their mouthparts are variable in form but the hypostome is never armed with teeth. The integument is usually thin and three orders are recognized on the basis of their respiratory systems: the Mesostigmata with respiratory spiracles (stigmata) near the third coxae; the Prostigmata (Trombidiformes) with spiracles between the chelicerae or on the dorsal hysterosoma; and the Astigmata (Sarcoptiformes) without tracheal systems as they respire through the tegument.

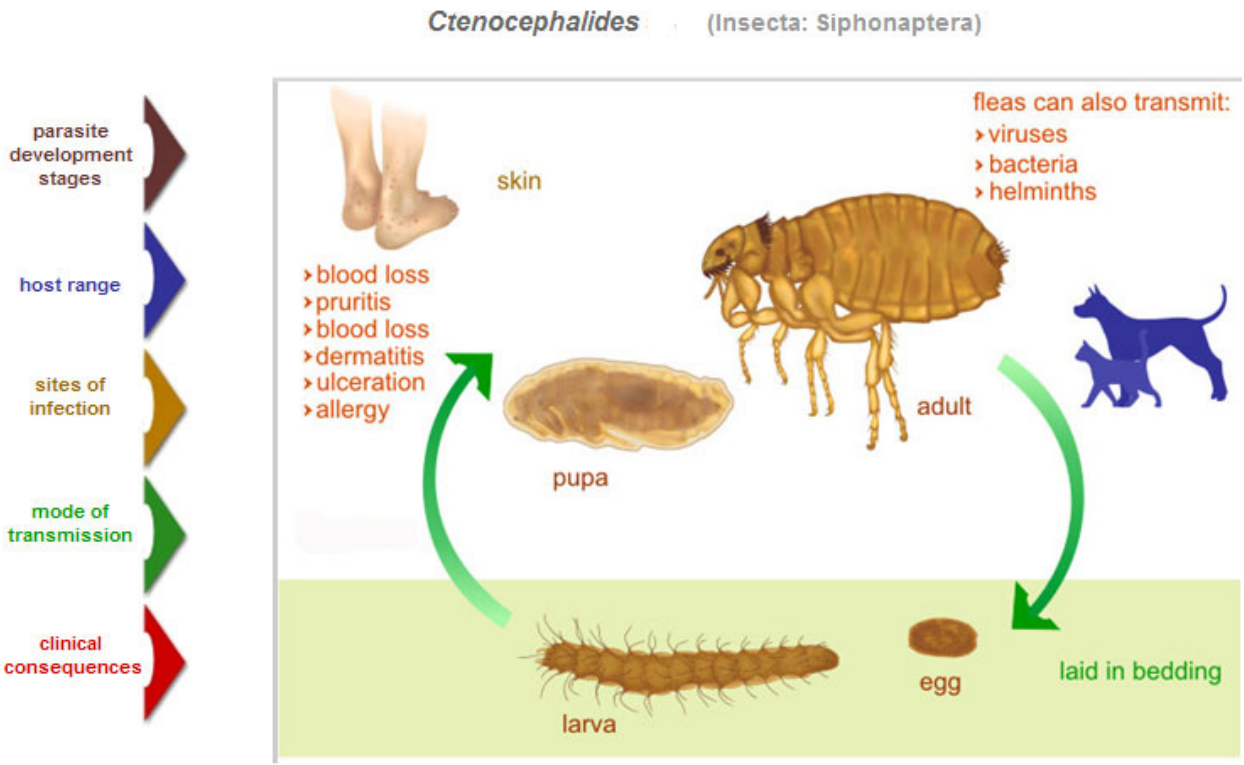
Ctenocephalides

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Arthropoda	(arthropods, segmented body, exoskeleton, jointed appendages)
Uniramia	(with antennae, first mouthparts mandibles)
Insecta	(insects, 3 body parts, 6 legs, many with wings)
Siphonaptera	(fleas, wingless, laterally compressed, complete metamorphosis)

Family: Pulicidae

Fleas are bilaterally-flattened wingless insects with three body parts, head, thorax and abdomen. The thorax has 6 legs arranged in 3 bilateral pairs, and the hindlimbs are enlarged and specially adapted for jumping (using elastic resilin pads rather than muscles). Fleas undergo complete metamorphosis whereby grub-like larvae form pupae from which adult fleas emerge. The larvae are not parasitic but feed on debris associated mainly with bedding, den or nest material, whereas the adult stages are parasitic and feed on host blood. This family contains several genera and species that are important parasites of humans, domestic and companion animals and wildlife, especially rodents.



Ctenocephalides spp. [these species cause dermatoses in domestic animals]

Parasite morphology: Fleas form four developmental stages: eggs, larvae, pupae and adults. The eggs are pearly-white ovoid bodies up to 0.5 mm in size. Larvae appear as slender elongate brown grubs up to 5 mm long, with each segment bearing a ring of bristles. Pupae appear as opaque ellipsoidal encysted stages surrounded by thin silk cocoons, often with detritus adherent to the external surface. Adult fleas vary in size according to gender, female fleas are larger measuring up to 2.5 mm in length, while males are smaller, sometimes measuring less than 1mm in length. All adults have three distinct body segments; head, thorax, and abdomen. The head often bears genal ctenidium (spines), the dog flea *C. canis* and the cat flea *C. felis* have genal ctenidia with >5 teeth. The spacing of the spines is correlated to hair diameter. They are backward facing and used with setae to maintain position among the hair/fur of the host despite grooming.

Host range: Adult fleas attach to dogs, cats, humans, other mammals and occasionally chickens. Most fleas have promiscuous feeding habits and will try to feed on any available host. Most flea species are considered to be host-preferential rather than host-specific.

Site of infection: Adult fleas are blood-sucking ectoparasites living amongst the hair/fur on the skin of their hosts. They can also live off their hosts for extended periods in suitable micro-habitats (bedding, carpets, etc) awaiting the arrival of new hosts on which to jump.

Pathogenesis: Fleas have piercing mouthparts composed of cutting laciniae (back-and-forth action) and a stabbing epipharynx which enters small blood vessels. Saliva is ejected into the general area. Bite sites develop erythematous (reddened) papules or wheals, surrounding the central puncture site. Wounds may persist for days to several weeks and develop a crust of dried exudate. They are intensely itchy (pruritis) and may develop secondary infections if disturbed by scratching. Fleas are particularly annoying pests on dogs and cats, and can cause severe allergic reactions; especially in inbred strains. Flea-allergy dermatitis is a hypersensitive reaction to components of flea saliva injected into the skin. Severely-affected areas exhibit significant hair loss (alopecia), moist dermatitis (wet eczema) or the skin becomes hardened and thickened. Animals aggravate conditions by licking, biting and scratching and they exhibit restlessness, irritability, and weight loss. Fleas are blood-feeders (ingesting up to 10µl per day), so heavy infestations may also cause iron-deficiency anaemia, particularly in young animals. Fleas may act as vectors for a range of viral and bacterial infections and *Ctenocephalides* and *Pulex* fleas are intermediate hosts for the tapeworm *Dipylidium caninum* in dogs and cats.

Mode of transmission: Fleas undergo complete metamorphosis (egg-larva-pupa-adult). The female usually oviposits on the host but the eggs are not sticky and therefore drop off the host usually in den/lair/nest/bedding where there is a good supply of debris and flea faeces on which the larvae feed. The eggs hatch within 2-21 days releasing maggot-like larvae which are legless and eyeless. Larvae cannot close their spiracles and are sensitive to low humidity. There are usually 3 larval instars which moult over 9-15 days before forming a pupa. The pupa completes development over several days to several months. Low temperatures, however, can extend larval and pupal stages up to one year. Adults can survive long periods without food (up to 100 days at high humidity).

Differential diagnosis: Animals attempt to groom infested areas, and an ‘itch-and-scratch’ syndrome may develop, sometimes associated with intense inflammation or allergic reactions. Adult fleas can be found in infested areas by visual examination (manually parting hairs or using a fine -toothed comb).

Treatment and control: Many chemicals have been developed to kill fleas. These insecticides can be used as powders, washes, sprays, pour-ons or impregnated into collars. They are generally organophosphorous compounds, carbamates, or pyrethrum and its derivatives. Several new generation ectoparasiticides have also been developed as spray or spot-on formulations, including fipronil and imidacloprid. Treatments should be repeated regularly to avoid re-infestation and also to reduce environmental contamination by eggs. Drug efficacy should also be monitored as there are growing reports of insecticide resistance developing in flea populations. Corticosteroids are often used topically or systemically for palliative treatment of flea-bite allergy. Control measures should include environmental management such as the provision of clean bedding, efficient waste disposal and rodent control. Several methods of environmental decontamination have been developed including the use of light traps, indoor insecticides and flea bombs (diflubenzuron, pyriproxyfen, methoprene).

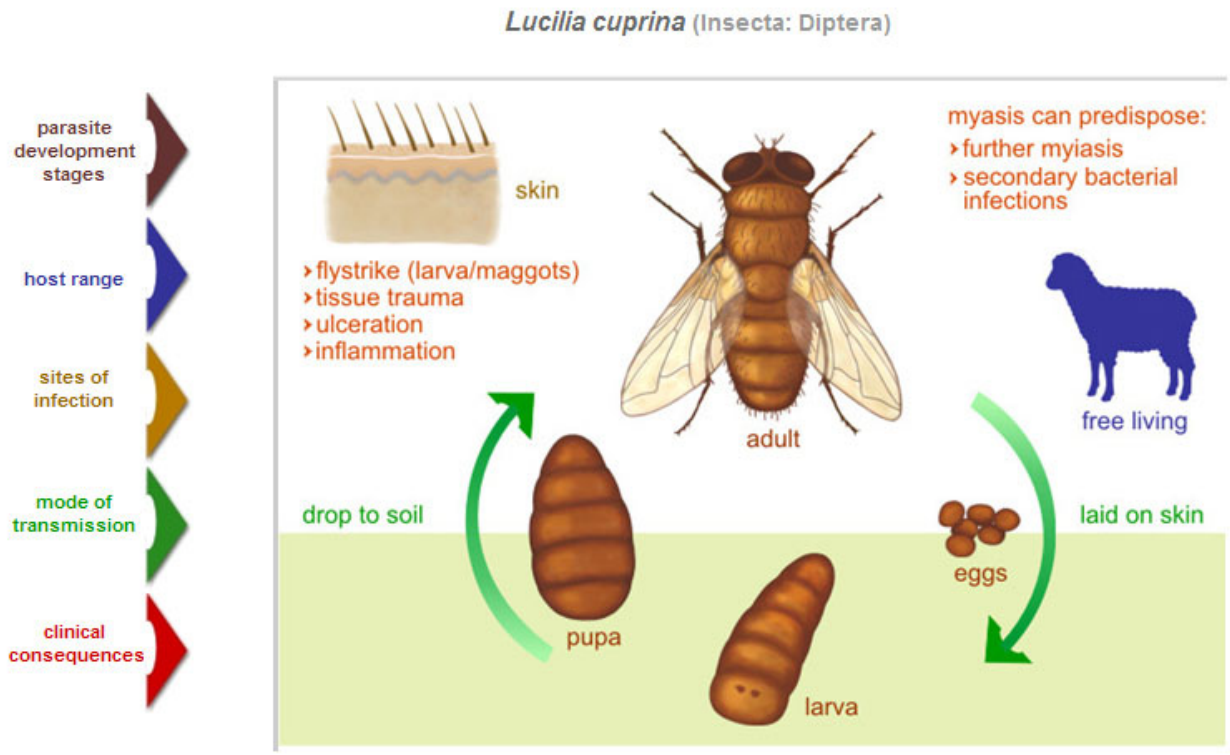
Lucilia

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Arthropoda	(arthropods, segmented body, exoskeleton, jointed appendages)
Uniramia	(with antennae, first mouthparts mandibles)
Insecta	(insects, 3 body parts, 6 legs, many with wings)
Diptera	(flies, mosquitoes, winged, complete metamorphosis)
Brachycera	(short antennae, reduced wing venation, incomplete larval head capsule)

Family: Calliphagidae (Calliphoridae)

Diptera are the true flies, a large insect order with over 120,000 described species. They have three body parts (head, thorax and abdomen), six legs but only one pair of wings (the hind pair having been reduced to halteres). All species undergo complete metamorphosis whereby larval stages pupate to transform into adults. Dipterous flies can be parasites as larvae or adults, rarely both. Blow flies are important parasites of domestic animals as their larvae (maggots) cause fly strike (myiasis) in sheep (breech and body strike). Blow flies are categorized as causing primary, secondary or tertiary strike according to whether they initiate strike or occur later. Most primary strike flies belong to the subfamily Calliphorinae, including *Lucilia cuprina* (green bottle fly), *Lucilia sericata* (European green bottle fly), *Calliphora augur* (lesser brown blowfly) and *Calliphora stygia* (large brown blowfly), while many secondary strike flies belong to the subfamily Chrysomyinae, including *Chrysomya rufifacies* (secondary green blowfly or hairy maggot blowfly) and *Chrysomya micropogon* (*mallochi*) (steel blue blowfly).



Lucilia cuprina [this species causes myiasis (flystrike) in sheep]

Parasite morphology: Blow flies form four developmental stages: eggs, larvae, pupae and adults. Eggs appear as creamy-yellow ovoid bodies (~ 1 mm long) deposited in clusters. Larvae (maggots, grubs or gents) have elongate opaque segmented bodies (8-14 mm long) with a pair of oral hooks at the anterior end, and peritremes with spiracles at the posterior end. Pupae appear as ellipsoidal creamy-brown cocoons (10-14 mm long) with barely visible transverse striations. Adult flies measure up to 10mm in length and they have a characteristic metallic bronze to greenish sheen. They have one pair of wings with a bare stem vein and have three pairs of dorsocentral thoracic bristles. Male and female flies are similar in appearance except the eyes of males are almost touching while those of females are clearly separated.

Host range: *Lucilia* spp. are facultative ectoparasites mainly on sheep, but other domestic and wild animals may be affected. They are considered to have a cosmopolitan distribution due to stock translocations and other anthropogenic activities, but *L. cuprina* if found more frequently in warm-temperate and subtropical areas while *L. sericata* is more common in cool-temperate regions.

Site of infection: Eggs are laid in batches of 50-250 on carrion or on moist wounds or the soiled wet fleece of live animals, causing body, breech or tail strike depending on where emergent larvae invade cutaneous tissues. Body strike is found commonly around the shoulders and along the back, and has been associated with bacterial dermatophilosis and pseudomonal fleece rot. In Merino sheep, breech and tail strike commonly occur due to the excessive wrinkled skin of the hindquarters that becomes fouled with faeces and urine.

Pathogenesis: Some dipterous flies are obligate ectoparasites and can only complete their development using a living host. The majority, however, are facultative ectoparasites and can develop in both living and dead organic material. They comprise primary facultative species, which can initiate myiasis but also live as saprophages in decaying organic matter or carcases, and secondary facultative species, which live normally as saprophages and cannot initiate myiasis but can secondarily invade pre-existing infestations. Larvae invade necrotic or living tissue causing traumatic cutaneous myiasis. Three larval instars develop over 4-6 days and they cause great suffering by feeding directly on host tissues. Maggots secrete proteolytic enzymes and tear at the tissues with strong oral hooks resulting in extensive invasive lesions. Light infestations may be well tolerated by sheep whereas heavily affected sheep become anorexic, dull and depressed. Fleece in the affected area becomes damper, darker and develops a foul odour, which appears to act as a chemo-attractant for subsequent infestations.

Mode of transmission: Adult flies are free-flying near animals and females require protein meal for eggs to mature. Females may lay 2-3 batches of eggs during their 2-3 week life. Eggs hatch on sheep in 8 hours to 3 days depending on temperature and humidity (desiccation is the main cause of egg mortality). Three larval instars develop in the tissues and the third larval instars drop from the host, burrow into soil and form pupae. Pupation may be completed within a week or delayed depending on environmental conditions. Overwintering may lead to synchronized emergence and fly swarms in spring.

Differential diagnosis: Infestations are diagnosed on the basis of clinical signs and the visual detection of larvae in lesions. The larvae of many fly species can be differentiated on the basis of their size, shape and appearance as well as the arrangement of their posterior spiracles. The peritreme (outer perimeter) of the spiracles is entire in primary strike flies and broken in secondary strike flies. It is thin in *Lucilia* spp. and thick in *Calliphora* spp. The spiracles of blowfly larvae have straight slits compared to sinuous slits in house fly larvae. First stage larvae have one slit, second stage larvae have 2 slits and third stage larvae have 3 slits.

Treatment and control: Sheep should be regularly inspected during fly season, and infested livestock identified and isolated. The skin surrounding the lesion should be clipped, the wound cleaned (taking care to kill emergent larvae as they may pupate producing another generation of flies) and then dressed by topical application of dilute insecticides, such as diazinon, cypermethrin or deltamethrin. Sheep can also be treated prophylactically to prevent infestations using organophosphorous and pyrethroid insecticides which persist in the fleece for up to 10 weeks. These formulations may be applied by whole body plunge dipping, jetting or shower sprays. Some insect growth regulators, such as cyromazine and dicyclanil, have been shown to give good protection as single pour-on applications but only when used in timely fashion before anticipated challenge. Certain breeds of sheep are more susceptible to strike because the wool and skin are too easily wetted with urine or remain wet after rain. Various management procedures have been

developed to prevent strike, such as crutching (shearing hindquarters), tail docking and mulesing (removing hindquarter skin folds). Infections by gastrointestinal helminths should also be controlled to prevent diarrhoeal wetting of perineal wool. Any carcases in the field should be removed and destroyed to remove alternative breeding places for blow flies.

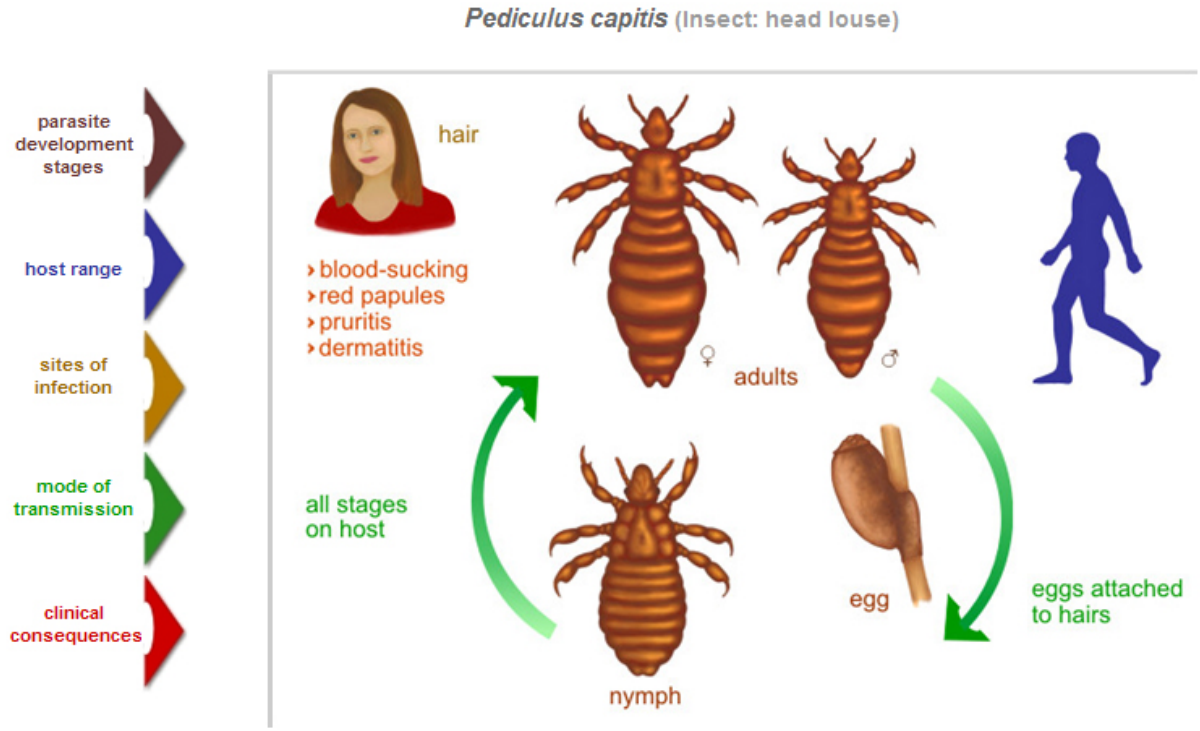
Pediculus

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Arthropoda	(arthropods, segmented body, exoskeleton, jointed appendages)
Uniramia	(with antennae, first mouthparts mandibles)
Insecta	(insects, 3 body parts, 6 legs, many with wings)
Anoplura	(sucking lice, wingless, ectoparasites, incomplete metamorphosis)

Family: Peliculidae

Lice are small wingless dorsoventrally flattened insects with three body parts, head, thorax and abdomen. The head has two antennae and the thorax has six legs arranged in three bilateral pairs. All lice undergo gradual metamorphosis and there are no free-living stages. Eggs are cemented to host hairs whereas nymphs and adults cling to hairs using enlarged tarsal claws. Over 500 species of sucking lice parasitize mammals. The sucking mouthparts are retracted in the narrow head when not feeding. The mouthparts are introduced directly into host blood vessel (solenophage mode of feeding).



Pediculus capitis [this species causes head lice infestation in humans]

Parasite morphology: Head lice form three developmental stages: eggs, nymphs and adults. Eggs (commonly called nits) appear as white ellipsoidal operculate bodies (0.8 x 0.3 mm) which are glued to hair shafts. Nymphs are similar in appearance to adults, but are smaller measuring 1-2 mm in length. Adult lice have elongate dorsoventrally flattened bodies (2-4 mm long) which appear opaque although darker internal organs can be seen mainly in the abdomen. Head lice are known colloquially as cooties, greybacks, or mechanized dandruff.

Host range: *P. capitus* is highly host-specific for humans and will not infest other animals. Some authorities regard head lice as a unique species (*P. capitus*) while others consider it to be a subspecies (*P. humanus capitus*) closely related to body lice (*P. humanus corporis*). Only body lice colonies can be bred in the laboratory after their adaptation to feeding on rabbits. Body lice spend most of the time in host clothing. Their life-cycle is completed in 2-4 weeks. Eggs attached to fibres in clothes hatch in 7 days and there are 3 nymphal moults taking 8-9 days. Pubic lice (or 'crabs') are also found on humans. These lice belong to a separate species (*Phthirus pubis*) which have grasping tarsi reminiscent of crab pincers. Infections are not confined to the pubic region, but may also involve the armpits, beard, moustache, eyebrows and eyelashes. The lice remain in position for some time with mouthparts inserted in skin and the bites cause intense pruritus. The life-cycle is completed in less than 1 month and infestations are transmitted mainly venereally, but can be passive especially in crowded situations.

Site of infection: All developmental stages of head lice can be found attached to, or grasping, hairs on the head, especially at the back of the neck and behind the ears. They are highly site-specific and head lice transplanted to other body regions attempt to migrate back to the head.

Pathogenesis: Nymphs and adults of both sexes feed by piercing the skin and sucking blood about every 2-3 hours. Light infestations may only cause moderate itching of the scalp exacerbated by sensitization to louse saliva. Heavy infestations, however, may cause considerable discomfort as the bites produce red papules, fever, aches and intense pruritus which induces scratching leading to dermatitis and secondary infections. Heavy louse infestation is known as pediculosis and is often associated with crowded conditions and poor sanitation.

Mode of transmission: Once hatched, head lice undergo gradual metamorphosis whereby nymphs moult several times before forming adults. No free-living stages are formed and lice do not survive long off their hosts. Infestations are therefore transmitted between hosts by direct physical contact, although some transmission via contaminated clothing or bedding cannot be entirely dismissed. The complete life-cycle takes 2-3 weeks, and louse populations often exhibit pronounced seasonal fluctuations, apparently linked to crowding during winter housing, particularly in temperate regions. Female head lice lay around 90 eggs which are cemented singly onto hair shafts.

Differential diagnosis: Infestations are diagnosed by finding live lice or empty eggs shells in the hair either by direct visual examination or using a fine-toothed nit comb (using hair conditioner to untangle hairs and trap lice).

Treatment and control: Many insecticides (e.g. malathion, carbamyl and pyrethrins) can be used to control lice and they are available in many hair care products (shampoos or lotions). Repeat washing are required within 10 days as most insecticides have limited activity against eggs. Over recent years, mounting problems with insecticide resistance have been encountered, and researchers are currently exploring herbal remedies. During infestations, daily grooming with nit combs is recommended to remove eggs and lice. Some countries still enforce home quarantine of infested school-children to curtail outbreaks. Inter-personnel hygiene must be improved and clothing and bedding should be well laundered.

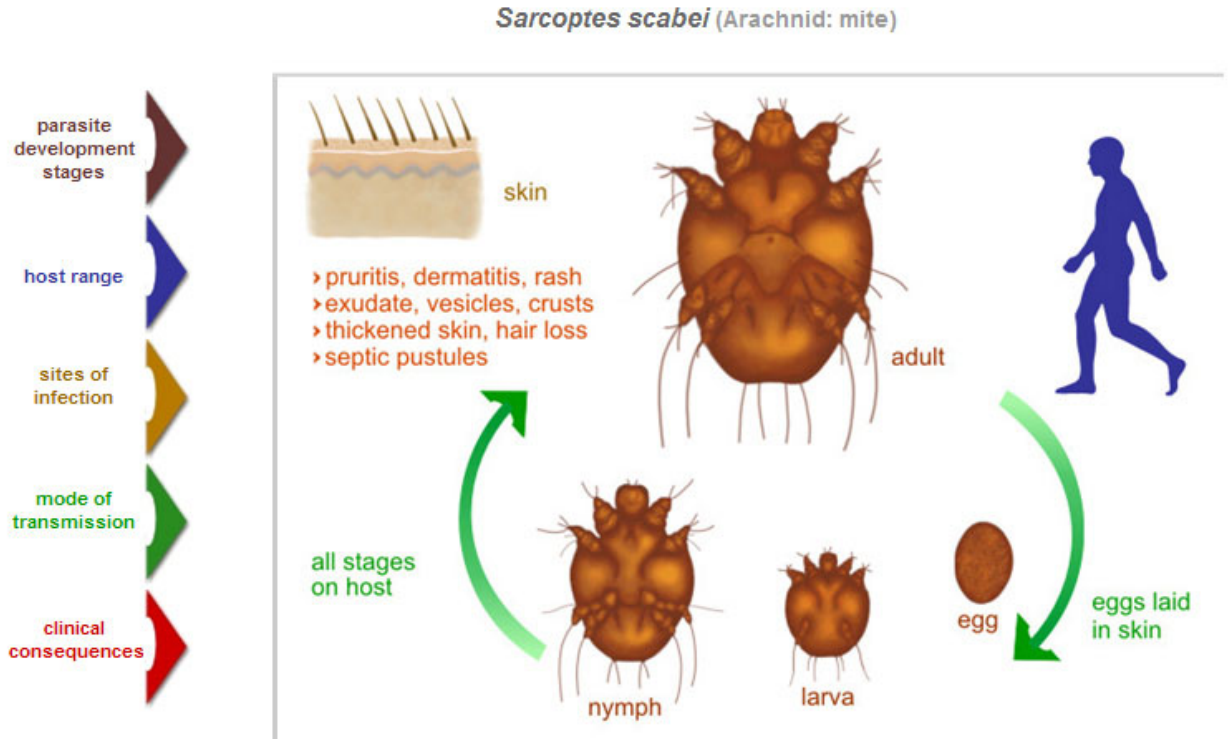
Sarcoptes

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Arthropoda	(arthropods, segmented body, exoskeleton, jointed appendages)
Chelicerata	(2 body parts, 8 legs, first mouthparts chelicerae, no antennae, wingless)
Arachnida	(abdomen without appendages)
Acari	(ticks and mites, ectoparasites)
Astigmata (Sarcoptiformes)	(without tracheal system, respire through tegument)

Family: Sarcoptidae

Mites are small wingless arachnids with two body parts, eight legs and no antennae. Astigmatid mites are weakly sclerotized, lack stigmata and tracheae and respiration occurs directly through the tegument. They include many species of medical and veterinary significance and cause skin conditions known as mange, scab and scabies. Sarcoptid mites burrow in the skin of their hosts and lack claws but have suckers at the ends of their legs. They undergo incomplete metamorphosis whereby eggs hatch larvae which transform to nymphs and then adults. All feeding stages are parasitic and infestations are transmitted directly between hosts by contact.



Sarcoptes scabiei [this species causes scabies in humans]

Parasite morphology: Mites form four developmental stages: eggs, larvae, nymphs and adults. The eggs are oval and large compared to the size of the adult mites (about half their length). Emergent larvae have three pairs of legs but undergo metamorphosis to form nymphs then adults which have four pairs (pairs 3 and 4 do not project beyond the body margin). These developmental stages are variable in size but successively become larger. Adult female mites are the largest (0.3-0.6 mm long) while adult males are smaller (up to 3 mm long). They have circular bodies which are flattened ventrally and covered with fine transverse striations. They have two body parts, the anterior gnathosoma bearing specialized feeding structures including palps and chelicerae, and the posterior idiosoma bearing the legs and elongate sensory setae.

Host range: *Sarcoptes scabiei* (scabies/sarcoptic mange mites) are minute skin parasites of homiotherms throughout the world. Different subspecies are found on different mammals and are responsible for causing mange in animals and scabies in humans. Although the cross-transmission potential of many subspecies has not been established, zoonotic transmission is thought to occur although such infestations do not appear to become permanently established on humans.

Site of infection: Sarcoptid mites are ectoparasitic and live on the skin of their hosts where the females burrow to lay their eggs. Infestations can occur anywhere on the body, but are more common in areas where the skin is thin and wrinkled, such as between the fingers, toes and genitals of humans, and the ears, muzzle and face of animals.

Pathogenesis: Infestation by mites is known as acariasis and can produce severe dermatitis. Nymphs and males do not burrow, but females form long tortuous tunnels in the horny layer of skin, depositing eggs and faeces, causing intense itching and rashes. Burrows may be 2-3cm in length and may be excavated at up to 5 mm per day. Mites reproduce on their hosts so infestations can become progressively worse without further exposure. Common signs are papular eruptions with erythema, pruritis and alopecia. The scabies itch takes 6-8 weeks to appear after the patient becomes sensitized, and is characteristically noctural and aggravated by warmth. As infestations progress, the skin becomes thickened and crusted with exudates. Septic pustules due to secondary infections are common in severe infestations, particularly when hosts scratch causing traumatic damage. A rash is sometimes evident around the waist, buttocks, wrists or ankles due to cell-mediated immune reactions. In immunocompromised patients, extensive thickening and crusting of the skin may occur.

Mode of transmission: Mites spend most of their lives in intimate contact with their hosts, so transmission between hosts is mainly by direct physical contact. Female mites lay 1-3 eggs per day and they mature within 4 days. Emergent larvae moult 2-3 days later to form nymphs which then moult several times over several days before forming adults. Larvae and nymphs move out of the burrows and find food and shelter in hair follicles. Adults feed and mate on the surface, the males die and the fertilized females start burrowing. The entire life cycle is usually completed within 3 weeks but can take as little as 12 days under the right conditions. Epidemics of scabies occur in human populations in 20-30 year cycles or in times of famine or war. However, mites are common in poor communities with inadequate washing facilities.

Differential diagnosis: Confirmation of suspect infestations is generally done by microscopic examination of skin scrapings or by wiping black ink over affected areas to reveal burrows.

Treatment and control: Scabies responds to whole body treatment from the neck down with acaricides, such as malathion, gamma benzene hexachloride, benzyl benzoate or crotamiton for infants. Topical steroids should not be used on humans and whole families should be treated. Infestations in animals can be treated with topical or systemic acaricides, including organochlorines (trichlorphon), bromocyclen, organophosphates (amitraz, phosmet) and the macrocyclic lactones (moxidectin, ivermectin, selamectin). Many formulations contain surfactants which serve to soften crusts and remove skin scales. Hair can also be clipped from affected areas and the skin cleaned with anti-seborrhoeic shampoos prior to acaricide treatment. Lime-sulphur dips have also been used at 10 day intervals for treating dogs and cats. Treatments should be repeated weekly for several weeks to ensure newly emergent mites are killed. Infested animals should be isolated or treatments extended to animals in close proximity. Corticosteroids can also be used in severely distressed animals to reduce pruritis and prevent further excoriation.

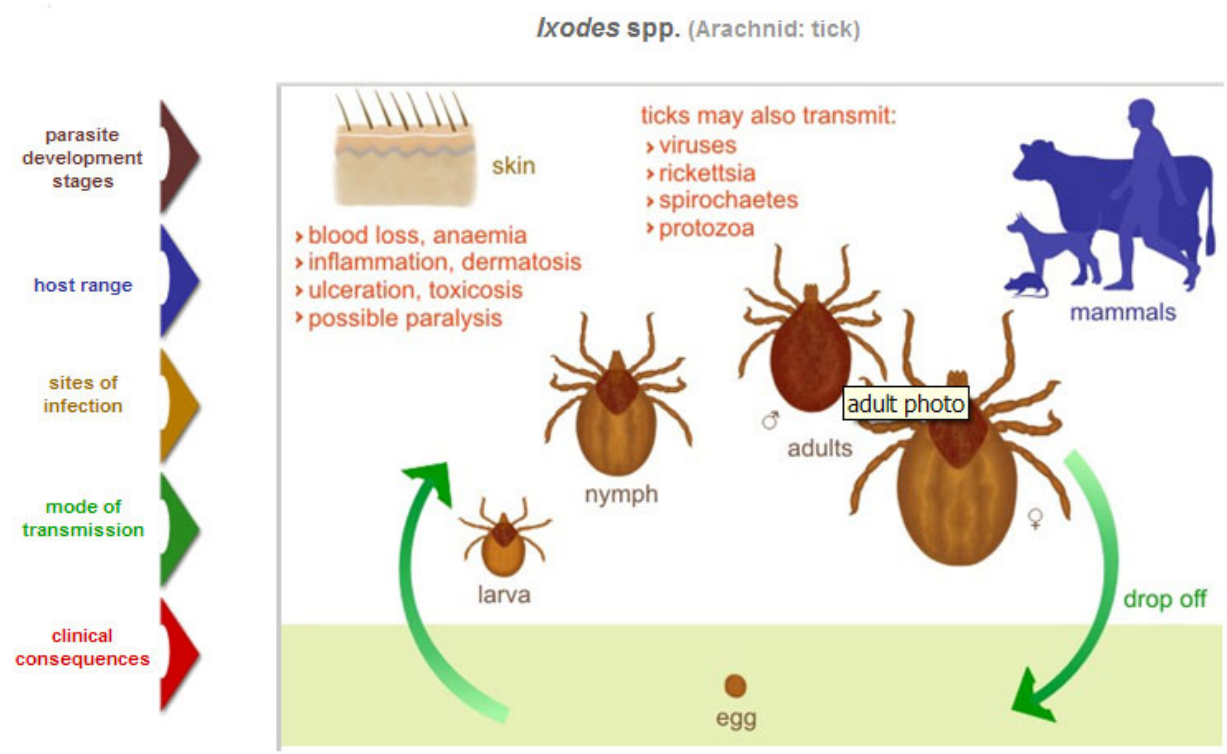
Ixodes

Classification: Taxonomic ranks under review (cf. Encyclopedic Reference of Parasitology, 2001, Springer-Verlag)

Metazoa (Animalia)	(multicellular eukaryotes, animals)
Arthropoda	(arthropods, segmented body, exoskeleton, jointed appendages)
Chelicerata	(2 body parts, 8 legs, first mouthparts chelicerae, no antennae, wingless)
Arachnida	(abdomen without appendages)
Acari	(ticks and mites, ectoparasites)

Family: Ixodidae

Ticks are obligate blood-sucking ectoparasites with two body parts and eight legs. Ixodid (hard) ticks have a characteristic hard cuticle, a terminal capitulum which can be seen in dorsal view and a large shield-shaped plate (scutum). Ticks undergo incomplete metamorphosis whereby eggs hatch larvae which moult to nymphs and then adults. Male and female ticks exhibit marked size and/or colour differences, with males generally being smaller and plainer. Eggs are laid on the ground and emergent larvae (seed ticks) quest for hosts upon which to feed. All ticks have specific life-cycles involving one, two or three hosts depending on whether moulting occurs on or off the host. Some 650 species of hard ticks infest mammals, birds and reptiles. Three species are of particular medical and/or veterinary importance in Australia: the scrub or paralysis tick *Ixodes holocyclus*, the cattle tick *Rhipicephalus* (*Boophilus*) *microplus* and the brown dog tick *Rhipicephalus sanguineus*.



Ixodes holocyclus [this species causes tick paralysis in humans and companion animals]

Parasite morphology: Ticks form four developmental stages; eggs, larvae, nymphs and adults. Eggs appear as small brown ovoid bodies (<0.5 mm long) clustered together in large masses. The small emergent larvae (<1 mm long) have six legs, whereas the larger nymphs (<2 mm long) and adults (2-3 mm long) have eight legs. Engorging females swell markedly in size and become dark blood-filled sacs (measuring up to 1-2 cm in diameter). Ticks have two body parts: a small inconspicuous anterior gnathosoma (containing sensory palps, feeding chelicerae and a barbed hypostome); and a large posterior sac-like idiosoma (to which the legs are attached anteroventral). They have a hard chitinous covering (scutum) covering the whole dorsal surface of adult male ticks but only the anterior idiosoma of larvae, nymphs and adult female ticks. Ixodids are prostriata ticks where the anal groove is located in front of the anus. Adult *I. holocyclus* ticks are inornate without notches (festoons) or pigmented 'eyes' on the scutum.

Host range: The genus *Ixodes* contains over 200 species of 3-host ticks which are ectoparasitic on small mammals. Ticks are often named after a particular host (e.g. dog tick) but they are generally not host-specific, but rather host-preferential, attempting to feed on many passing animal species. Over 20 ixodid tick species occur in Australia. The paralysis tick, *I. holocyclus*, is found along the east coast on a range of native animal species, especially bandicoots which appear to be resistant or immune to any toxic effects. The ticks, however, can infest a range of domestic animals (dogs, cats, lambs, foals) and humans, all being more susceptible to toxic sequalae. In America, *I. pacificus* and *I. dammini* from rodents, deer and other wildlife act as vectors for Lyme disease (caused by the spirochaete *Borrelia burgdorfi*).

Site of infection: Larval, nymphal and adult ticks are obligate but transient ectoparasites that attach to the skin of their hosts. Most species have preferred (predilection) sites of attachment on different hosts, often involving cryptic areas among skin folds which are difficult for hosts to groom. Ticks on humans often move to the head behind the ears, or attach to the skin under tight-fitting clothing (such as elasticized waist-bands). Infestations on animals generally involve the head, neck, back and groin.

Pathogenesis: Mouthparts of feeding ticks are embedded in the host forming a tubular food channel through which saliva is injected and blood is ingested. Ticks are relatively long-lived, feeding periodically and taking large blood meals. Tick bites cause irritation, inflammation, hypersensitivity, and even anaemia when present in large numbers. Local reactions to bites vary considerably, although small granulomatous reactions consisting of mixed inflammatory cells with fibrosis are common. Infestation of humans and domestic animals by toxin-producing species, such as *I. holocyclus*, can result in ascending motor paralysis due to neurotoxic anticoagulants released by engorging females. Clinical signs may appear within 3 days of attachment, first paralysing the legs, then the arms and finally the thorax and throat. Death can result from respiratory failure unless the tick is removed. Tick bites often become infected, especially when ticks are forcibly removed leaving their mouthparts embedded in the skin. Many tick species also transmit viral, bacterial, rickettsial, and protozoan diseases of medical and veterinary importance.

Mode of transmission: Ticks actively seek hosts, not by pursuing them but by sedentary questing; i.e., climbing vegetation and waiting for hosts to brush past. Ticks are prone to desiccation so they quest more actively when hydrated, and return to humid ground level when dehydrated. Once contact is made with a host, the ticks migrate to suitable or preferred sites of attachment. For three-host tick species, larvae, nymphs and adults all feed on different hosts. Blood feeding takes from 3-10 days after which they drop from the host and moult to the next developmental stage or lay eggs. Time spent off the host may be as long as one year for each developmental stage so the entire life-cycle may take up to three or more years. Each female tick can lay several thousand eggs leading to heavy contamination of the environment by larval stages ('seed' or 'pepper' ticks).

Differential diagnosis: Infestations are detected by visual detection of feeding stages attached to the skin, especially large engorging females. Evidence of recent infestation may be seen at predilection sites as small inflamed nodules. Differential diagnosis is performed by removing ticks and examining them microscopically for species-specific morphotypic characters.

Treatment and control: Individual ticks attached to hosts can be physically removed, preferably by sliding fine forceps under their mouth parts and then exerting gentle backwards pressure until the tick lets go. Excessive force should not be used to avoid squeezing tick contents into the wound as well as to avoid tearing the mouthparts out leaving them behind. Tick removal may be aided by wiping the attached tick with oil or dabbing it with chloroform. A variety of treatment and control strategies have been developed for tick

infestations of domestic animals but their efficacy is diminished in many instances by the persistence of ticks on wildlife reservoirs, especially in areas where wildlife and domestic stock constantly intermingle. Many native animal species are genetically resistant to heavy tick infestations. This is being exploited in cross-breeding programs e.g. *Bos indicus* cattle are tick-resistant whereas *Bos taurus* cattle are susceptible. More recently, several experimental vaccination programmes have been developed whereby tick gut antigens are used to stimulate protective antibody responses against feeding ticks. Various acaricides have proven effective for treatment when used as dips, sprays pour-ons or slow-release ear-tags. Domestic animals have been treated successfully with topical organophosphates (dichlorvos, cythoate, diazinon, malathion, fenthion, propetamphos, phormet) and pyrethroids (permethrin, deltamethrin), as well as with parenteral macrocyclic lactones or closantel. Companion animals may be treated with topical acaricides, such as fipronil, imidacloprid, selamectin, amitraz and the organophosphates. However, there are growing concerns about the development of resistance to acaricides in some tick populations. Many states and countries have adopted legislature which restricts stock movement into and from endemic areas and facilitates appropriate quarantine. Various management strategies (such as pasture rotation or spelling, cultivation or burning pastures) have also been used to minimize the transmission of infestations and reduce tick burdens on pastures.

TAXONOMIC CLASSIFICATION OF PARASITES

Taxonomic classification systems are intended to show phylogenetic relationships between life-forms, reflecting their evolution by descent. Many taxonomic characters have been used to show differences and similarities between organisms, moving from conventional phenotypic characters (such as morphology, biology, geography) to contemporary genotypic characters (DNA and protein characterization). After several centuries of considered debate and informed revision, the taxonomic classification of organisms now generally adheres to a three-domain system; recognizing the Archaea, Eubacteria and Eukaryota as profoundly different organisms, nonetheless with common ancestry. Four kingdoms of Eukaryota ('true-nucleated' organisms) are generally recognized: the Protista, Fungi, Animalia and Plantae. Parasites are found in each kingdom.

Definitive hosts (support sexual development of parasite) listed where appropriate;
otherwise: IH = intermediate host (asexual development); PH = paratenic (transport) host

Kingdom: Protista (unicellular eukaryotes)

Subkingdom: Protozoa (motile protists)

Supergroup: Excavata (with conspicuous ventral feeding groove)

Group: Metamonad (amitochondriate flagellates with karyomastigonts)

Phylum: Fornicata (diplomonads)

Order: Diplomonadida (with 1-2 karyomastigonts (each with 4 basal bodies/flagella associated with nucleus))
Family: Hexamitidae (2 karyomastigonts arranged in binary axial symmetry)
Giardia vertebrates, small intestines, direct (faecal-oral)
Hexamita (+ *Spironucleus*), vertebrates, intestines/organs/skin, direct (faecal-oral, water-borne)

Phylum: Parabasalia (anaerobic flagellates with parabasal body supporting Golgi cisternae or dictyosome, trichomonads, hypermastigids, retortamonads)
Class: Hypermastigia (Cristamonadea) (with multiple flagella)
Order: Trichomonadida (with 3-5 anterior flagella, and single recurrent flagellum)
Family: Monocercomonadidae (simplest forms, costa absent, most without undulating membrane, some aflagellate)
Histomonas birds, caeca/liver, direct (+ nematode PH)
Dientamoeba humans/rodents, gut, direct (faecal-oral)
Family: Trichomonadidae (stout axostyle, costa present, supporting undulating membrane)
Trichomonas mammals/birds, gut/urogenital tract, direct
Family: Cochlosomatidae (cells with anterior adhesive disc, lateral groove, 6 flagella, axostyle)
Cochlosoma birds, intestines, direct

Group: Discoba (diverse group supported robustly by molecular studies)

Phylum: Heterolobosea (diverse group, incl. amoebo-flagellates, most form cysts or clusters of fruiting bodies)
Order: Schizopyrenida (no fruiting bodies)
Family: Vahlkampfidae (eruptive limax amoeboid form cylindrical, most form temporary flagellated stages)
Naegleria human, CNS, opportunist (normally free-living)

Phylum: Euglenozoa (flagella inserted in anterior pocket, some heterotrophs, some autotrophs (with chloroplasts))

Order: Kinetoplastida (heterotrophs, with extranuclear DNA (= kinetoplast) associated with mitochondrion)
Suborder: Trypanosomatina (single anterior flagellum, non-emergent/emergent, often forming undulating membrane)
Family: Trypanosomatidae (monogenetic forms in insects/plants, digenetic forms in vertebrates & arthropods)
Trypanosoma brucei vertebrates, blood, indirect (fly vectors)
Trypanosoma cruzi vertebrates, tissues, indirect (bug vectors)
Leishmania vertebrates, tissues, indirect (sand fly vectors)

Suborder: Bodonina (mastigotes with two heterodynamic flagella, one trailing)
Family: Bodonidae (free-living bactivores, sometimes symbiotic on fish)
Ichthyobodo (= *Costia*), fish, gill/skin, direct (water)
Cryptobia fish, gills/skin, direct
Trypanoplasma fish, blood, indirect (leech vector)

Supergroup: SAR (Stramenopiles + Alveolata + Rhizaria)

Group: Alveolata (with cortical alveoli)

Phylum: Protalveolata (incl. perkinsids parasitic in molluscs)
Class: Perkinsea (parasitic in marine bivalves and abalone, form biflagellated zoospores)
Order: Perkinsorida (with characters of class)
Family: Perkinsidae (with characters of order)
Perkinsus shellfish, tissues, direct (water-borne)

Phylum: Dinoflagellata (with unique mesokaryotic nuclei (lacking histones), autotrophs and heterotrophs)

Class: Blastodiniophyceae (extracellular athecate parasites of zooplankton, algae, crustacea and fish)
Order: Blastodiniales (uninucleate trophonts with chloroplasts)
Family: Oodiniaceae (trophont fusiform with rhizoid-like invasive organelle)
Amyloodinium/Crepidoodinium/Piscinoodinium fish, skin, direct (water)
Class: Syndiniophyceae (multinucleate plasmodial trophonts)
Order: Syndiniales (parasitic in copepods, appendicularians, crabs, radiolaria and fish eggs)
Family: Syndiniaceae (multinucleate trophonts without chloroplasts)
Syndinium/Haematodinium/Ichthyodinium crustaceans, fish, tissues, direct (water)

Phylum: Apicomplexa (with apical complex, all parasitic, sexual development (gamogony))

Class: Gregarinomorphea (gregarines, gamogony and sporogony in aquatic hosts, trophonts with specialized attachment apparatus, epimerite or mucron, syzygy)
Subclass: Cryptogregaria (epicellular parasites of vertebrates with feeder organelle but lacking apicoplast)
Family: Cryptosporidiidae (oocysts with 4 naked sporozoites, mucosal parasites in vertebrates)
Cryptosporidium vertebrates, intestines/stomach/lungs, direct (faecal-oral)

Class: Coccidiomorphea [Conoidasida] (with conoid)
Subclass: Coccidia [Coccidiasina] (small intracellular gamonts)
Order: Eucoccidiorida (cyclic merogony (schizogony), gamogony, sporogony)

Suborder: Adeleina (syzygy, 1-4 microgametes)
Family: Haemogregarinidae (ookinete, gamonts in blood cells, invertebrate vectors)
Haemogregarina reptiles/amphibia/fish, tissues/blood, indirect (leech/arthropod vectors)
Hepatozoon mammals/birds/reptiles, tissues/blood, indirect (ingestion of arthropod vector)
Family: Klossiellidae (zygote inactive, sporocysts formed (rather than oocysts))
Klossiella mammals, kidney, direct

Suborder: Eimeriorina (no syzygy, many microgametes)

Family: Eimeriidae (monoxenous, endogenous intracellular merogony and gamogony, exogenous sporogony)
Caryospora birds/reptiles/mammals, gut, direct (faecal-oral)
Cyclospora mammals/reptiles, gut, direct (faecal-oral)
Isospora (+ *Atoxoplasma*), birds/reptiles, intestines, direct (faecal-oral)
Eimeria non-carnivorous vertebrates, intestines + tissues, direct (faecal-oral)
Epieimeria fish, gut/intestines, direct (faecal-oral, water)
Goussia fish, gut, direct (faecal-oral, water)

Family: Sarcocystidae (heteroxenous, oocysts with two sporocysts, tissue cyst formation in intermediate hosts)

Subfamily: Cystoisosporinae (monozoic cysts in paratenic transport hosts, sporocysts without Stieda bodies)
Cystoisospora carnivores/omnivores, gut/tissues, direct/indirect

Subfamily: Sarcocystinae (metrocytes present in cysts, simple/elaborate cyst walls)
Sarcocystis mammals/birds/reptiles, gut/muscles, indirect (predator-prey)
Frenkelia birds/mammals/reptiles, gut/tissues, indirect (predator-prey)
Subfamily: Toxoplasmatinae (metrocytes not present, thin cyst walls)
Besnoita mammals/reptiles, gut/tissues, indirect (predator-prey)
Hammondia mammals, gut/tissues, indirect (predator-prey)
Neospora dogs/herbivores, gut/muscles/CNS, indirect (predator-prey)
Toxoplasma cats/vertebrates, gut/muscles/CNS, indirect (predator-prey + vertical)

Class: Aconoidasida (without conoid)

Order: Haemospororida (pleomorphic stages in blood of vertebrates, insect vectors. motile zygote (ookinete))
Family: Plasmodiidae (schizogony in tissues then blood cells, gamonts in blood cells, haemozoin pigment)
Plasmodium mammals/birds/reptiles, liver/erythrocytes, indirect (mosquito vectors)
Family: Haemoproteidae (schizogony in tissues, gamonts in blood cells, haemozoin pigment)
Haemoproteus birds, endothelia/erythrocytes, indirect (hippoboscid fly vectors)
Family: Leucocytozoidae (schizogony in tissues, gamonts in blood cells, no haemozoin pigment)
Leucocytozoon (+ *Akiba*), birds, tissues/leucocytes, indirect (simuliid fly vectors)

Order: Piroplasmidora (pear-shaped stages in blood cells of vertebrates, tick vectors)
Family: Babesiidae (merogony in erythrocytes, trans-stadial + trans-ovarian transmission in ticks)
Babesia mammals, erythrocytes, indirect (ixodid tick vectors)
Family: Theileriidae (merogony in leucocytes then erythrocytes, trans-stadial transmission in ticks)
Theileria ruminants, leucocytes/erythrocytes, indirect (ixodid tick vectors)

Phylum: Ciliophora (with cilia, nuclear dualism, pellicular alveoli, reproductive conjugation)
Subphylum: Intramacronucleata (microtubules occur inside macronuclear envelope during division))

Class: Litostomatea (simple mouths, special somatic kineties)
Subclass: Trichostomatia (endosymbionts, holotrichous ciliation)

Order: Vestibuliferida (distinct oral depression (= vestibulum))
Family: Balantidiidae (monoxenous symbiotes, in vertebrates, sometimes histophagous)
Balantidium pigs/primates, large intestine, direct (faecal-oral)

Class: Phyllopharyngea (cytopharynx with leaf-like phyllae)
Subclass: Phyllopharyngia (cyrtos, ventral cilia)

Order: Chlamydodontida (body dorsoventrally flattened, ventral cilia thigmotactic)
Family: Chilodonellidae (reniform body dorsoventrally flattened, two fields of dorsal ciliary rows)
Chilodonella fish, gills/skin, direct (water)

Class: Oligohymenophorea (distinct oral ciliature, comprising right paroral membrane and 3 left membranelles)

Subclass: Scuticociliatia (with scuticum or scuticovestige)

Order: Philasterida (short paroral dikinetid membrane)
Family: Uronematidae (membranelles aligned with long axis, anterior pole non-ciliated)
Uronema fish, tissues, opportunist (normally free-living)

Subclass: Hymenostomatida (right paroral dikinetid plus 1-3 left polykinetids)

Order: Hymenostomatida (preoral suture, somatic monokinetids)
Suborder: Ophryoglenina (with organelle of Lieberkuhn (watchglass organelle))
Family: Ichthyophthiriidae (monoxenous ectoparasites, form encysted tomonts which release swarmers/theronts)
Ichthyophthirius (+ *Cryptocaryon*), fish, skin/gills, direct (water)
Suborder: Tetrahymenina (organelle of Lieberkuhn absent)
Family: Tetrahymenidae (pyriform body, longitudinal ciliary rows)
Tetrahymena fish, skin/gills/organs, direct (water)

Subclass: Peritrichia (lacking somatic kineties, oral cilia extend from infundibulum)

Order: Mobilida (mature trophont mobile, aboral holdfast organelle)
Family: Trichodinidae (stout cylindrical body, posterior adhesive disc with denticular ring)
Trichodina fish, skin/gills, direct (water)

Order: Sessilida (attached to substrate with scopula (specialized flattened thigmotactic area) with or without stalk)
Family: Epistylididae (scopula produces noncontractile stalk, retractile lip encircles elevated peristomial disc)
Apiosoma fish, skin/gills, direct (water)
Epistylis fish/crustacea, exoskeleton, direct (water)
Family: Scyphidiidae (solitary ciliates, attached by scopula)
Riboscyphidia syn *Scyphidia* fish/crustacea, exoskeleton, direct (water)
Ambiphrya fish/crustacea, exoskeleton, direct (water)
Family: Vorticellidae (solitary, gregarious or colonial, retractile stalks with central myoneme)
Vorticella fish/crustacea, exoskeleton, direct (water)
Carchesium fish/crustacea, exoskeleton, direct (water)
Family: Zoothamniidae (solitary or colonial, retractile stalks with shared myonemes)
Genus: *Zoothamnium* fish/crustacea, exoskeleton, direct (water)

Group: Rhizaria (various amoebae and flagellates)

Division: Cercozoa (biflagellated and/or amoeboid, usually with filopodia, plus ascetospora)

Phylum: Ascetospora (haplosporidian and paramyxean parasites forming unique spores)

Class: Haplosporea (haplosporosomes present)
Order: Haplosporida (spore with one sporoplasm, spore orifice covered externally by operculum or internally by diaphragm)
Family: Haplosporididae (spores with operculum)
Haplosporidium/Minchinia/Urosporidium oysters, tissues, direct
Bonamia oysters, haemocytes, direct

Class: Paramyxea (form unique multicellular spores with cells enclosed within each other)
Order: Marteilida (internal cleavage of secondary cells then sporonts)
Family: Marteiliidae (sporonts contain 2-4 tricellular spores)
Marteilia oysters, tissues, direct
incertae sedis
"Microcells" (uninucleate microcells, no spores, no plasmodia, no haplosporosomes)
Mikrocytos oysters, tissues, direct?

Supergroup: Amorphea (unikonts with single flagellum, or nonflagellated amoebae)

Phylum: Amoebozoa (locomotion by noneruptive pseudopodia, asexual development)

Subphylum: Conosa (archamoebae & mycetozoa, many flagellated forms, flagellar root with microtubular cone)
Class: Archamoebae (amoebae (no flagellates), cysts rounded, uni-/multi-nucleate, amitochondriate)
Family: Entamoebidae (uninucleate amoeboid forms, symbiotic in digestive tract of vertebrates)
Entamoeba mammals, colon (liver/brain), direct (faecal-oral)

Subphylum: Lobosa (with lobose pseudopodia)
Class: Discosea/Flabellinea (flattened forms, protoplasmic flow polyaxial)
Order: Dactylopodida (tapering finger-like subpseudopodia (= dactylopodia), most do not form cysts)
Family: Vexilliferidae (long slender subpseudopodia, spiny appearance, many with glycostyles/scales on cell surface, paramoebids with parasomes (Nebenkorper) near nucleus)
Neoparamoeba/Paramoeba fish, gills, direct (water)
Class: Longamoebea (flattened elongated cells with pointed subpseudopodia)
Order: Centramoebida (finely-tapering subpseudopodia (= acanthopodia), most form cysts)
Family: Acanthamoebidae (trophozoites flattened, prominent subpseudopodia, cysts stellate)
Acanthamoeba human, CNS, direct (water)
Balamuthia mammals, CNS, direct (soil/water)

Group: Opisthokonta (stages with single posterior flagellum)

Subgroup: Nucletmycea (Holomycota, fungi and relatives)

Kingdom: Fungi (with chitinous walls, includes microsporidia)

Division: Microsporidia (form unicellular spores, with coiled polar tubes, amitochrondriate, all parasitic)

Class: Microsporea (polar filament well-formed, oval spores)
Order: Microsporida (polaroplast present)
Suborder: Apansporoblastina (sporophorous vesicle absent)
Family: Nosematidae (all stages diplokaryotic)
Nosema insects (bees), tissues, direct?
Family: Unikaryonidae (all stages unikaryotic, in cell cytoplasm or in parasitophorous vacuole)
Encephalitozoon mammals, tissues, direct?
Enterocytozoon mammals, gut, direct?
Suborder: Pansporoblastina (sporophorous vesicle present)
Family: Glugeidae (all stages unikaryotic, numerous sporoblasts formed in vesicles)
Glugea fish, tissues, direct?
Pleistophora fish, muscles, direct (water)
Trachipleistophora fish, tissues, direct?
Pseudoloma fish, nervous system, direct (water, carnivorism
Family: Thelohaniidae (meronts diplokaryotic, spores unikaryotic, 8 spores formed in each vesicle)
Thelohania crustaceans/insects, tissues, direct?

Group: Holozoa (metazoans, filasterans, ichthyosporeans, choanomonads)

Kingdom: Metazoa (Animalia) (multicellular eukaryotes, heterotrophs, notably animals)

Phylum: Cnidaria (diploblastic, radial symmetry, cnidocytes with nematocysts, sea anemones, corals, jellyfish, hydrozoa, myxozoa)

Subphylum: Myxozoa (form multicellular valved spores with polar filaments)
Class: Myxosporea (spores with 1-2 sporoplasms, 1-6 polar capsules)
Order: Bivalvulida (spores with two valves)
Suborder: Platysporina (polar capsules in sutural plane)
Family: Myxobolidae (spores flattened, suture forms elevated ridge, one polar capsule smaller than the other)
Myxobolus fish, tissues, direct + indirect?
Order: Multivalvulida (radially symmetrical spores, 3-7 valves, 3-7 polar capsules grouped together at apex)
Family: Kudoidae (four valves and polar capsules, mainly histozoic in muscles of marine fish)
Kudoa fish, muscles, direct/indirect?
Family: Trilosporidae (three valves and polar capsules, coelozoic/histozoic in marine fish)
Unicapsula fish, muscles, direct/indirect?

Group: Protostomia (triploblastic, spiral cleavage)

Subgroup: Lophotrochozoa (lophophore feeding structure or trochophore larva or neither)

Phylum: Platyhelminthes (flatworms, acoelomate, free-living/parasitic, most parasites hermaphroditic, prominent attachment organs)

Clade: Neodermata (syncytial tegument = neodermis)

Class: Trematoda (flukes, most with dorsoventrally-flattened bodies, sac-like gut)

Subclass: Digenea (two or more hosts (one a mollusc), cycle involves larval miracidium, sac-like sporocyst/redia stages in snail, cercariae/metacercariae)

Superorder: Anepitheliocystidia (larval excretory bladder wall retained in adult)

Order: Strigeatida (adult with spines, midventral acetabulum, rediae without appendages, brevifurcate cercariae with two eyespots)
Family: Schistosomatidae (blood flukes, cylindrical bodies, in blood vessels of alimentary/urinary tract, separate sexes, male with gynaecophoric canal to hold female)
Schistosoma mammals/birds, blood vessels, indirect (fw snail IH)
Trichobilharzia, Austrobilharzia birds, blood vessels, indirect (snail vectors)

Order: Echinostomatida (adult with scales/spines, acetabulum near oral sucker, rediae with appendages, cercariae without eyespots, metacercariae in open or in IH-2)
Family: Fasciolidae (large leaf-shaped flukes, in herbivores, conical anterior end, ventral sucker at level of shoulders)
Fasciola mammals, liver, indirect (freshwater snail IH)
Fasciolopsis man/pig, intestines, indirect (planorbid snail IH)
Family: Echinostomidae (slender worms, collar of peglike spines, in piscivores, two IH (snails and fishes/frogs))
Echinostoma birds/mammals, gut, indirect (snail IH-1, molluscs/planaria/fish/tadpoles IH-2)

Order: Paramphistomida (thick fleshy worms, acetabulum near posterior end, rediae with appendages, cerceriae with two eyespots, metacercariae in open)
Family: Paramphistomidae (rumen flukes, conical shape, water snail IH)
Paramphistomum et al. cattle/sheep, rumen/reticulum, indirect (planorbid snail IH)
Gastrodiscoides pig/humans, large intestine, indirect (snail IH)

Superorder: Epitheliocystidia (excretory bladder newly formed, unforked cercariae)

Order: Opisthorchiida (medium-sized flukes, often spinose, no cirrus sac, rediae without appendages, cerceriae with two eyespots, metacercariae in second IH)
Family: Opisthorchidae (delicate leaf-shaped flukes, in bile ducts of fish-eating mammals, two IH (snails and fish))
Opisthorchis piscivorous mammals, liver, indirect (fw snail IH-1, fw fish IH-2)
Clonorchis carnivores, liver, indirect (fw snail IH-1, fw fish IH-2)
Metorchis cat/dog/fox/seal, liver, indirect (snail IH-1, fish IH-2)
Family: Heterophyidae (tiny pyriform flukes, in intestines of mammals/birds, two IH (snails and fishes/frogs))
Heterophyes carnivores, intestines, indirect (fw snail IH-1, fw fish IH-2)
Metagonimus dogs/cats/pigs/humans, small intestines, indirect (snail IH-1, fish IH-2)

Order: Plagiorchiida (adult with spines, midventral acetabulum, cercariae with two eyespots, not furcate, metacercariae in second IH)
Family: Dicrocoeliidae (small lancet-like flukes, eggs ingested by snails, no redial stage, two-three IH)
Dicrocoelium ruminants, liver, indirect (terrestrial snail IH-1, ant IH-2)
Family: Troglotrematidae (thick oval flukes, scale-like spines, miracidia, snail IH-1, crustacean/insect IH-2)
Paragonimus carnivores, lungs, indirect (fw snail IH-1, fw crustaceans IH-2)

Class: Monogenea (monoxenous ectoparasites, sac-like gut, hermaphroditic, direct cycles, oncomiracidium with 3 ciliary bands)

Order: Monopisthocotylea (posterior haptor comprising a single symmetrical attachment unit, no haptoral clamps)

Family: Gyrodactylidae (small worms, posterior haptor with pair of large central hooks and 16 small marginal hooks; viviparous, sometimes hyperviviparity (Russian nested dolls))

Gyrodactylus fish, skin/fins/gills, direct (water)

Family: Dactylogyridae (small worms, posterior haptor with 2 pairs large ventral anchors and 14 small marginal hooks, oviparous)

Dactylogyrus fish, gills, direct (water)

Family: Capsalidae (large worms, haptor with pair anterior suckers and two pairs of posterior hooks)

Benedenia fish, skin/gills, direct (water)

Class: Cestoda (tapeworms, gut absent, anterior scolex, proglottid segments, heteroxenous, predator-prey cycles)

Subclass: Eucestoda (larvae hexacanth (with six hooks))

Order: Cyclophyllidea (terrestrial species, scolex with four suckers, often bearing hooks, eggs release oncospheres)

Family: Taeniidae (tapeworms of carnivores/humans, scolex often armed, proglottids with unpaired reproductive organs and single genital pore, fluid-filled cystic metacestodes)

Taenia carnivores/omnivores, intestines/tissues, indirect (predator-prey)

Echinococcus dogs/omnivores, gut/tissues, indirect (predator-prey)

Multiceps dog/herbivores, muscle/brain, indirect (predator-prey)

Family: Anoplocephalidae (tapeworms of hoofed animals, scolex unarmed, cysticerci in arthropods)

Anoplocephala, Anaplocephaloides, Equinia, Moniezia, Thysaniezia herbivores, intestines, indirect (soil mite/insect IH)

Family: Dipylidiidae (armed scolex, proglottids with paired reproductive organs and two lateral genital pores)

Dipylidium dog/cat, small intestines, indirect (flea/louse IH)

Family: Dilepididae (tapeworms of dog/cat and fowl, armed scolex, genital pores alternate, cysticercoid larva)

Amoebotaenia birds, small intestines, indirect (earthworms IH)

Choanotaenia birds, small intestines, indirect (beetle/fly IH)

Family: Davaineidae (tapeworms of birds, large rostellum with hammer-shaped hooks and spiny suckers)

Davainea birds, small intestines, indirect (terrestrial mollusc IH)

Raillietina birds, small intestines, indirect (ants/beetles/cockroaches IH)

Family: Hymenolepididae (tapeworms of birds/rodents/humans, slender strobilia, 1-4 testes, cysticercoid larva)

Hymenolepis mammals/birds, small intestines, indirect (arthropod/annelid/mollusc IH)

Order: Diphyllobothriidea (= Pseudophyllidea) (aquatic host species, unarmed scolex, with two grooves (bothria), genital organs and pores centrally placed, indirect cycles with two IH)

Family: Diphyllobothriidae (eggs release coracidium, more than one IH (procercoid in copepods, pleroceroids in frogs and other aquatic vertebrates) and often PHs)

Diphyllobothrium piscivorous mammals, small intestines, indirect (copepod IH-1/fw fish IH-2)

Spirometra carnivores, small intestines, indirect (copepod IH-1/frogs IH-2)

Family: Bothriocephalidae (eggs, hexacanth coracidia, procercoid larvae in copepods)

Bothriocephalus fish, intestines, indirect (copepod IH-1)

Clade: Gnathifera (small cuticular jaws, except acanthocephala)

Group: Syndermata (eutelic syncytial epidermis)

Phylum: Acanthocephala (thorny-headed worms, pseudocoelomate, unsegmented, anterior retractable proboscis with numerous hooks, lack gut, indirect cycles, eggs with acanthor, acanthella develops in arthropod IH (or PH))

Class: Archiacanthocephala (oval thick-shelled eggs, body wall lacunar canals dorsal & ventral (or just dorsal))

Order: Oligacanthorhynchida (proboscis subspherical, short rows of several hooks, protonephridial organs present)

Family: Oligacanthorhynchidae (single family)
Macracanthorhynchus pig, small intestines, indirect (beetle IH)
Oncicola cats/foxes/dingoes, small intestines, indirect (beetle IH + bird PHs)

Class: Palaeacanthocephala (elongate eggs, sometimes with polar thickenings, body wall lacunar canals lateral)
Order: Polymorphida (trunk wrinkled, proboscis bulbose/cylindrical, with numerous hooks in alternating rows)
Family: Polymorphidae (spinose trunk, proboscis bulbous, double-walled proboscis receptacle)
Polymorphus ducks, small intestines, indirect (copepod IH)

Subgroup: Ecdysozoa (cuticle moulted = ecdysis)

Clade: Nematoidea (collagenous cuticle without microvilli)

Phylum: Nematoda (unsegmented, pseudocoelomate roundworms, hydrostatic skeleton, tubular digestive tract, longitudinal musculature, dioecious, free-living/symbiotic species)

Class: Enoplea (Aphasmidea, Adenophorea) (gland-bearers, cylindrical oesophagus, no phasmids, setae, two testes)
Subclass: Dorylaimia (five or more oesophageal glands, buccal stylet (odontostyle), free-living or parasitic)

Order: Trichinellida (Trichocephalida, Trichurida) (single spicule, stichosome oesophagus, L1 with buccal stylet)

Superfamily: Trichinelloidea (oesophagus with short muscular anterior portion and long glandular posterior portion)
Family: Trichinellidae (males with copulatory pseudobursae, spicules absent, viviparous, juveniles and adults can occur in same host, juveniles intracellular in skeletal muscle nurse cell)
Trichinella mammals, small intestines/muscles, direct (carnivorism)
Family: Trichuridae (whipworms, sudden transition in width, slender anteriorly, barrel-shaped eggs with polar plugs)
Trichuris mammals, caeca, direct (faecal-oral)
Family: Capillariidae (gradual transition in width, in gut/respiratory tract of mammals/birds, eggs with polar plugs)
Capillaria (*Eucoleus*) mammals/birds, various tissues, direct (faecal-oral) + earthworm PH
Pseudocapillaria fish, intestines, direct (water) + indirect oligochaete PHs

Class: Chromadorea (spiral amphids, 3 oesophageal glands, usually annulated bodies, free-living and parasitic)

Order: Rhabditida (Secernentea, Phasmidea) (secretors, phasmids present, amphids anterior, setae absent on females, single testis in males, cuticle 2-4 layers, oesophagus divided into bulbs)

Suborder: Rhabditina (free-living or parasitic in invertebrates/lower vertebrates)

Infraorder: Rhabditomorpha ('rod'shaped' buccal cavity)

Superfamily: Rhabditoidea (open tube stoma, excretory system with lateral canals)
Family: Rhabditidae (protandrous hermaphrodite (male becomes female), parasitic and free-living generations)
Rhabditis, Pelodera animals, skin, direct (faecal-oral, transdermal)

Superfamily: Strongyloidea (bursate males, prominent buccal capsules, parasites of mammals, some birds)
Family: Ancylostomatidae (hookworms, large buccal capsule bent dorsally, armed with teeth/cutting plates, infection usually by percutaneous/transdermal penetration of infective L3)
Ancylostoma humans/dogs/cats, small intestines, direct (faecal-oral, transdermal)
Necator humans/pigs, small intestines, direct (faecal-oral, transdermal)
Bunostomum ruminants, small intestines, direct (transdermal, faecal-oral)
Globocephalus pigs, small intestines, direct (faecal-oral)
Gaigeria sheep, small intestines, direct (transdermal)
Uncinaria dogs/foxes/cats, small intestines, direct (faecal-oral)
Family: Metastrongylidae (infection of pigs by ingestion of earthworm/molluscan IH carrying L3)
Metastrongylus pigs, lungs, indirect (molluscan IH)

Family: Protostrongylidae (infection of ruminants by ingestion of earthworm/molluscan IH carrying L3)
Protostrongylus, Muellerius sheep/goats, lungs, indirect (mollusc IH)
Parelaphostrongylus cervids, brain, indirect (snail IH)
Elaphostrongylus cervids, muscles, indirect (snail IH)
Family: Angiostrongylidae (no buccal cavity, infection of vertebrates by ingestion of earthworm/molluscan IH)
Aelurostrongylus cats, lungs, indirect (mollusc IH) + PHs
Parastrongylus (formerly *Angiostrongylus*) rat, dog, pulmonary artery, indirect (mollusc IH) + PHs
Family: Filaroididae (direct cycle, infection of carnivores by ingestion of L1)
Filaroides dogs/mustelids, lungs, direct (faecal-oral)
Oslerus dogs, trachea, direct (faecal-oral)
Family: Strongylidae (strongyles, large buccal capsules, often with teeth/leaf crown, infection by ingestion of L3three pairs of branches in dorsal ray, equid hosts)
Subfamily: Strongylinae (large strongyles, red-worms, globular buccal capsules)
Strongylus equines, caecum/colon, direct (faecal-oral)
Subfamily: Cyathostominae (small strongyles, cylindrical buccal capsule)
Cyathostomum, Poteriostomum equines, caecum/colon, direct (faecal-oral)
Triodontophorus/Oesophagodontus/Craterostomum equines, caecum/colon, direct (faecal-oral)
Family: Chabertiidae (nodular worms, two pairs of branches in dorsal ray)
Chabertia ruminants, caecum/colon, direct (faecal-oral)
Oesophagostomum ruminants/pigs/humans, caecum/colon, direct (faecal-oral)
Family: Stephanuridae (kidney-worm, in pigs)
Stephanurus pig, kidneys, direct (faecal-oral, transdermal) + earthworm PHs
Family: Syngamidae (gapeworm, in trachea of birds and mammals)
Syngamus birds, trachea, direct (faecal-oral) + earthworm/mollusc PHs
Family: Trichostrongylidae ((hair-like trichostrongyles, found in gut, infection by ingestion of L3, oesophagus lacking bulb, bursate males, lips reduced/absent, females lay thin-shelled eggs in morula stage, direct cycles)
Trichostrongylus herbivorous mammals/birds, gut, direct (faecal-oral)
Ostertagia cattle, abomasum, direct (faecal-oral)
Teladorsagia sheep/goats, abomasum, direct (faecal-oral)
Haemonchus ruminants, abomasum, direct (faecal-oral)
Cooperia ruminants, small intestines, direct (faecal-oral)
Nematodirus ruminants, small intestines, direct (faecal-oral)
Hyostrongylus pig, stomach, direct (faecal-oral)
Family: Dictylocaulidae (lung worms, direct cycle, infection by ingestion of L3)
Dictylocaulus ruminants/equids/camelids, lungs, direct (faecal-oral)
Family: Ollulanidae (head with spiral coil, female tail with cusps, viviparous (develop to L3 in uterus))
Ollulanus cat/fox/pig, stomach, direct (ingestion of vomitus)
Family: Heligmosomatidae (adults filiform, reddish in colour, direct cycle)
Nippostrongylus rodents, small intestines, direct (percutaneous)

Suborder: Spirurina (mostly parasitic, males often with coiled tail)
Incertae sedis

Superfamily: Dracunculoidea (elongate parasites of vertebrate tissues, freshwater crustacean IH)
Family: Dracunculidae (buccal capsule reduced, female highly enlarged, filled with L1)
Dracunculus humans, subcutaneous tissues, indirect (copepod IH)

Infraorder: Ascaridomorpha (large roundworms, mouth opening surrounded by three large lips, numerous caudal papillae)

Superfamily: Ascaridoidea (ascarids, eggs thick-shelled, direct cycle but larvae undertake hepato-pulmonary migration)
Family: Ascarididae (large pale roundworms, in terrestrial mammals)
Ascaris humans/pigs, small intestines, direct (faecal-oral)
Parascaris horses, small intestines, direct (faecal-oral)
Toxascaris dogs/foxes/cats, small intestines, direct (+ PHs)
Toxocara dogs/cats/bovids, small intestines, direct (vertical + faecal-oral) + PHs
Family: Anisakidae (large stout worms, in marine mammals/fishes/birds)
Anisakis dolphins/whales, gut, indirect (copepod IH) + fish PHs

Superfamily: Heterakoidea (preanal sucker anterior to cloaca in males, direct cycle, infection by ingestion of eggs)
Family: Heterakidae (worms with lateral alae, oesophagus with rounded terminal bulb)
Heterakis birds, caeca, direct (faecal-oral) + earthworm PHs
Family: Ascaridiidae (slender club-shaped oesophagus without rounded terminal bulb)
Ascaridia birds, small intestines, direct (faecal-oral) +earthworm PHs

Infraorder: Gnathostomatomorpha ('jaw-mouthed' due to unique bulbous armed heads)

Superfamily: Gnathostomatoidea (first IH copepod, often use paratenic hosts)
Family: Gnathostomidae (swollen anterior head bulb, covered with rows of hooks, two lateral lips, four cervical sacs)
Gnathostoma cats/pigs, stomach, indirect (copepod IH) + vertebrate PHs

Infraorder: Oxyuridomorpha (small pinworms, pointed tails, oesophagus with terminal bulb, males with single spicule)

Superfamily: Oxyuroidea (common in mammals, birds, reptiles, amphibians)
Family: Oxyuridae (direct cycle, females deposit sticky eggs around anus, infection by ingestion of egg)
Oxyuris horse, large intestines, direct (faecal-oral)
Enterobius humans, large intestines, direct (faecal-oral)
Passalurus rabbits, large intestines, direct (faecal-oral)
Syphacia rodents, large intestines, direct (faecal-oral)

Infraorder: Spiruromorpha (enigmatic clade linked by molecular characters, indirect cycles with IHs)

Superfamily: Acuarioidea (small parasites mostly of birds, with cephalic cordons, ptilina or serrated shields)
Family: Acuariidae (cepahlic cordons, gooved cuticular structures)
Acuaria, Cheilospirura, Dispharynx birds, gizzard, indirect (water fleas/grasshoppers/beetles IH)

Superfamily: Camallanoidea (conspicuous phasmids, L1 with dorsal prominence/tooth, ovoviviparous, L1-L3 in copepod)
Family: Camallanidae (buccal capsule well-developed, with pair sclerotized valves, male with caudal alae)
Camallanus fish, intestines, indirect (copepod IH)

Superfamily: Filarioidea (tissue-dwelling filarial parasites, lack lips, infect subcutaneous/intermuscular tissues, blood vessels or lymphatic systems of hosts, indirect cycles with arthropod IH)
Family: Filariidae (numerous anterior papillae and cuticular ridges, lay eggs with L1 already fully formed)
Parafilaria horses/cattle, connective tissue, indirect (muscid flies IH)
Stephanofilaria cattle, skin, indirect (buffalo flies IH)
Family: Onchocercidae (adults loose in tissues or in nodules, viviparous (live birth of L1 microfilariae))
Onchocerca humans/cattle/horses, connective tissue, indirect (ceratopogonid/simuliid IH)
Dirofilaria dogs/cats/humans, heart, indirect (mosquito IH)
Dipetalonema/Acanthocheilonema dogs/camelids/humans, connective tissue, indirect (fleas/lice IH)
Wuchereria humans, lymphatics, indirect (mosquito IH)
Brugia humans/cats, lymphatics, indirect (mosquito IH)
Setaria sheep/cattle/horses, peritoneum/eye/scrotum, indirect (mosquito IH)
Loa humans, subcutaneous, indirect (fly IH)
Mansonella humans, body cavities, indirect (midges IH)

Superfamily: Habronematoidea (unique head structures with small pseudolabia and median lips)
Family: Habronematidae (pharynx with dorsal and ventral tooth, indirect cycle involving ingestion of fly)
Habronema, Draschia horses, stomach, indirect (muscid flies IH)
Family: Tetrameridae (extravagant sexual dimorphism, females swollen, coloured bright red)
Tetrameres birds, proventriculus, indirect (water fleas/grasshoppers IH)

Superfamily: Physalopteroidea (stomach worms in mammals, insect IH)
Family: Physalopteridae (two large lateral pseudolabia, armed with teeth, lips with basal collar, caudal alae on males)
Physaloptera cats, stomach, indirect (crickets IH) + vertebrate PHs

Superfamily: Spiruroidea ((oesophagus divided into anterior muscular and posterior glandular portions, never with bulb, coiled tail in males, two spicules invariably dissimilar, indirect cycles, arthropod IHs, two prominent trilobed lips (pseudolabia), infect oesophagus/stomach (crop/gizzard))
Family: Gongylonematidae (anterior cuticle covered with large bosses or irregular scutes arranged in 8 rows)
Gongylonema cattle/sheep, oesophagus, indirect (beetle/cockroach IH)
Family: Spirocercidae (stout pink-red worm, well-developed buccal capsule, with 6 rudimentary lips)
Spirocerca dog, oespohagus/aorta, indirect (beetle IH) + vertebrate PHs
Ascarops, Physocephalus pigs, stomach, indirect (beetles IH) + vertebrate PHs
Cylicospirura, Cyathospirura cats/foxes/dasyurids, stomach, indirect (beetle IH)

Superfamily: Thelazioidea (eye-worms of birds and mammals, transmitted by insects)
Family: Thelaziidae (hexagonal mouth, lacking lips, conspicuous transverse anterior striations, live on surface of eye)
Thelazia cattle/horses, conjunctiva, indirect (muscid flies IH)
Oxyspirura birds, eye, indirect (cockroaches IH)

Suborder: Tylenchina (fungal, plant and animal parasites)

Infraorder: Panagrolaimomorpha (free-living or parasitic (insects, reptiles, amphibians, mammals))

Superfamily: Strongyloidoidea (dauer stages, lip region without processes, striated cuticle)
Family: Strongyloididae (threadworms, parasitic parthenogenetic females, free-living sexual generations)
Strongyloides mammals/birds, small intestines, direct (faecal-oral + transmammary)

Clade: Panarthropoda (with haemocoel, ventrolateral appendages)

Phylum: Arthropoda (coelomate metameric invertebrate animals, chitinous exoskeleton, segmented body, jointed limbs, moults (ecdyses) between instars, metamorpohosis common)

Subphylum: Chelicerata (2 tagmata (cephalothorax + abdomen), chelicera, no antennae)

Class: Arachnida (spiders, scorpions, ticks, mites, two tagmata, 4 pairs of legs, no antennae, slit sensilla, incomplete metamorphosis)

Order: Acari (Acarina) (ticks & mites, segmentation inconspicuous/absent, sac-like body, mouth and appendages on capitulum)

Suborder: Ixodida (= Metastigmata) (ticks, macroscopic, spiracles/stigmata posterior to legs, hypostome toothed, exposed, obligate blood-feeding ectoparasites of vertebrates)

Family: Argasidae (soft ticks, lack dorsal scutum, capitulum covered by body, hide in cracks/crevices)
- *Argas* birds, skin, direct
- *Ornithodorus, Otobius* mammals, skin, direct

Family: Ixodidae (hard ticks, with dorsal scutum, capitulum projects anteriorly, 1, 2 or 3 hosts)
- *Ixodes* mammals/birds, skin, direct
- *Rhipicephalus* (= *Boophilus*) mammals, skin, direct
- *Haemaphysalis* mammals, skin, direct
- *Amblyomma* (*Aponomma*) mammals/reptiles, skin, direct
- *Boophilus* mammals, skin, direct
- *Dermacentor* mammals, skin, direct
- *Hyalomma* mammals, skin, direct

Suborder: Mesostigmata (gamesid mites, legs grouped anteriorly, spiracles/stigmata between second and fourth legs)

Family: Macronyssidae (large blood-sucking ectoparasites, only protonymph and adults feed, relatively long legs)
- *Ornithonyssus* birds, skin/feathers, direct

Family: Dermanyssidae (large blood-feeding ectoparasites, greyish-white bodies becoming red when engorged)
- *Dermanyssus* mammals/birds, skin/feathers, direct

Family: Halarachnidae (obligate parasites in respiratory tracts or ears of mammals)
- *Pneumonyssoides* dogs/primates, nasal passages/sinuses, direct
- *Raillietia* mammals, ears, direct

Family: Rhinonyssidae (parasites of nasopharynx of birds)
- *Sternosoma* birds, nasal passages, direct

Family: Varroidae (bee mites, flat button shape, red-brown colouration, suck haemolymph)
- *Varroa* bees, cuticle, direct

Suborder: Prostigmata (Trombidiformes) (mites with spiracles/stigmata on capitulum, distinct setae on body/legs)

Family: Demodecidae (small follicle mites, elongate cigar-shaped body, 4 pairs stumpy legs at front of body)
- *Demodex* mammals, hairs, direct

Family: Cheyletiellidae (predatory and parasitic mites, body with waist, palps enlarged, legs terminate in combs)
- *Cheyletiella* dogs/cats/rabbits, skin, direct

Family: Psorergatidae (body circular, legs regularly spaced, long posterior setae, legs with inward-curved spines)
- *Psorergates* sheep, skin, direct

Family: Trombiculidae (only larval stages parasitic, nymphs and adults free-living)
- *Eutrombicula, Neotrombicula, Guntheria* mammals/birds, skin, direct

Suborder: Astigmata (Sarcoptiformes) (mange mites, without spiracles, respire through body surface, first two pairs of legs separated from posterior pairs, lack claws, with sucker-like modifications)

Family: Psoroptidae (non-burrowing mites, oval bodies, third and fourth pairs of legs project beyond body margin)
- *Psoroptes* ruminants/horses/rabbits, skin, direct
- *Otodectes* cats/dogs/foxes/ferrets, ear, direct
- *Chorioptes* horses/sheep/cattle, skin, direct

Family: Sarcoptidae (burrowing mites, circular bodies, third and fourth legs do not project beyond body margin)
Sarcoptes humans/dogs, skin, direct
Notoedres cats/rabbits/rats, skin, direct
Trixacarus guinea pigs, skin, direct
Family: Knemidocoptidae (burrowing scaly leg and face mites, round body, no dorsal spines, short stubby legs)
Knemidocoptes, Neocnemidocoptes birds, skin, direct
Family: Ctyoditidae (respiratory parasites of birds, chelicerae absent, palps fused to form sucking organ)
Cytodites birds, air sacs, direct
Family: Listrophoridae (parasitic on fur-bearing mammals, distinct dorsal shield, legs modified for grasping hairs)
Lynxacarus cats, skin, direct
Lepoacarus rabbits/hares, skin, direct
Myocoptes mice, skin/hair, direct
Family: Myobiidae (parasitic on fur-bearing mammals, esp. bats, body with lateral bulges)
Myobia mice, skin/hair, direct
Family: Atopomelidae (fur and feather mites)
Chirodiscoides guinea pigs, skin, direct
Family: Laminosioptidae (small mites, smooth elongated body, few setae, affect muscles of birds)
Laminosioptes birds, subcutaneous tissues, direct

Subphylum: Crustacea (chitinous cuticle, gills, 2 pairs antennae, mouthparts comprise pair mandibles and 2 pairs maxillae, segments with pair biramous extremities (podia), metamorphosis involving larval nauplius/zoea)

Class: Maxillipoda (nauplius with maxillipodan eye, 5 cephalic, 6 thoracic and usually 4 abdominal segments plus telson)

Subclass: Copepoda (elongate body, thorax with 7 somites (first few fused with head to form cepahalothorax), gradual metamorphosis with series of copepodod instars succeeding naupliar instars, some ectoparasitic forms)

Order: Cyclopoida (antennules short with 10-16 articles, buccal cavity open)
Family: Lernaeidae (females insert anterior attachment organ into host tissues, develop paired egg sacs, free-swimming naupliar stage, five copepodid stages and adults on hosts)
Lernaea fish, gills, direct (water)
Order: Poecilostomatoida (simple parasitic forms of fishes to bizarre symbiotic forms of invertebrates)
Family: Ergasilidae (antennae modified into powerful organs of prehension, parasitic in freshwater and marine fishes)
Ergasilus fish, gills, direct (water)

Subclass: Branchiura (head with flattened bilobed cephalic fold, antennae reduced, carapace expands laterally to form respiratory alae, blood suckers on fish)

Order: Argulidea (single order)
Family: Argulidae (fish lice, discoid body, attaches using hooks/suckers/barbs, stylus inserted to feed on blood)
Argulus fish, skin/gills, direct

Subclass: Pentastomatida (tongue worms, crustacean-related parasites, lost virtually all appendages, elongate, segmented, anterior end with mouth and two pairs of tiny claws (penta-stome appearance))

Order: Porocephalida (mouth between or below anterior hooks, hooks with fulcrum, vuvla near posterior)
Family: Porocephalidae (parasites of snakes)
Porocephalus snakes, respiratory passages, indirect (rodent IH)
Family: Linguatulidae (parasites of mammals)
Linguatula mammals, respiratory passages, indirect (mammalian IH)

Subphylum: Hexapoda (3 tagmata (head+thorax+abdomen), 3 pairs uniramous legs, whole-limb mandibles, Malpighian tubules)

Class: Insecta (three body regions (head, thorax, abdomen), ectognathous mouthparts (bases lie outside head capsule), six legs, single pair antennae, free-living and parasitic species)

Subclass: Pterygota (with wings)

Infraclass: Neoptera (wings fold back over body)

Superorder: Hemipterodea (= Exopterygota) (young resemble adults, have externally developing wings, piercing/sucking mouthparts)

Order: Hemiptera (true bugs/aphids/scale insects, mouthparts with stylet-like mandibles/maxillae, gradual metamorphosis)
Suborder: Heteroptera (some plant-feeders, some predatory on other arthropods, some blood-feeders on vertebrates)
Family: Cimicidae (small wingless bugs, incl. bed-bugs, blood feeders on animals)
Cimex mammals/birds, skin, direct
Family: Reduviidae (large winged cone-nose/kissing/assasin bugs, incl. triatome bugs, blood feeders on animals)
Triatoma mammals, skin, direct

Order: Phthiraptera (lice, small wingless insects, permanent obligate ectoparasites, dorsoventrally flattened, stout legs and claws, incomplete metamorphosis (eggs, nymphs, adults))

Suborder: Anoplura (sucking lice, narrow pointed head, pierce skin and feed on fluids (solenophagy))
Family: Haematopinidae (short-nosed lice, ectoparasites of domestic animals, claws on ends of legs of similar size)
Haematopinus horses/cattle/pig, skin/hair, direct
Family: Linognathidae (long-nosed lice, claws on first leg smaller than those on other legs)
Linognathus ruminants/dogs/foxes, skin/hair, direct
Solenoptes cattle, skin/hair, direct
Family: Pediculidae (head/body lice of primates)
Pediculus primates, skin/hair, direct
Family: Pthiridae (pubic lice of primates)
Pthirus humans, skin/hair, direct

Suborder: Mallophaga (= wool-eating) (chewing lice, broad rounded head, feed on keratin, host/site specific)
Superfamily: Ischnocera (without maxillary palps, prominent filiform antennae, keratin feeders (hairs/feathers))
Family: Trichodectidae (parasitize mammals, 3-segmented antennae, single claw on tarsi)
Trichodectes dogs, skin/hair, direct
Bovicola sheep/cattle/horses, skin/fleece/hair, direct
Felicola cats, skin/hair, direct
Family: Philopteridae (parasitize birds, five-segmented antennae, paired claws on tarsi)
Lipeurus, Goniocotes birds, skin/feathers, direct
Superfamily: Amblycera (with maxillary palps, large rounded heads, 4-segmented antennae in antennal grooves)
Family: Menoponidae (parasitize birds)
Menopon, Menacanthus birds, skin/feathers, direct
Family: Boopiidae (parasitize mammals/marsupials)
Heterodoxus dogs/macropods, skin/hair, direct

Superorder: Holometabola (= Endopterygota) (young do not resemble adults, holometabolous (complete) development, with internally developing wings)

Group: Panorpoid (complex of orders)

Order: Siphonaptera (fleas, wingless (=-aptera), adults feed on blood ("siphon-), laterally compressed, third pair of legs adapted for jumping, complete metamorphosis with vermiform larvae, pupation in silk cocoons)

Family: Pulicidae (parasites of mammals)
Pulex humans/dogs/cats, skin, direct
Echidnophaga mammals/birds, skin, direct
Ctenocephalides dogs/cats/humans, skin, direct
Xenopsylla rats/dogs/cats/humans, skin, direct
Spilopsyllus rabbit, skin, direct
Family: Ceratophyllidae (parasites of small rodents and birds)
Nosopsyllus rats, skin, direct
Ceratophyllus small rodents/birds/humans, skin, direct
Family: Tungidae (chigoes/jiggers/chiggers/chique/sand fleas, females burrow under skin, enclosed in sinus)
Tunga mammals, skin, direct

Order: Diptera (true flies, midges, mosquitoes, with single pair of membranous forewings (diptera), hindwings modified into halteres, complete metamorphosis with vermiform larvae)

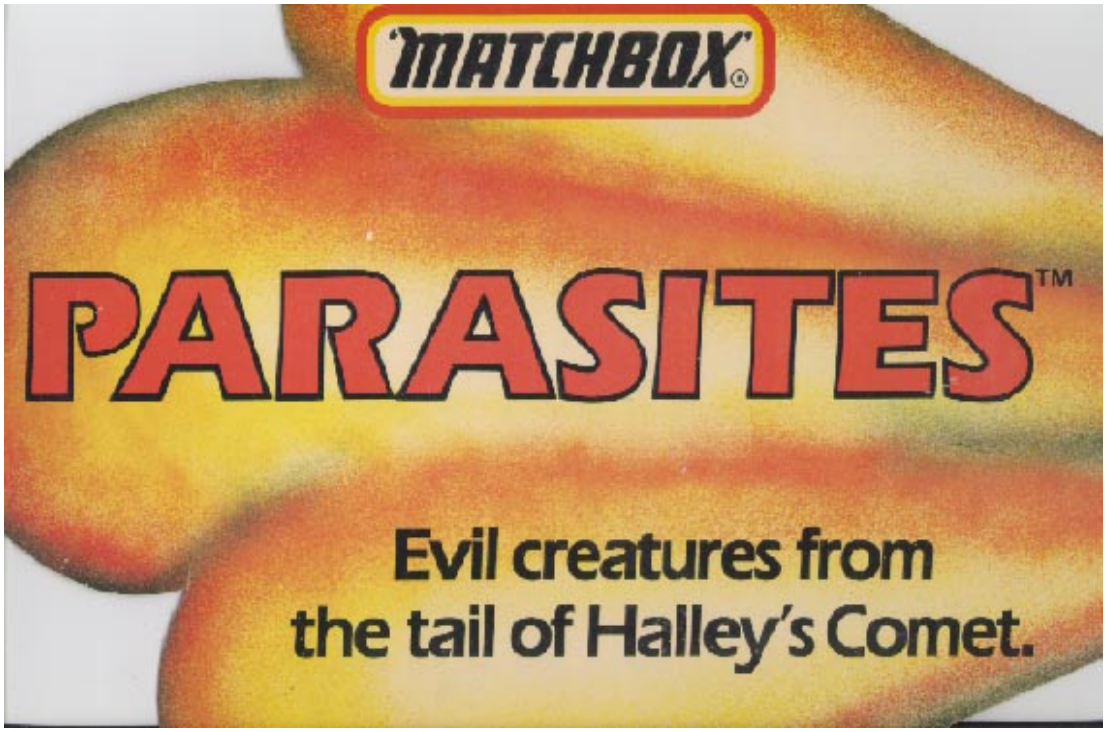
Suborder: Nematocera (small midges/mosquitoes, long filamentous segmented antennae (= nemato-cera), aquatic life-cycles (larval/pupal stages associated with water), female adults require blood meal before they can lay eggs)
Family: Culicidae (mosquitoes, elongate mouthparts form proboscis, slender wings with scales on veins/margins)
Subfamily: Culicinae (scutellum with trilobed posterior margin, scaly abdomen, larva with prominent air-tube)
Culex, Aedes, Mansonia mammals/birds, skin, direct
Subfamily: Anophelinae (scutellum rounded or straight, addominal sternites lack scales, larva lacks air-tube)
Anopheles mammals/birds, skin, direct
Family: Ceratopogonidae (small biting midges/sand flies, narrow spotted wings, maritime species associated with mangroves/swamps; native species associated with freshwater; introduced species associated with dung)
Culicoides (incl. *Lasiohelea*) mammals/birds, skin, direct
Family: Simuliidae (small black flies/buffalo gnats, characteristic humped backs, wings not patterned or hairy)
Simulium, Austrosimulium mammals/birds, skin, direct
Family: Psychodidae (moth flies/sand flies, incl. phlebotomines, characteristically hairy bodies and wings)
Phlebotomus/Sergentomyia/Lutzomyia mammals/birds, skin, direct

Suborder: Brachycera (large tabanid/March flies, with stout and fewer antennal segments (= brachy-cera), antennae often with aristae, females with slashing-sponging mouthparts to pierce skin and feed on pool of blood (telmophagy))

Infraorder: Tabanomorpha (larval head capsule incomplete posteriorly (only anteruior parts sclerotized))
Family: Tabanidae (large stout horse/deer/March flies, often brightly coloured, painful bite, daytime feeders)
Chrysops, Tabanus mammals, skin, direct

Infraorder: Muscomorpha **(**Cyclorrhapha) (small-medium sized flies, sponging/biting mouthparts, cyclorrhaphous (circular-seamed) pupa, larva lacks sclerotized head capsule, short pendulous antennae composed of 3 segments usually with feather-like arista, some cause larval myiases)
Division: Schizophora (head with frontal suture (lunule))
Section: Calyptratae (calypters cover halteres)
Family: Glossinidae (tsetse flies, biting mouthparts, characteristic proboscis bulb, both sexes blood-feeders)
Glossina mammals, skin, direct
Family: Hippoboscidae (flat/louse flies, leathery abdomen, piercing mouthparts, strong claws on feet)
Melophagus sheep, skin/fleece, direct
Hippobosca mammals, skin, direct
Family: Muscidae (house/bush/stable/buffalo flies, nuisance flies, synanthropic (associated with human activity))
Subfamily: Muscinae (with sucking mouthparts adapted to feeding on decaying organic matter)
Musca mammals, nonparasitic
Subfamily: Stomoxinae (with elongate biting mouthparts adapted to blood feeding)
Stomoxys mammals, skin, direct
Haematobia (= *Lyperosia*) bovines, skin, direct

Family: Calliphoridae (blow flies, often metallic, larvae cause myiases (flystrike/screw-worm infestation))
Lucilia (primary), *Calliphora* (secondary) mammals, skin/subcutaneous tissues, direct
Cochliomyia (primary screw-worm) *Chrysomya* (Old World screw-worm, primary/secondary)) mammals, skin/subcutaneous tissues, direct
Cordylobia (tumbu fly) mammals, skin/subcutaneous tissues, direct
Family: Sarcophagidae (flesh flies, not metallic, breed in excrement/carrion/decomposing organic matter)
Sarcophaga mammals, skin/subcutaneous tissues, direct
Wohlfahrtia mammals, skin/subcutaneous tissues, direct
Family: Oestridae (large hairy bot flies, third larval stage or bot resemble small sausages, larvae cause myiases)
Subfamily: Cuterebrinae (skin bot flies)
Dermatobia cattle/humans, skin, direct
Subfamily: Oestrinae (head maggots)
Oestrus sheep, nasal sinuses, direct
Subfamily: Hypodermatinae (cattle grubs, ox warbles, heel flies)
Hypoderma cattle, subcutaneous tissues, direct
Subfamily: Gasterophilinae (stomach bots)
Gasterophilus equines, stomach, direct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