Parasitism: the Variety of Parasites

Secondary article

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Parasitism is the association of two different animals (species) in which one benefits at the expense of the other and frequently causes serious harm in the process.

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Introduction – Forms of Association Between Animals

There are a variety of forms of association between animals of different species. At one end of the range we have commensalism, in which the partners lead independent lives but, when in association with one another, one or both derive some benefit. An example, well known to viewers of natural history programmes, is the association between the cattle egret and game animals. Game animals invariably are hosts for a number of blood-feeding arthropods, especially ticks, attaching themselves to and burying their mouth parts into the skin. The egrets remove these ectoparasites, thus providing themselves with a meal, and for the buffalo, antelope and other beasts the numbers of these troublesome pests are reduced. At the other end of the range we have an association where only one of the partners (the parasite) benefits and this partner is for most or all of its life dependent on and lives at the expense of the other, the host. This association is parasitism and usually the parasite damages its host, although the damage caused might not always be outwardly visible. In between parasitism and commensalism we have mutualism, the term used to describe partnerships that are obligatory for the well-being of both parties. Termites provide us with an excellent example. The destructive activities of termites on wooden buildings is well known. Less well known is the fact that because their digestion systems do not secrete the enzyme cellulase most termites are not capable of breaking down the cellulose of wood and plant material. The problem is solved by the presence of flagellate protozoa, such as *Trichonympha* (**Figure 1**), in the hindgut of the termite, which do secrete this digestive enzyme and break down the cellulose for the termite. The nutritive breakdown products are then available for both termite and the protozoa. The termites would starve without the protozoa.

When applied to the chosen lifestyle of a fellow human being, we use the term 'parasite' as a derogatory term implying idleness, sloth and cunning. While it is true that there are many parasites causing much suffering, there is much to be admired about parasites. Many are incredibly well adapted to life with and within their host. They often have improbably complicated but nonetheless successful life cycles, which might involve more than one host and within those hosts they may occupy, at different times, different locations.

Parasites in the Animal Kingdom

Within the eukaryotes the animal kingdom is divided broadly into the invertebrates and the vertebrates. Parasitology textbooks confine themselves to the invertebrates because this is where the vast majority of parasitic animals are to be found and this will be the treatment here. Within the vertebrates there are, however, several examples of lifestyles that would satisfy a definition of parasitism. The cuckoos, which lay their eggs in the nests of other birds, would be a good example. On hatching, the nestling cuckoo evicts the host's eggs, leaving it as the sole occupant of the nest, and becomes the charge of its adoptive parents.

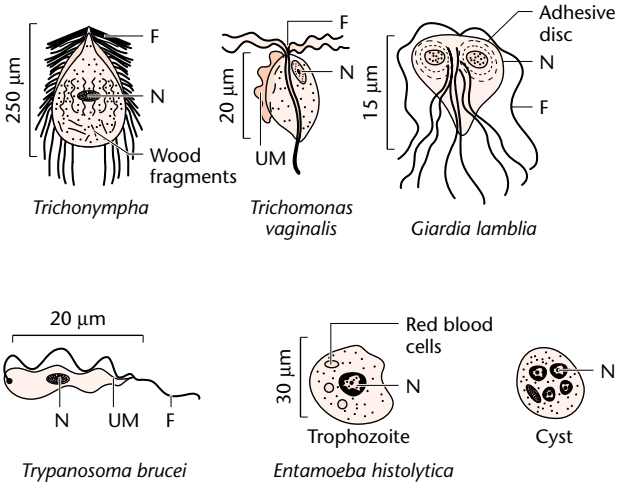

Figure 1 Some examples of parasitic protozoa. *Trichonympha* is found in woodeating termites and digests cellulose in the termite's wood diet; *Trichomonas vaginalis* is found in the human vagina and is transmitted by sexual intercourse; *Giardia* is found in the small intestine and causes diarrhoea; *Trypanosoma brucei* is the tsetse fly transmitted agent of sleeping sickness in humans and the disease is fatal unless treated; *Entamoeba histolytica* can cause amoebic dysentry and in serious cases invades the liver. UM, undulating membrane (for locomotion); N, nucleus; F, flagellum.

The list of parasites is very long. It is stated that humans can be host to more than 300 different kinds of parasitic helminths (worms). Fortunately most of these are rarely if ever pathogenic.

Parasitic protozoa (single-celled animals)

The protozoa are traditionally divided into four principal groups: the amoebae, the flagellates, the ciliates and the sporozoa. It is said that over a quarter of all the protozoa are parasitic, over 10 000 different species. Only a relatively small number are serious parasites of humans and domestic animals, causing morbidity and mortality and loss of productivity. **Table 1** gives a summary of the major parasites in humans.

Amoebae

The amoebae include both parasitic and free-living members, the latter being found in terrestrial, freshwater and marine environments. Typically, amoebae move by pseudopodia (false feet) which are extensions of the cell into which the rest of the animal flows. The parasitic members are mostly parasites of the alimentary tract, dividing into two by binary fission, and most have a resistant stage or cyst. The cyst allows survival outside the host for a period, which facilitates passage to another host. Transmission is by the so-called faecal–oral route, i.e. the contamination of food or drink by faeces containing the cysts of the parasitic amoebae. Of the half dozen or so parasitic amoebae of humans, only one, *Entamoeba histolytica*, which causes amoebic dysentery, is a serious pathogen. It is found all over the world but clinical disease is most prevalent in the tropics and subtropics. During the trophozoite (feeding) stage, the amoeba multiplies in the lower small intestine and the colon. In some infections, the amoeba invades the lining and the wall (mucosa and submucosa) of the bowel to form an ulcer, which can cause perforation of the bowel wall. In damaging the intestine wall, trophozoites enter the bloodstream and can be carried to secondary sites, particularly the liver and the lungs, where abscesses form and severe damage ensues. David Livingstone is thought to have died in 1873 of amoebiasis (Bray, 1996).

Flagellates

The flagellates move about using one or more paddle-like structures, the flagellum/a. This group of protozoa includes both free-living and parasitic members. The parasitic forms occupy a variety of habitats: the genitourinary tract in the case of the human parasite *Trichomonas vaginalis* (**Figure 1**), the gut in the case of *Giardia* (**Figure 1**), the vertebrate bloodstream in the case of the trypanosomes and in host cells in the case of *Leishmania* spp. The African trypanosomes, *Trypanosoma brucei* subspp. (**Figure 1**), cause sleeping sickness in humans and 'nagana' in large domestic stock and are passed from host to host by the blood-sucking tsetse fly. The descriptor 'sleeping sickness' derives from the fact that in the later stages of the disease the parasites penetrate the blood–brain barrier and subsequent damage to the brain causes the patient to become lethargic and eventually comatose. South American trypanosomiasis, caused by *Trypanosoma cruzi*, is transmitted by the triatomid kissing bug, which is so-called because it feeds on the lips of its victims while they sleep. *Leishmania* spp. are also transmitted by an arthropod vector, the sandfly, and multiply within the mammalian host in macrophages (phagocytic cells in the body's defence system). The trypanosomes and leishmanias cause considerable morbidity and mortality in the tropics. Control is complicated because, for a number of them, the parasites have reservoirs of infection in wild animals from which the vectors can become infected and subsequently infect people.

Ciliates

The ciliates, which move via a multitude of small hairs on their surface called cilia, contain very few important parasitic forms and can be left out of this review.

Sporozoa

All sporozoa are parasitic and include the most important parasites that attack humans, the malaria parasites. They lack any obvious means of locomotion but some life-cycle stages are motile. They frequently have complicated life cycles, typified by the malaria parasites where there is a sexual cycle in a vector, the female mosquito, and phases of multiplication in the mammalian host involving more than one cell type. In humans, multiplication occurs in the liver and the red blood cells.

All the clinical illness caused by malaria is a consequence of the parasite multiplying in and destroying the red blood cells of the host. Close relatives to malaria parasites are the piroplasms, *Babesia* spp. and *Theileria* spp., which are transmitted by ticks. These are very important veterinary parasites, predominantly in cattle. Other important veterinary sporozoa are the coccidia, *Eimeria* spp., which are responsible for serious losses in the poultry industry. *Eimeria* multiply in the lining of the intestine and after a sexual stage produce resistant cysts which are released in the host's faeces. Another coccidian is *Toxoplasma gondii*, a ubiquitous intracellular parasite of mammals (including humans) and birds. In the UK about one-third of adults are infected with *T. gondii*. In the majority, it is an inapparent and asymptomatic infection because the immune system controls an infection before symptoms occur, although the parasite is not eliminated. If the immune system is subsequently compromised, for example by human immunodeficiency virus (HIV) infection, the parasite can multiply to reach life-threatening numbers. A number of parasitic infections including *T. gondii* and a near relative

Table 1 Important parasites of humans

	Parasite		Life cycle	Vector, intermediate host	Distribution
	Genus	Common name or disease			
Protozoa	*Trypanosoma cruzi*	South American trypanosomiasis/Chagas' disease	Indirect	Triatomid bugs	Central and South America
	Trypanosoma brucei gambiense	Trypanosomes/sleeping sickness	Indirect	Tsetse fly	West Africa
	T.b. rhodesiense	Sleeping sickness	Indirect	Tsetse fly	East Africa
	Leishmania spp.	Cutaneous and visceral leishmaniasis (many local names)	Indirect	Sand fly	Tropics and warm temperate areas
	Giardia spp.	Giardiasis	Direct	–	Worldwide
	Entamoeba histolytica	Amoebic dysentery	Direct	–	Worldwide
	Plasmodium spp.	Malaria	Indirect	Female *Anopheles* mosquito	Subtropics and tropics
	Toxoplasma	Toxoplasmosis	Direct and indirect	Cat – definitive host. Mammals and birds – intermediate hosts	Worldwide
Platyhelminths	*Schistosoma* spp.	Schistosomiasis (bilharzia)	Indirect	Snails	Africa, South America, Middle East, China, SE Asia
	Taenia spp.	Tapeworms/taeniasis	Indirect	Cattle, pigs	Worldwide
	Echinococcus	Tapeworm/hydatid disease	Indirect	Dog – definitive host. Humans – an unusual intermediate host	Worldwide
	Diphyllobothrium	Broad fish tapeworm	Indirect	Fish-eating mammals – definitive hosts. Copepods and fish – intermediate hosts	Worldwide

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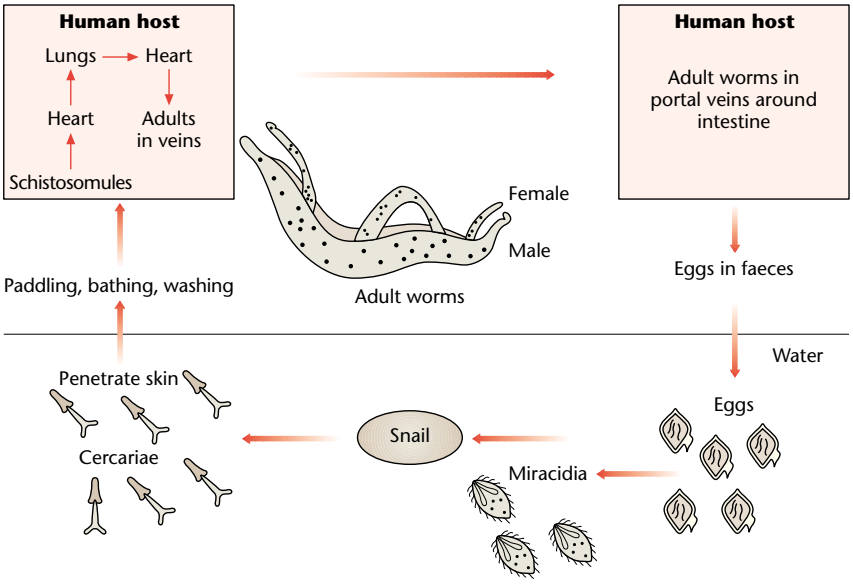

Figure 2 Life cycle of the blood fluke *Schistosoma mansoni* which causes bilharzia. The fluke has two hosts – humans and a freshwater snail. Humans become infected when in water containing the infective cercariae, which are released from the infected snail. The adult worms live in the veins around the gut and the eggs are released in the faeces of the infected individuals.

Cryptosporidium spp., that are of no danger to healthy people, can kill AIDS (acquired immunodeficiency syndrome) patients (Kasper and Buzoni-Gatel, 1998).

Parasitic worms

The helminths or worm-like parasites are metazoan organisms (multicellular) and are contained in three taxonomic units or phyla. These are the flatworms or Platyhelminthes, the roundworms or Nematoda, and the spiny-headed worms or Acanthocephala. The latter are exclusively parasitic while the former groups include both free-living and parasitic forms. Some helminth infections cause major infectious diseases of humans, such as schistosomiasis (bilharzia).

Platyhelminthes

There are three main classes of Platyhelminthes: the Monogenea, the Digenea and the Cestoda. These animals are relatively simple in their structure, being dorsoventrally flattened and lacking a body cavity. The monogeneans are predominantly leaf-like ectoparasites on the skin or gills of fish; *Gyrodactylus* is a serious pest on young fish in commercial fish farms.

The digeneans, the flukes, are endoparasites and found in all vertebrates and in a variety of organs but predominantly in the gut or in 'offshoots' of the gut such as the bile ducts and lungs. The life cycles are complex and involve alternate asexual and sexual reproductive phases, in snail and vertebrate hosts respectively. Sexual reproduction results in eggs, which are released most frequently in faeces. Free-swimming ciliated forms (miracidia) hatch from the eggs and seek a snail host in which there is asexual multiplication through sporocyst and redia stages. The final product of multiplication is the cercaria, a tailed, actively swimming form which infects the final host, in some cases passing through a resistant (metacercaria) stage. A single miracidium may give rise to more than a thousand cercariae in the snail. Of the 6000 or more species of digeneans only a handful are of medical or veterinary importance. Four species of *Schistosoma* infect humans and cause over 200 million cases in the world of schistosomiasis (bilharzia), causing considerable morbidity and mortality (see **Figure 2**) (World Health Organization, 1993). The adult worms are located in the veins around the bladder or the intestine, depending on the species. The worm's eggs cause the pathology. Another digenean, the liver fluke, *Fasciola hepatica*, is an important veterinary parasite in cattle and sheep, occasionally infecting humans.

The Cestoda, the tapeworms, are very specialized flatworms, possessing no gut and typically having very long bodies made up of a string of units, proglottids, each containing a set of male and female reproductive organs. The adults are normally to be found in the gut or gut-associated ducts of the vertebrate host. Nutrients are absorbed through the body surface. Tapeworm life cycles are complex, involving larval stages in one or more intermediate hosts. Human disease caused by cestodes, cestodiasis, can be divided roughly into two kinds: disease caused by the larval cestodes locating in a variety of sites

such as the liver, the brain and the lungs, and disease caused by the adult worms.

Nematodes

The nematodes are roundworms, with a gut and a body cavity known as a pseudocoelom, which is filled with fluid under pressure. This gives the animal a hydrostatic skeleton. The group includes free-living and parasitic members, ranging in size from less than a millimetre to several metres in length, and occupying a wide range of habitats from beer mats to the ice of the Antarctic (Matthews, 1998). The life cycle of the nematodes is relatively simple: the adult female releases eggs that hatch to give the first-stage larva. These feed and grow and pass through three more larval stages before attaining sexual maturity. Nematodes cause important diseases in humans. For example, they are the most important intestinal parasites of humans, and the insect-transmitted filarial nematodes can cause blindness and serious deformity depending on the species. *Ascaris lumbricoides*, the large intestinal roundworm of humans, infects about 25% of the world's population (Crompton, 1989).

Arthropods

The final group of animals to be mentioned is the Arthropoda, which includes the insects. There are more species of insects than all other animals put together. The Crustacea, largely aquatic, are familiar as the crabs, lobsters and woodlice, but many of the crustacean classes include parasitic members such as copepods, amphipods and barnacles. The adult parasitic barnacle, for example, looks very unlike its free-living relatives, its sac-like body ramifying through the body of the shore crab. The class Arachnida is familiar to us as free-living spiders and scorpions but also includes the important parasitic mites and ticks, which are not only important through the nuisance they might cause through sucking blood but may also be vectors of serious pathogens. The scabies or itch mite, *Sarcoptes scabiei*, causes severe itching and rashes but does not transmit a pathogen. The minute adult mites, the female at 0.45 mm long is slightly larger than the male, burrow through the superficial layers of the skin, feeding on liquids oozing from chewed dermal cells. Blood-feeding ticks can cause anaemia, and toxins in their salivary secretions can cause paralysis but their principal challenge to their host's health is through acting as vectors of a variety of pathogens, arboviruses, bacteria and protozoa. Lyme disease in humans (*Borrelia burgdorferi*) transmitted by ixodid ticks is a particular problem in Europe and North America. Finally, the class Insecta includes a number of groups with parasitic members (e.g. lice, fleas, bugs and flies) which again include a number of important vectors of disease in humans and domestic livestock. Examples follow later in the article.

Where Parasites are Found on/in the Host

Ectoparasites

From the foregoing it is evident that parasites are found in a wide variety of situations. Different ectoparasites can be found in different parts of the skin and use different means of attachment and durations. Some hard ticks, for example, can attach for days at a time taking a blood meal by semi-gluing their mouth parts into position in the skin, especially on the ears and eyelids. Human lice, which also penetrate the skin for a blood meal, are particularly adapted to holding onto and moving through body hair and have a well-defined predilection for a type of hair. The human head louse, *Pediculus capitis*, whose eggs glued to the hair are called nits, prefers the long fine hair of the head, whereas the crab louse, *Pthirus pubis*, is found in the coarser hair of the genital region, and under the arms. Lice and fleas are very sensitive to temperature changes and quickly leave a dead body. The scabies mite, which burrows into the skin, selects areas of the body where the skin is thin, such as between the fingers, the wrists and the penis.

Endoparasites

Endoparasites occupy almost every conceivable situation in their chosen host(s). Many parasitic protozoa are intracellular. The cells parasitized include macrophages by *Toxoplasma gondii* and *Leishmania* spp. (important parasites of humans in the skin, spleen and liver); heart muscle and nerve cells by *Trypanosoma cruzi*; the epithelial lining of the gut by *Eimeria* spp.; and lymphocytes by *Theileria* spp.

Many parasites are associated with the gastrointestinal tract and ducts leading off, from mouth to anus. Some gut helminths are completely buried deep in the lining of the gut such as *Trichinella spiralis*. Others have the major part of their body in the lumen of the gut, such as the pork and beef tapeworms of humans, which can be several metres long. In addition to malaria parasites, the blood also harbours trypanosomes, filarial worms and the schistosomes. The lungs can be the final location for some parasites as well as an important staging post for others. The hookworms of humans, *Ancylostoma* and *Necator*, as adults attach to the mucosa of the upper small intestine and suck blood by slicing off lumps of the mucosa with sharp mouth parts, causing anaemia. The infective larvae lying on the surface of the soil infect people by burrowing through thin skin of the feet and thereafter are carried in the bloodstream via the liver to the lungs. The worms then burrow from the circulatory system into the alveoli and up the trachea to the throat where they are swallowed and eventually reach the small intestine. The lungs are the final

location for the adults of the lungworm of cattle, *Dictyocaulus viviparus*, where the adult females release their eggs. This clever nematode uses a fungus to spread its infective larvae around the pasture and away from the cowpat in which the larvae were deposited. *D. viviparus* is one of a very few parasites for which there is an effective vaccine.

Other sites of parasitization include the skin, the lymphatics, the urino-genital tract, the liver, brain and the placenta. The adults of the nematode *Onchocerca volvulus* occur encapsulated beneath the skin and are visible as nodules. This helminth causes blindness as a result of the microfilariae dying in the eye. Adults of other filarial worms such as *Wuchereria bancrofti* are found in the lymphatic vessels, which can lead to the blockage of these vessels resulting in some spectacular and horrific conditions such as elephantiasis where there is gross enlargement of the legs or scrotum. The flagellate *Tritrichomonas foetus* is a venereal disease transmitted by coitus in cattle and causes abortion. It is very difficult to eliminate the parasite in the bull but it is self-limiting in the cow. The dog tapeworm, *Echinococcus granulosus*, in the adult stage in the small intestine is very small for a tapeworm, only a few millimetres long. Its intermediate stage, in contrast, forms large bladder-like cysts (hydatid cysts), containing hundreds of larval worms, protoscolices, predominantly in the liver, but sometimes in the brain and lungs of the intermediate host, domestic herbivores. Occasionally, with serious consequences, humans become hosts to hydatid cysts by ingesting the tapeworm eggs, which are released in dog faeces. Many of us have antibodies to *Toxoplasma gondii* and are chronically infected with the parasite but cannot relate this infection to any clinical illness. If infection occurs for the first time during pregnancy the outcome can be very serious because the parasite can cross from the mother's bloodstream to infect the placenta and eventually the developing foetus. Stillbirths and abortion can occur and when the pregnancy proceeds to term the newborn can suffer hydrocephalus, retinochoroiditis and mental retardation. Toxoplasmosis is a major cause of abortion in sheep in the UK and New Zealand but a vaccine is now available for ewes.

Macroparasites and Microparasites

In some textbooks, large parasites that do not multiply in or on a host, are referred to as macroparasites. We refer to a number of these, such as adult flukes, tapeworms, most of the nematodes and arthropods, such as fleas and ticks. Small parasites that multiply in their host, such as malaria parasites, are referred to as microparasites. In some texts the latter includes bacteria and viruses, which are not discussed in this article.

Control of Parasites

Epidemiology is the study of the distribution of disease through a population and the factors that determine this distribution. It is a very important subject in the world today both in the context of human and veterinary diseases and also diseases of crops. An understanding of the biology of a parasite and the epidemiology of that parasite are essential for the planning and implementation of strategies to control and possibly eliminate the parasite. Achieving the latter is not necessarily wishful thinking. The adult female of the guinea worm, *Dracunculus medinensis*, which is one of the largest nematode worms, lives in the subcutaneous tissues and releases larvae through a blister in the skin when the infected person enters water. The larvae are picked up by a free-swimming crustacean, *Cyclops* and infect people if water containing the intermediate host is drunk. It is known that the adult worm is relatively short lived and therefore measures to provide safe drinking water by preventing infected individuals having contact with potential drinking water and/or treating water before making it available for human consumption, should reduce the incidence of the worm. The World Health Organization (WHO), in 1991, set itself a target of eliminating this worm by the end of 1995, and although this target was not met the prevalence had been markedly reduced and the prospects for elimination remain good.

There are a number of factors and rate-determining processes that can regulate the transmission of parasites between hosts and the passage of parasites through complex life cycles. The average number of new infections that arise from one infected individual introduced into a host population in which there are at least some individuals which are susceptible, is called the basic reproductive rate, denoted by R. In planning, executing and evaluating control programmes for parasitic infections it is necessary to measure R before, during and after the control programmes. As a generalization, parasites with high R values will be much more difficult to control than those with low R values. The population dynamics of parasites under a variety of situations can be described in mathematical models: interested readers are directed to the work of Anderson and colleagues for further exploration of this area.

Concluding Remarks

This chapter has introduced the rich variety of parasites and parasitic ways of life in the animal kingdom. It has indicated that parasitic life cycles can be complex, often involving more than one host. Many parasites and their hosts live together in relative harmony; the host's life expectancy may not be significantly shortened and

pathology caused is minimal. This state of affairs is usually indicative that host and parasite have been together for a long time, in evolutionary terms. Many parasites, however, are major threats to the health of their hosts, and these include parasites of humans and their domestic stock. For example, malaria remains the most important parasitic disease of humans. It kills 2–3 million people each year, the majority of whom are children under 5 in Africa (Phillips, 2001). There are no vaccines currently available against any parasites of humans and very few against parasites of domestic stock. Equally there is a major need for new or better drugs to control many parasites, not least malaria parasites, because of the problems of drug resistance. Regrettably the people most in need of these drugs are those in the world least able to pay. Hence there is little incentive for pharmaceutical companies to develop these drugs and vaccines. A reduction in the impact of many serious parasites of humans may not be seen, therefore, in the near future.

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