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An Introduction to Parasitology

Second Edition

R. Alan Wilson

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General Preface to the Series

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Preface to the Second Edition

In this short book I have given a personal view of those aspects of parasitology in which there is currently a lively research interest. Since the publication of the first edition there have been some notable shifts of emphasis within parasitology. Studies on the immunology of parasite infections have increased, with the production of anti-parasite vaccines as their ultimate, if elusive, goal. In parasite epidemiology there is now a concerted effort to place the understanding of transmission dynamics on a quantitative base.

In the choice of topics and the examples with which they are illustrated, I have necessarily been selective. There is a bias towards parasites of medical or veterinary importance with a consequent neglect of countless other interesting associations.

Animal parasitology has recently received a considerable impetus from the designation by the World Health Organisation of six major tropical diseases as targets for research. Five of these, malaria, trypanosomiasis, leishmaniasis, schistosomiasis and filariasis fall within the scope of this book.

I would like to thank the authors whose illustrations are acknowledged in the various figures. I am also indebted to my wife, Margaret, for checking the text, and to many others who have assisted in various ways.

York, 1978

R.A.W.

Contents

1 What is a Parasite?

Parasitism is just one among many types of association between two organisms and there is no single feature which can be used to label an animal indubitably as a parasite. We must therefore examine the phenomenon from several viewpoints if we are to form a coherent picture.

The parasite obtains food at the expense of its host by consuming either host tissues and fluids, or the contents of the host intestine. The relationship of parasite to host therefore has a nutritional basis. How then do we distinguish between parasitism and other ways of acquiring food, such as predation or scavenging? An obvious answer is to regard parasitism as a special form of predation in which the host is not killed in providing the parasite with a meal. However, many small animals such as blood-sucking insects feed on larger animals without killing them. Are mosquitoes or fleas to be considered as parasites or predators? The criterion for deciding is clearly the length of time which the feeding animal remains with the host. Most parasitologists would agree that the stay must be a significant length of time, certainly more than the few seconds for which a biting fly feeds: they would disagree about the minimum duration of stay needed to qualify the feeder as a parasite.

It is necessary to distinguish still further between parasitism and other nutritional associations such as commensalism and symbiosis, in which the associates remain together for long periods. If the association results in mutual benefit to the participants then clearly it cannot be classed as parasitism. Conversely, if one of the associates harms the other then we must consider it to be a parasite. The problem is that it has proved impossible to demonstrate that many so-called parasites harm the host in any way.

Finally, we need to consider a unique property of the environment provided for the parasite by the host. The parasite may be recognized as a foreign invader against which the host can mount an immune response. A measure of a parasite's success is its ability to evade this response which is aimed at its elimination.

The animals dealt with in this book almost invariably cause disease in their hosts and in practice, the reader will have no difficulty in identifying them unequivocally as parasites. The fact that a parasite causes disease has often been considered a measure of its poor adaptation, but that is to take an oversimplified view of the nature of parasitism. It is now apparent that some parasites are important natural regulators of host populations. The excellent adaptation of parasites can equally well be measured by the limited success of schemes aimed at their control and eradication.

2 Life Cycles

2.1 The scope of parasitology

In the broadest sense, parasitology is the study of those organisms which spend all or part of their lives as parasites in or on other organisms. In practice it has a more restricted usage principally covering the study of parasitic Protozoa, Platyhelminthes and Nematoda. These three groups contain the majority of parasites of medical and veterinary importance which form the subject matter of this book. Other invertebrate groups with significant parasites include acanthocephalans, leeches, ticks, crustacea and insects. For a wider view of these the reader should consult the general references listed at the end of the book.

From another standpoint, parasitology can be viewed as a microcosm of biology embracing subjects as disparate as molecular biochemisty and the mathematics of population processes. In this chapter the reader is introduced to the parasites with their intricate life cycles. Subsequent chapters deal with some of the major areas on which research interest is currently focused.

2.2 Protozoa

The phylum Protozoa contains several thousand parasitic species. Members of two groups, the Sarcomastigophora (amoebae and flagellates) and the Sporozoa (coccidia and malaria) are described here. The parasitic Protozoa are unicellular and some are so small that their structure is hard to resolve by light microscopy. However, the application of electron microscopy has revealed that these minute scraps of protoplasm have a complex and hitherto unsuspected ultrastructure.

2.2.1 *Parasitic amoebae*

A number of genera of amoebae are parasitic in various parts of the alimentary tract of vertebrates and invertebrates. There are several non-pathogenic species in man together with one important pathogen *Entamoeba histolytica*, found in the colon. The trophozoite, the feeding stage, has a typical amoeboid form using pseudopodia for movement and phagocytosis. In the lumen of the colon it feeds on bacteria and cell debris, multiplying by binary fission. For unknown reasons, these lumen-dwelling trophozoites may become pathogenic. They invade the mucosa of the colon, feed on blood and tissues, and produce ulcers. In a proportion of infections, trophozoites are carried in hepatic portal blood

to the liver and become established there forming liver abscesses. These abscesses may enlarge due to the activities of amoebae at the periphery, destroying liver tissue. From the liver the amoebae can spread to adjacent organs, particularly the lungs and pleural cavity.

The trophozoites dwelling in the lumen of the intestine are capable of forming resistant cysts which pass out with the faeces. Infection of another host results from ingestion of these cysts.

2.2.2 *Parasitic flagellates*

There are two main groups of parasitic flagellates: one group is found in the alimentary and genital tracts, and the other in the tissues and blood stream of vertebrates. The lumen-dwellers include *Trichomonas*, *Giardia* and *Histomonas*. Members of the genus *Trichomonas* have simple life cycles with transmission of the unprotected trophozoite by direct contact. *Giardia* causes a form of dysentery in man and, like parasitic amoebae, is transmitted by resistant cysts. *Histomonas*, parasitic in the caecum of turkeys and other gallinaceous birds, has an unusual mode of transmission. The trophozoites invade the tissues of another gut parasite, the nematode *Heterakis* and are passed on to a new host in its eggs.

The tissue and blood-dwelling flagellates are often referred to as haemoflagellates. Because the site of infection is enclosed, transmission to a new vertebrate host is by means of an intermediate host or vector, usually a blood-feeding insect. The haemoflagellates are thought to have evolved from genera similar to *Leptomonas*, parasitic in the intestine of insects. The trophozoites of the haemoflagellates are polymorphic, the different forms being termed amastigote, promastigote, epimastigote and trypomastigote according to the positions of the kinetoplast (a prominent cellular feature) and flagellum, relative to the nucleus (see Figs 2–1 and 2–2). The trypomastigote of *Trypanosoma* (Fig. 2–1) has an elongate body to which a single flagellum is attached by an undulating membrane, and it swims through the blood with a rapid jerking motion. The flagellum inserts at one end of the cell near the kinetoplast, a specialized region of the single elongate mitochondrion, distinguished by the presence of cytoplasmic DNA. The trypomastigote has a cytostome which may ingest material by pinocytosis. The exterior of the cell is covered by a glycoprotein coat. It is unlikely that sexual reproduction occurs in haemoflagellates and multiplication is by binary fission.

Members of the genus *Trypanosoma* are important parasites of man and his livestock. There are two groups divided according to their mode of transmission by the insect vector: the stercoraria are transmitted via the faeces and the salivaria via the salivary glands.

The life cycle of *T. cruzi*, a parasite of man in South and Central America causing Chagas' disease, is illustrated in Fig. 2–2. Chagas' disease is a zoonosis, i.e. a disease with a large number of wild mammals

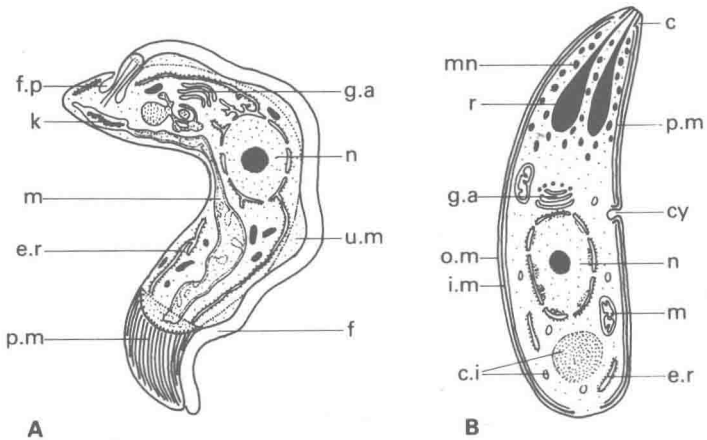

Fig. 2–1 Body form of protozoans. (A) The trypomastigote of *Trypanosoma congolense* (after VICKERMAN K., (1969). *J. Protozool.*, 16, 54–69). (B) A generalized sporozoite/merozoite, typical of the genera *Eimeria* and *Plasmodium*. c – conoid, c.i – cytoplasmic inclusions, cy – cytosome, e.r – endoplasmic reticulum, f – flagellum, f.p – flagellar pocket, g.a – golgi apparatus, i.m – inner membrane, k – kinetoplast, m – mitochondrion, mn – micronemes, n – nucleus, o. m – outer membrane, p.m – pellicular microtubules, r – rhoptries, u. m – undulating membrane.

acting as reservoir hosts. The vectors are blood-feeding bugs. Infection of man results when faeces containing metacyclic (between cycles) forms contaminate the bite wound or are transferred to the mucous membranes of the mouth. Multiplication of the amastigote results in the appearance of sac-like pseudocysts, particularly in cardiac muscle. The pseudocysts burst, releasing trypomastigotes into the bloodstream. Reinvasion of tissue or ingestion by the vector may occur. There is further multiplication in the vector and the infective metacyclic forms develop in its hind-gut.

There are numerous pathogenic species of salivarian trypanosomes in Africa. *T. brucei*, *T. vivax* and *T. congolense* attack cattle. *T. rhodesiense* and *T. gambiense* are the cause of sleeping sickness in man. (*T. rhodesiense* is another example of a widespread zoonosis.) The insect intermediate hosts are tsetse flies of the genus *Glossina*. Metacyclic trypanosomes are found in the salivary glands of the fly, and infection of man results from the direct inoculation of these forms into the skin when it feeds. In the bloodstream, the trypomastigotes develop into three forms: slender, intermediate and stumpy. The slender forms multiply most frequently; the stumpy are infective to the tsetse fly host. In the fly mid-gut the trypomastigotes multiply and eventually migrate forward to enter the salivary glands. Here they assume the epimastigote form and undergo further multiplication giving rise to the infective metacyclic trypanosomes.

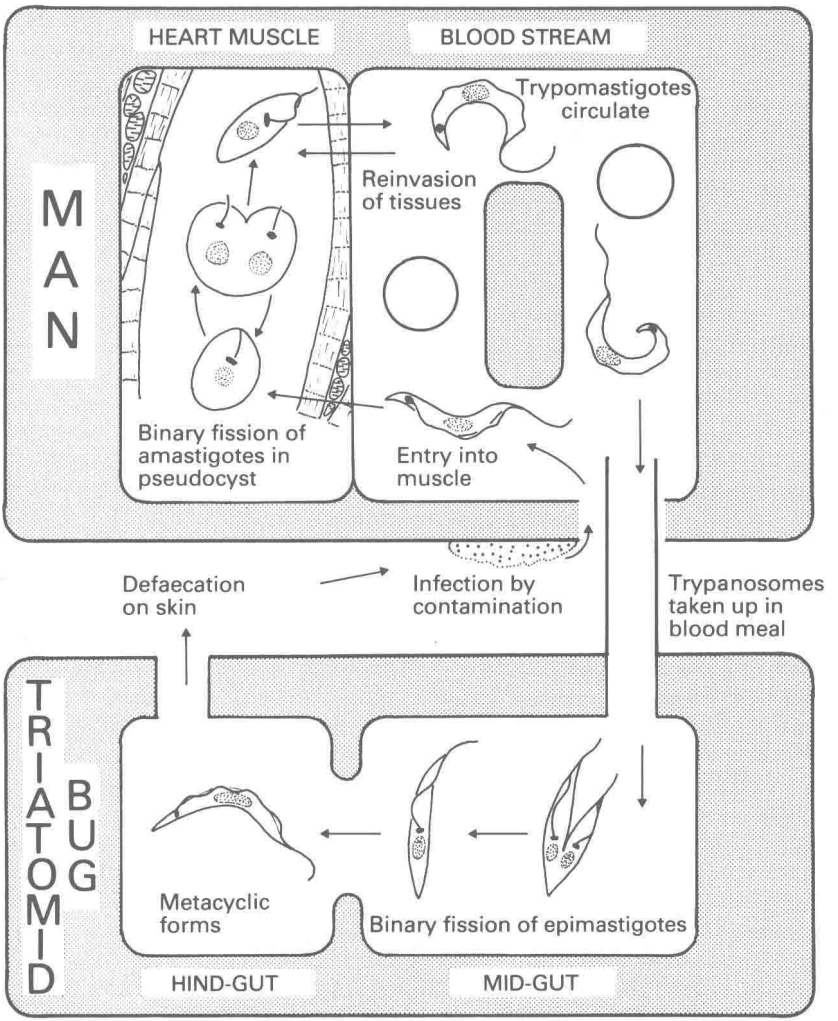

Fig. 2–2 The life cycle of *Trypanosoma cruzi*.

Members of the genus *Leishmania* are another group of haemoflagellates which parasitize man. They are transmitted by female sandflies of the genera *Phlebotomus* and *Lutzomyia*. The amastigote form invades macrophages of the reticulo-endothelial system of man. The amastigotes multiply and are released when the cells burst. They may then invade neighbouring macrophages producing a spreading lesion (see Chapter 7). The sandfly becomes infected when it takes a blood meal and multiplication of the parasite in the promastigote form occurs in the mid-

gut. From here the promastigotes pass to the pharynx and proboscis and are inoculated into a new host when the fly takes its next meal.

The different leishmanias are distinguished by their antigenic structure, rather than by morphological criteria, and several species groups are recognized. *L. tropica* occurs principally in the Middle East and causes a disease of the skin called Oriental Sore. *L. braziliensis* occurs in South and Central America and attacks the skin and the mucous membranes of the mouth, nose, etc. *L. donovani* occurs in Southern Europe, Africa and Asia and causes visceral leishmaniasis or Kala-azar. In this disease the parasite spreads rapidly to the macrophages of the spleen, liver and other internal organs. All leishmaniases are zoonoses with a range of mammal reservoir hosts.

2.1.3 Sporozoa

The Sporozoa are a numerous and exclusively parasitic group of Protozoa. They are thought to have originated as extracellular intestinal parasites of invertebrates, transmitted by resistant cysts. Some species presumably became parasitic in intestinal tissues, but retained transmission via cysts in the faeces. Eventually parasites of the bloodstream evolved and acquired insect vectors.

The Coccidia are intracellular parasites of the alimentary tract. Species of the genus *Eimeria* are responsible for the disease coccidiosis in poultry, and also infect other farm livestock. The life cycle of *Eimeria* is direct with transmission by means of sporozoites (Fig. 2–1) enclosed within a protective oocyst. The sporozoites are released into the lumen of the intestine when the oocyst is ingested by the host. They penetrate single epithelial cells and multiply by a process of schizogony in which the nucleus of the parasite divides several times but its cytoplasm remains intact. The daughter nuclei migrate into outgrowths at the periphery of the schizont and differentiation into merozoites occurs. These escape to the gut lumen and invade further epithelial cells to repeat the schizogony. In this manner, the entire intestinal epithelium may be destroyed, resulting in death of the host. Schizogony is followed by sexual reproduction. merozoites enter intestinal cells and develop into either microgametocytes or macrogametocytes. Motile microgametes are formed and escape into the intestinal lumen. They then fuse with the much larger macrogametes to form a zygote. The zygote secretes a protective coat to become the oocyst and is passed out in the faeces. The final phase of development, sporogony, takes place outside the host, resulting in the formation of eight sporozoites within the oocyst.

Another widely distributed protozoan, *Toxoplasma gondii*, is now recognized as a coccidian. The trophozoites, contained in cysts up to 0.1 mm in diameter, have been identified in the tissues of many mammals and birds. In some regions of the world up to 90% of the human population may be infected. The infection is usually asymptomatic but in

situations where resistance is lowered, the trophozoites may proliferate rapidly, causing death. *Toxoplasma* can also be transmitted congenitally to the foetus if contracted during early pregnancy and the foetus may be damaged or aborted. In 1969 it was demonstrated that *Toxoplasma* can behave like a typical coccidian with cycles of schizogony and gamete formation in the small intestine of the cat. Oocysts are passed in the faeces, and when sporulated are remarkably similar to those of the coccidian genus *Isospora*. Two routes of infection are therefore possible in man: ingestion of the tissue cysts containing trophozoites, or ingestion of oocysts acquired from cat faeces.

The blood-dwelling Sporozoa include the genus *Plasmodium*, four species of which (*P. vivax*, *P. ovale*, *P. malariae* and *P. falciparum*) cause malaria in man. Although eradication programmes have been undertaken on a huge scale for more than twenty years, malaria is still arguably the most important transmissible human disease. The vectors are female mosquitoes of the genus *Anopheles* and the life cycle of *P. falciparum* is illustrated in Fig. 2–3. Man becomes infected when sporozoites are inoculated into the bloodstream in the saliva of a feeding mosquito. The first cycle of schizogony takes place in the liver parenchyma. The resulting merozoites then enter erythrocytes and further cycles of schizogony occur, producing a rapid rise in parasitaemia (the number of parasites detectable in the blood). Eventually gametogony takes place in the erythrocytes and the circulating gametocytes are taken up by the mosquito when it feeds. The gametes develop rapidly in the mid-gut of the mosquito. The motile microgamete locates and fuses with a macrogamete to form a zygote, which then penetrates the mid-gut epithelium. Sporogony takes place in large oocysts which lie on the outside of the mid-gut wall. Sporozoites infective to man are released into the body cavity when these oocysts rupture, and eventually enter the insect's salivary glands.

Two other blood-dwelling haemosporidia which infect cattle, deserve a mention. These are *Babesia bigemina* with worldwide distribution causing red-water fever, and *Theileria parva* in East Africa causing East Coast fever. Both parasites are transmitted by cattle ticks.

2.3 Platyhelminthes

There are three major groups of parasitic flatworms, the Monogenea, Digenea and Cestoda, whose interrelationships are not clear. The Monogenea were formerly classed with the Digenea as the Trematoda but some authorities now consider that their closest affinities are with the Cestoda. Both monogeneans and digeneans possess a functional alimentary tract, but cestodes have no trace of this organ at any stage in their life cycle. The body surface of a parasitic flatworm (Fig. 2–4) was originally described as being covered with an inert cuticle. It is in fact a

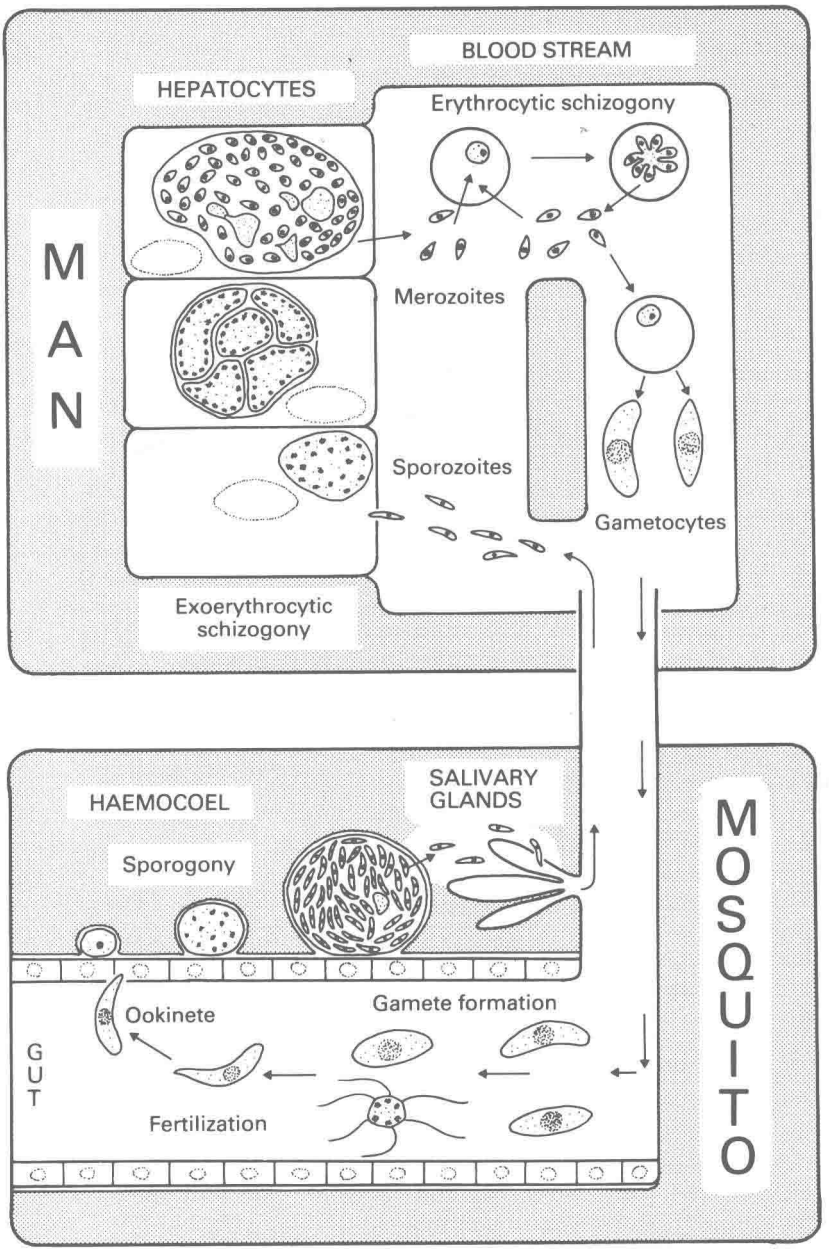

Fig. 2–3 The life cycle of *Plasmodium falciparum*.

syncytial layer of cytoplasm (i.e. without transverse walls) bounded on inner and outer surfaces by a plasmamembrane. It is connected by numerous narrow cytoplasmic tubules to nucleated cell bodies which lie beneath the musculature of the body wall. The layer is termed a tegument to distinguish it from an inert and secreted cuticle such as that of nematodes. The parasitic flatworms are generally hermaphrodite.

The body organization of a typical adult digenean is illustrated in Fig. 2–4. There are generally prominent oral and ventral suckers for

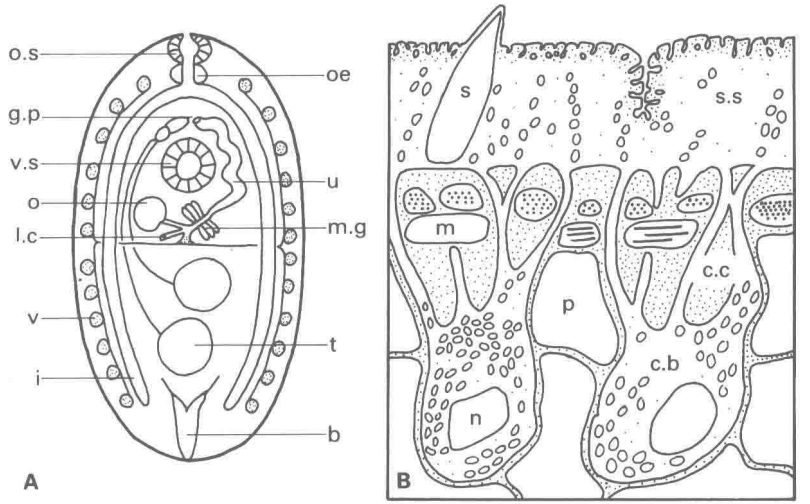

Fig. 2–4 Body form of digenetic flatworms. (A) Diagrammatic plan of the worm. (B) Section through the tegument of *Fasciola hepatica* (after THREADGOLD, L. T., (1963). *Quarterly J. of micr. Sci.*, 104, 502–12). b – bladder, c.b – cell body, c.c – cytoplasmic connections, g.p – genital pore, i – intestine, l.c – Laurer's canal, m – muscle, m.g – Mehlis' gland, n – nucleus, o – ovary, oe – oesophagus, o.s – oral sucker, p – parenchyma, s – spine, s.s – surface syncytium, t – testis, u – uterus, v – vitellaria, v.s – ventral sucker.

attachment to the host tissues. Internal organs include a bifurcated gut, a protonephridial system and separate male and female genitalia. The nervous system is relatively simple, consisting of paired anterior ganglia with connections to the musculature and peripheral sense organs.

2.3.1 Monogenea

These flatworms are chiefly ectoparasites of cold-blooded aquatic vertebrates. The organization of the body is in most aspects similar to that of the Digenea. However, monogeneans attach to the host using a specialized posterior opisthaptor. In skin parasites it takes the form of a simple sucker-like disc with associated hooks. In gill-dwellers there may

be an arrangement of suckers and clamps for attachment to the gill filaments.

The life cycle of monogeneans is direct. The mature worm lays shelled, operculate eggs which are either attached to host tissues or released into the water. A minute ciliated larva, the oncomiracidium, develops and hatches from the egg. If the free-swimming larva locates a host it will attach and grow directly into an adult worm.

Monogenea are not generally pathogenic but in circumstances where host population densities are artificially increased (e.g. fish hatcheries or fish farms) the normal balance between host and parasite populations may be altered. This leads to a much increased parasite burden and mortality in the host fish population.

2.3.2 Digenea

The Digenea have complex life cycles involving two or three hosts and the adult worms parasitize virtually all the organ systems of vertebrates. The first intermediate host is, with few exceptions, a gastropod mollusc. When there is a second intermediate host in the cycle it often features in the diet of the vertebrate final host. Transmission is generally effected by two free-swimming larval stages, and most digenean life cycles are therefore dependant upon water for their completion.

Members of the genus *Schistosoma* are important parasites of man and domestic livestock. The three species which infect man are *S. mansoni* in Central and South America, and Africa; *S. haematobium* in Africa and the Middle East; *S. japonicum* (a zoonosis) in China, Japan and the Philippines. Collectively these three species are second only to malaria in medical importance, with an estimated 150–200 million people currently infected. The schistosomes are unusual in having separate sexes. The adult worms are thread-like, about 1 cm in length, and inhabit the blood vessels of the hepatic portal system. The life cycle of *S. mansoni* is illustrated in Fig. 2–5.

The female worm deposits undeveloped spined eggs in the tissues of the intestine. There the eggs develop and by abrasion of the tissues reach the lumen. They pass out with the faeces and hatch if they enter freshwater. The miracidium is a non-feeding larval stage capable of rapid swimming. It either locates and penetrates through the epidermis of a suitable snail host (various species of the genus *Biomphalaria*) or dies within 24 hours of hatching. Immediately after entering the snail's haemocoel, the miracidium metamorphoses into the sac-like mother sporocyst. This is a feeding stage but, lacking a gut, must acquire nutrients by diffusion or active transport. Within the body of the sporocyst the second generation, consisting of numerous daughter sporocysts, develops by asexual multiplication. The hepato-pancreas of the snail becomes packed with daughter sporocysts, inside which a further phase of asexual multiplication gives rise to the third generation, the cercaria larvae. When

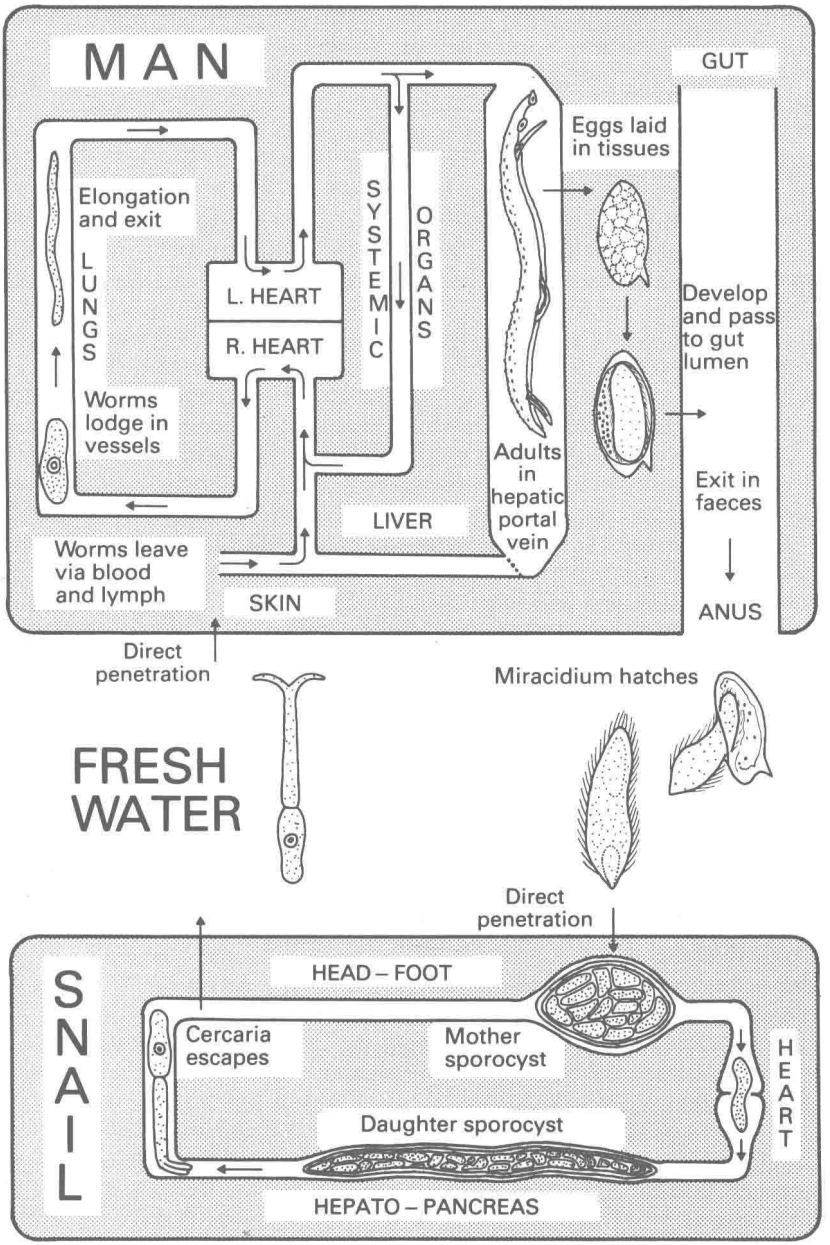

Fig. 2–5 Life cycle of *Schistosoma mansoni*.

these are mature, they leave the daughter sporocyst and migrate via the haemocoel of the snail to the mantle cavity where they escape into freshwater. The cercaria, which possesses a forked tail used for propulsion, is also a non-feeding larva with a brief life.

Man becomes infected by contact with water containing cercariae. The larvae possess special gland cells, the secretions of which enable them to penetrate human skin directly. Within hours of entering the skin, the cercaria completes a metamorphosis into the schistosomulum stage. It remains there for at least 48 hours before migrating to the hepatic portal system. Several routes have been postulated and one, the intravascular route, is illustrated in Fig. 2–5. A schistosomulum might need to make several circuits of the vascular system before arriving by chance at the hepatic portal system. It is then inhibited from further migration and stimulated to mature. After about three weeks the male and female worms pair. The male worm clasps the female in a ventral groove, the gynaecophoric canal, and carries her against the flow of blood to the mesenteric capillaries where she commences to lay eggs.

Because the schistosome life cycle is intimately linked with snails and water, the disease is especially prevalent in areas where irrigation is practised (e.g. the Nile Valley).

The common liver fluke *Fasciola hepatica* parasitizes domestic livestock, and occasionally man, with a world-wide distribution. The leaf-shaped mature worms, up to 3 cm long, live in the bile ducts, feeding on tissue and blood. Eggs pass out with the faeces and develop in freshwater. The free-swimming miracidium infects the mud snail *Lymnaea truncatula* (and other lymnaeids) and metamorphoses into a sporocyst. The second generation larva within the snail is termed a redia. It possesses a sac-like gut and consumes the gonads and hepatopancreas. The redial generation gives rise either to daughter rediae, or to cercariae which exit from the snail. After a brief swimming period the cercaria attaches to vegetation and secretes a resistant cyst. It is now a metacercaria infective to livestock which ingest it when grazing. When the cyst reaches the small intestine, the larva escapes, bores through the intestinal wall and makes its way to the surface of the liver. It then eats its way through the liver tissue to reach the bile ducts. This is the period when the host is most at risk, and death can result from damage caused by the invasion. The fluke also creates the conditions in which the bacterium *Clostridium oedimatiens* infects the liver, causing Black's disease.

Fasciola is particularly common in regions with high rainfall or poor drainage where the prevailing wet conditions favour both the snail and transmission of the parasite.

Dicrocoelium dendriticum is another important liver fluke of grazing animals. In Britain it is restricted to the Hebrides and land snails such as *Helicella itala* serve as the first intermediate host. Livestock become infected when they accidentally ingest metacercariae contained within