Textbook of CLINICAL PARASITOLOGY

DAVID L. BELDING, M.D.
Professor of Bacteriology and Experimental Pathology,
Emeritus, Boston University School of Medicine

SECOND EDITION

APPLETON-CENTURY-CROFTS, INC.
NEW YORK

597-15

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

Clinical Parasitology is designed for medical students, physicians, medical personnel in the armed services, public health officials, laboratory workers, and biologists. It describes the protozoan, helminthic, and arthropod parasites of man and the diagnosis, treatment, and prevention of the diseases that they produce. It differs in presentation from the traditional textbook of parasitology in its extensive use of tables and graphic representations that facilitate study and give ready access to information. The reception accorded the first edition, published in 1942, has shown that this approach meets with the approval of both teachers and students. Therefore, the same scheme of presentation is followed in the second edition, which also includes many helpful suggestions from teachers.

The present edition incorporates rapid and extensive advances in the field of parasitology during and after World War II. New material has been added dealing with amœbiasis, trypanosomiasis, leishmaniasis, malaria, and schistosomiasis. New procedures have been included in the technical section on diagnostic methods; new chemotherapeutic agents have been added to the list of drugs; and a new chapter on insecticides and repellents has been appended. The problem of selection and condensation of material has been met by featuring the common cosmopolitan parasites, by relegating the uncommon or minor parasites to small type and space, by grouping closely allied species, and by tabulating data whenever possible. The writer has considered the subject as a whole, allotting space commensurate with the importance of each parasite, and evaluating divergent views.

The practical needs of workers in the field have dictated the arrangement and selection of subject matter. Special emphasis has been placed upon the pathology, diagnosis, treatment, and prevention of the parasitic diseases. The scope of parasitology extends beyond the intimate knowledge of specialized workers in the varied fields of protozoology, helminthology, and entomology. The writer has approached the subject not as a specialist, but from the broad viewpoint of a biologist with a medical background, who has followed for many years the teaching of parasitology to medical students. The identification of parasites has been simplified and ready access to information has been provided by arranging the more important parasites in tables and keys, by grouping closely allied parasites so that their morphology and pathological activities may be readily compared, and by following a uniform order of presentation so that comparable facts for each parasite may be found under the same headings. Because of their importance in the application of preventive measures, especial attention has been given to the life cycles and modes of transmission of the various parasites.

The arrangement of the illustrations, largely diagrammatic or semidiagrammatic drawings to scale, is designed to give, independent of the text, a complete representation of the morphology and life cycle of each parasite. The diagrams of the life cycles and a few drawings are original, and several unpublished photographs have been used. The other illustrations have been taken or adapted from various sources. Except where specific credit is given, group drawings or those labeled schematic representations have been adapted or compiled from so many sources that it is impractical to give citations.

The text is annotated with references restricted to comparatively recent sources or to such older publications as mark important or historical developments. Several teachers have recommended the replacement of the brief citation of authors' names and dates, which were given as footnotes in the first edition, with specific references to journals. Therefore, such references, corresponding to numbers in the text, are listed alphabetically at the end of each chapter. Adequate references have been given to nearly all topics under each parasite not only to indicate the sources of material, but also to make available to interested readers the original presentations, discussions, and divergent opinions of the various investigators.

The writer wishes to acknowledge the generous help of Dr. Alice T. Marston, Mr. Ferdinand C. Lane, Mr. Francis E. Smith, Mrs. Mildred Pender Clark, and Mrs. Ruth D. Tolman in the preparation of material, and of Miss Martha Henderson, Miss Beulah Merrill, and Mrs. Maura Franceschini in typing and proofreading the manuscript. He is indebted to Mr. W. J. Clench for checking the scientific names of the gastropod mollusks, to Mr. C. E. B. Bernard, Miss Laura Ornstedt, and Miss Rosina Don Dero for the drawings, to Dr. Horace K. Giffen, Dr. A. Bonilla-Naar, Dr. C. Jung-Sun, and Dr. Merrill L. Welcker for original photographs, to Professor C. M. Wenyon for the loan of the beautiful colored drawing of malarial parasites (Plate IV) and to Baillière, Tindall and Cox, publishers of Wenyon's *Protozoology*, for permission to use it; and to various authors for illustrations taken from books and journals. He deeply appreciates the many helpful suggestions of Dr. Donald L. Augustine of the Harvard Medical School, and is obligated to the authors and publishers of Hegner, Root, Augustine and Huff's *Parasitology* for material and illustrations. He is grateful to the many workers in the field of parasitology whose original publications have provided the material for the book and to the publisher, Appleton-Century-Crofts, Inc., for guidance throughout the throes of publication.

DAVID L. BELDING

CONTENTS

Section Five. THE TREMATODA OR FLUKES

Section Six. ARTHROPODA

Section Seven. TECHNICAL METHODS FOR THE DIAGNOSIS AND TREATMENT OF PARASITIC INFECTIONS

Section One
GENERAL PARASITOLOGY

1

PARASITES AND PARASITISM

Parasitology is the science which deals with organisms that take up their abode, temporarily or permanently, on or within other living organisms for the purpose of procuring food. In a broad sense parasitology includes plants such as bacteria and fungi; animals such as protozoa, helminths, and arthropods; and borderline forms such as spirochaetes and ultramicroscopical viruses. In the more restricted sense employed in this textbook the term applies only to animal parasites.

The science of parasitology in relation to disease has been developed by zoologists and medical men. While zoologists have studied the morphology, physiology, and life history of the parasite, physicians have concerned themselves with the reaction of the host to the parasite (symptomatology, pathology, and immunity), and with the treatment of the infected host. The combined efforts of medicine and zoology are continually intensifying the importance of parasitology, particularly in the broad field of disease prevention. The medical aspect is concerned primarily with the parasites of man, but a knowledge of the parasites of other animals sheds light upon human parasitology. When information concerning the human forms is incomplete, studies of closely related species in animals foretell with considerable accuracy the probable development of similar species in man. Likewise, the knowledge derived from the study of the structure, life cycle, and activities of similar free-living forms may provide valuable information concerning the less known parasitic species.

History. Because of their size the large parasitic worms were among the first agents noticed and studied as probable causes of disease. The famous Ebers papyrus, about 1600 B.C., contains some of the earliest records of the presence of pathogenic worms in man. That the Israelites knew something of the relationship of helminths to human ailments, a knowledge doubtless acquired in Egypt, is shown by the laws of the Mosaic Code concerning animal flesh. Persian, Greek and Roman physicians were also familiar with various parasitic worms. Hippocrates and others described methods for the removal of hydatid cysts. The Arabian physician and philosopher, Avicenna (979 to 1037 A.D.) separated helminths into long, small, flat, and round worms.

Modern parasitology dates from 1379 when Jehan de Brie discovered the liver fluke, *Fasciola hepatica,* in sheep. During the eighteenth century many parasitic worms and arthropods were described, but there was little progress until the general use of the compound microscope made possible the study of the small protozoan parasites and of the life cycles and detailed structures of the larger forms.

Following the description of the larva of *Trichinella spiralis* by Owen in 1835, knowledge concerning the helminthic parasites of man began to accumulate. Many new species were discovered, prominent among which were the hookworm, *Ancylostoma duodenale,* in 1838 by Dubini, and the blood fluke, *Schistosoma hæmatobium,* in 1851 by Bilharz. Between 1850 and 1900, investigators traced the life cycles of *Tænia solium, Echinococcus granulosus, Fasciola hepatica* and *Ancylostoma duodenale,* and between 1900 and 1920, those of *Schistosoma japonicum, Clonorchis sinensis, Diphyllobothrium latum* and *Ascaris lumbricoides.*

The first protozoan parasites of man to be recognized were: *Trichomonas vaginalis* in 1836 by Donné, *Endamœba gingivalis* in 1849 by Gros, *Balantidium coli* in 1856 by Malmsten, *Giardia lamblia* in 1859 by Lambl, and *Trichomonas hominis* in 1860 by Davaine. In 1875 Lösch corroborated the earlier observations of Lambl upon motile amœbæ in patients with diarrhea. In 1880 Laveran observed the malarial plasmodia. In 1900 Leishman discovered *Leishmania donovani,* the cause of kala-azar, and in 1901 Forde found *Trypanosoma gambiense,* the parasite producing African sleeping sickness.

Although certain arthropods had been recognized as parasites since early times, their role as vectors of other parasites and in spreading disease was not established until Melnikov found in 1869 the larval stages of the dog tapeworm *Dipylidium caninum* in the dog louse, Manson showed in 1878 that *Culex quinquefasciatus* was the intermediate host of *Wuchereria bancrofti,* and Smith and Kilborne demonstrated in 1893 that ticks were the transmitting agents of Texas fever in cattle. In 1898 Ross observed the development of the avian malarial parasite in the mosquito and in 1900 Reed and his co-workers proved the transmission of yellow fever by *Aëdes ægypti.* Subsequently, other arthropods were found to be vectors of disease: the tsetse fly in African sleeping sickness in 1903; the tick in African relapsing fever, a spirochætal disease, in 1905; the reduviid bug, *Panstrongylus megistus,* in South American trypanosomiasis in 1907; and the body louse in typhus fever, a rickettsial disease, in 1909.

Types of Parasites. Parasitism includes any reciprocal association in which one species depends upon another. This association may be accidental and temporary or fixed and permanent. In **symbiosis** there is a permanent association of two organisms that cannot exist independently; in **mutualism** both organisms are benefited; and in **commensalism** one partner is benefited and the other is unaffected.

The term parasite, however, is ordinarily applied to a weaker organism that obtains food and shelter from another and derives all the benefit from the association. The harboring species, known as the host, may show no harmful effects or may suffer from a wide range of functional and organic disturbances. There is such a wide range of parasitic types that it is difficult to draw a sharp distinction between a permanent parasite and a temporary resident like a biting insect. Thus, arthropods that produce local and general reactions by the injection of toxic substances may be classed as parasites, although they are often more important as mechanical vectors of disease or as intermediate hosts.

Various descriptive names denote special types or functions of parasites. An **ectoparasite** lives on the outside and an **endoparasite** within the body of the host. Parasites are termed facultative when they are capable of leading both a free and parasitic existence, and obligatory when they take up a permanent residence in and are completely dependent upon the host. An incidental parasite is one that establishes itself in a host in which it does not ordinarily live. An occasional or periodic parasite seeks its host intermittently to obtain nourishment. Temporary parasites are free-living during part of their existence, while permanent parasites remain on or in the body of the host from early life until maturity, sometimes for their entire life. Pseudoparasites are artifacts mistaken for parasites. Coprozoic animals are fecal contaminants that have passed through the alimentary tract without infecting the host.

Nomenclature. Animal parasites are classified according to the International Code of Zoological Nomenclature. Each parasite belongs to a phylum, class, order, family, genus, and species. At times the further divisions of suborder, superfamily, subfamily, and subspecies are employed. The names are Latinized, and the scientific designation is uninominal for subgenera and higher groups, binominal for species, and trinominal for subspecies.

The law of priority obtains as to the oldest available name, even if only a portion of the parasite or its larva has been described. To be valid a generic name must not have been given already to another genus of animals. The names of genera and species are printed in italics; the generic name begins with a capital, and the specific name with a small letter. The name of the author is written without italics and without punctuation after the name of the parasite. The date of the discovery follows the author's name separated by a comma, e.g., *Dientamœba fragilis* Jepps and Dobell, 1918. When a species is transferred to another genus or when the specific name is combined with another generic name, the name of the original author is placed in parentheses and the name of the author of the new combination follows the parentheses, e.g., *Ancylostoma duodenale* (Dubini, 1843) Creplin, 1845.

The family name ends in "idæ," the superfamily in "oidea," and the subfamily in "inæ." The terminations of certain divisions are indicated by the following examples:

Division	Example
Phylum	Platyhelminthes
Class	Trematoda
Order	Prosostomata
Suborder	Distomata
Superfamily	Fascioloidea
Family	Fasciolidæ
Genus	*Fasciola*
Species	*Fasciola hepatica*

Classification. Animal parasites may be divided into two main groups, protozoa and metazoa. The former are simple unicellular organisms. The latter are multicellular animals, the cells of which are differentiated to perform special functions but are dependent upon one another for their existence. The metazoan cell differs in structure and function from the protozoan cell in the absence of differentiation into ectoplasm and endoplasm, in the absorption of food and excretion of waste products by osmosis, in reproduction by mitotic division only, and in the structure of the nucleus.

Animal parasites are legion. They are represented in practically every division of the animal kingdom and some classes are entirely parasitic, e.g., SPOROZOA, CESTOIDEA, and TREMATODA. The distribution of parasites in the animal kingdom is indicated in Table 1.

Geographical Distribution of Parasites. Several conditions govern the geographical distribution of parasites. Their endemicity depends upon the presence and habits of a suitable host, upon easy escape from the host, and upon environmental conditions favoring survival outside the host. Consequently, diseases due to parasites are most prevalent in the tropics.

Vital Requirements of Parasites. The activities of living organisms are directed toward maintaining the individual and the race. Animals require protection from enemies and a favorable environment in order to carry on, unimpeded, the bodily functions of digestion, excretion, respiration, and reproduction. The requirements of parasites do not differ essentially from those of free-living animals, except for such modifications as are necessary for existence in their hosts.

Parasites often lack the necessary organs for digesting raw food materials and depend upon the host for predigested food. Parasites also require moisture. An adequate supply is assured inside the host, but during the free-living existence of the parasite, inadequate moisture will either prove fatal or prevent larval development. Likewise, temperature exerts an important influence upon parasites, some of which are susceptible to slight variations. High temperatures are detrimental; a temperature of 45 to 47 C kills many species in from 5 to 10 minutes. Low temperatures arrest the development of larvæ and ova, and may even destroy them. Each species has an optimal temperature range for its development.

Table 1. DISTRIBUTION OF PARASITES IN THE ANIMAL KINGDOM

Phylum	Class	Parasitic Species	Human Parasites
PROTOZOA	SARCODINA	Many	+
	INFUSORIA	Many	+
	MASTIGOPHORA	Many	+
	SPOROZOA	All	+
COELENTERATA		Few	–
PORIFERA		Rare	–
ARTHROPODA	INSECTA	Very many	+
	ARACHNIDA	Very many	+
	CRUSTACEA	Many	–
PLATYHELMINTHES	CESTOIDEA	All	+
	TREMATODA	All	+
	TURBELLARIA	Few	–
	NEMERTEA	Few	–
NEMATHELMINTHES	NEMATODA	Very many	+
	ACANTHOCEPHALA	All	+
	NEMATOMORPHA	All (larva)	?
ANNELIDA		Rare	+
MOLLUSCA		Few	–
CHORDATA		Rare	–

Hosts. The range of a parasite is confined to the habitat of its host. Parasites restricted to a single species of host generally have a more limited range than those that infect several species. Moreover, parasites with alternate or complicated life cycles are more restricted in distribution, since the chances of survival decrease as the complexity of the life cycle increases. Increased egg production and parthenogenetic development tend to counterbalance decreased chances of survival. Parasites with the simplest life cycles are most likely to have a cosmopolitan distribution because of their relative independence of such environmental factors as climate, temperature, and humidity. The parasites of man are limited by the range of their intermediate hosts; hence, the establishment of new intermediate hosts is one means of widening parasitic distribution.

Climate. Although many important species of parasites have a world-wide distribution, tropical countries where optimal conditions of temperature more often occur are most favorable for their survival. A short summer season prevents the development of many species that require high temperatures during their larval stages and tends to establish zones of distribution according to latitude. By limiting the range of animal hosts, temperature indirectly affects the distribution of parasites.

Warm temperatures do not always favor the existence of parasites. Intense dry heat or direct sunlight will destroy the larval forms. Dry plateaus in the tropics because of lack of humidity are practically free from parasites except for resistant species or those that are transferred directly from host to host.

Moisture governs the distribution of parasitic species. Not only is it essential for the development of the free-living larvæ, but it is also necessary for the propagation of intermediate hosts such as mosquitoes, flies, snails, and fishes. The amount of moisture depends upon temperature, latitude, and topography. Regions where these factors produce heavy rainfall for a good part of the year usually have parasites in greatest abundance. Drainage has been used effectively in moist climates to reduce parasitic infection in man.

Customs and Habits of the Host. The distribution of parasites is also governed by economic and social conditions. Customs considered financially profitable may be hygienically unsound. For instance, the irrigation of the Nile Delta and the paddy fields of China favors the spread of schistosomiasis, and the use of night soil in agriculture provides an important source of parasitic infection.

Ignorance of sanitary measures or economic inability to enforce them usually explains the irregular distribution of parasitic diseases in favorable areas. Where individual and community sanitation is lacking and low standards of living are accompanied by overcrowding and absence of hygienic facilities, the promiscuous deposition of excreta favors the spread of parasitic infections. Raw or insufficiently cooked food may be a source of disease if infected by parasites or if contaminated by night soil or polluted water. Parasites may also be transmitted by infected food handlers. Religious rites such as immersion in heavily contaminated water may be responsible for the transmission of parasitic diseases.

Movements of Population. Historical events involving the intermingling of populations have spread bacterial and parasitic diseases. The importation of the Negro to the Western Hemisphere was accompanied by hookworm infection and schistosomiasis. Oriental immigrants introduced the lung fluke into South America and immigrants from the Baltic countries brought the fish tapeworm to the Great Lakes region of the United States of America. The study of parasites has also been of value in tracing the movements of animal populations throughout the world.

Geographical Distribution of Important Protozoan and Helminthic Parasites of Man. The usual geographical distribution of the more important parasites of man is given in Table 2. In designating geographical regions the parallel of latitude dividing North and Tropical Africa is taken arbitrarily as 20° N, and that dividing North and South Asia as 40° N. Australia is separated from Oceania.

Table 2. PRINCIPAL GEOGRAPHICAL DISTRIBUTION OF THE IMPORTANT PROTOZOAN AND HELMINTHIC PARASITES OF MAN

Parasite	Cosmopolitan	North America	South America	Central America and West Indies	Europe	North Africa	Tropical Africa	North Asia	South Asia	Australia	Malaysia	Oceania
PROTOZOA												
Balantidium coli	●											
Endamœba coli	●											
Endamœba histolytica	●											
Giardia lamblia	●											
Leishmania braziliensis		●	●	●								
Leishmania donovani					●	●	●	●	●			
Leishmania tropica					●	●	●		●			
Plasmodium falciparum		●	●	●	●	●	●		●	●	●	●
Plasmodium malariæ		●	●	●	●	●	●		●		●	●
Plasmodium vivax	●											
Trichomonas vaginalis	●											
Trypanosoma cruzi			●	●								
Trypanosoma gambiense							●					
Trypanosoma rhodesiense							●					
NEMATHELMINTHES												
Acanthocheilonema perstans			●			●	●				●	
Ancylostoma braziliense		●	●	●			●		●		●	●
Ancylostoma duodenale			●		●	●		●	●	●	●	●
Ascaris lumbricoides	●											
Dracunculus medinensis			●	●		●	●		●		●	
Enterobius vermicularis	●											
Loa loa							●					
Mansonella ozzardi			●	●								

Table 2 (cont.). PRINCIPAL GEOGRAPHICAL DISTRIBUTION OF THE IMPORTANT PROTOZOAN AND HELMINTHIC PARASITES OF MAN

Parasite	Cosmopolitan	North America	South America	Central America and West Indies	Europe	North Africa	Tropical Africa	North Asia	South Asia	Australia	Malaysia	Oceania
NEMATHELMINTHES (cont.)												
Necator americanus		●	●	●			●		●	●	●	●
Onchocerca volvulus		●		●			●					
Strongyloides stercoralis		●	●	●	●	●	●		●	●	●	●
Trichinella spiralis	●											
Trichuris trichiura	●											
Wuchereria bancrofti			●	●		●	●		●	●	●	●
PLATYHELMINTHES (CESTOIDEA)												
Diphyllobothrium latum		●			●		●	●	●			
Dipylidium caninum	●											
Echinococcus granulosus	●											
Hymenolepis nana	●											
Tænia saginata	●											
Tænia solium	●											
PLATYHELMINTHES (TREMATODA)												
Clonorchis sinensis									●			
Fasciola hepatica	●											
Fasciolopsis buski									●		●	
Heterophyes heterophyes						●			●		●	
Metagonimus yokogawai					●			●	●		●	
Opisthorchis felineus					●			●	●			
Paragonimus westermani			●	●			●	●	●		●	
Schistosoma hæmatobium						●	●		●			
Schistosoma japonicum									●			
Schistosoma mansoni			●	●		●	●					

Evolution of Parasites. The present relationship between parasite and host has been gradually evolved throughout the ages. While no instance of a sudden change from a free-living to a parasitic existence has been recorded, evolution has produced so many gradations of parasitic existence that no sharp line can be drawn between occasional parasites and allied free-living species. In the earliest stages of parasitic existence the host acted simply as a vehicle of transportation. Later the parasite became dependent upon the host for food, and finally it reached the degenerate state of consuming the tissues of the host. Naturally, adaptation of a free-living organism to an endoparasitic existence demands more adjustment than is required for an ectoparasitic existence. Whether endoparasitism evolved directly from ectoparasitism or from commensalism and symbiosis is unknown. In any event, the process has produced far-reaching changes in the parasite and in its life history, and has affected the life of its host.

Changes in the Parasite. The dependent existence of the parasite has brought about structural changes in both adult and larval forms. Organs no longer necessary have atrophied and others useful for a parasitic existence have developed. The more specialized endoparasites show the greatest changes.

RETROGRESSIVE CHANGES. The most marked retrogressive changes are found in the organs of locomotion and alimentation. Although in many instances the larval forms retain the power of locomotion, the adults, because of their more sedentary habits, may show partial or complete degeneration of the muscles of locomotion. In adult tapeworms the digestive tract has disappeared, while that of the flukes has undergone marked changes, and digestion is effected by absorption through the integument. In certain species the organs of excretion have been practically eliminated, although as a rule they are little altered. There is general retrogression of the nervous system and sense organs to conform to the altered existence. Such changes in morphology are of value in identifying species.

DEVELOPMENT OF USEFUL ORGANS. A parasitic existence has produced specialization in the organs concerned with resistance, attachment, and reproduction. A thickened integument resists the digestive juices of the host and protects against desiccation and physical injury. The spinous integument of the intestinal flukes prevents abrasion. The cysts of the protozoa and the special coverings of the ova and larvæ of the helminths protect the parasite during the free-living period and aid in resisting the digestive juices when ingested by the host. Hooks, setæ, and suckers, fortified by a highly developed musculature, anchor parasitic worms in the body of the host and facilitate migration through the tissues. The shape of the parasite also becomes adapted for maintaining its hold in the host. In the adult and larval stages of some worms, secretory glands near the mouth aid in feeding and penetration.

Parasitism necessitates quantitative and qualitative changes in the reproductive organs. Sporogeny and parthenogenesis supplement sexual development in the SPOROZOA. The nematodes are bisexual and have specialized sexual organs. In the tapeworms each segment or proglottis contains a full complement of male and female reproductive organs, which are capable of producing thousands of ova. With few exceptions the flukes also are hermaphroditic. Self-fertilization in some species has become the usual method of reproduction. Propagation in free-living generations or asexual multiplication of larvæ in intermediate hosts has markedly increased the reproductive output.

Changes in Relation of Parasite and Host. Since the existence of a parasite depends upon its transfer from host to host, its life history has been modified by evolution to meet the changing conditions of environment. An ideal parasitic existence depends upon (1) the presence of an available host, (2) ability to secure entrance to the host, and (3) adaptability to residence without endangering the life of the host.

The evolution of a parasite usually extends over a long period before final adaptation to a particular host is effected. Parasitism involves not only existence in the host and favorable conditions for reproduction, but also the development of proper channels of transmission. A casual relationship has changed into one in which the host is essential for the life of the parasite. Hence, changes in the environment and habits of the host may produce changes even in the free-living existence of the parasite.

The ability of a parasite to infect more than one host favors its existence. The presence of a parasite in a new species is usually the fortuitous result of the habits of its host. Such a transmission may result from (1) changes in the habits of the previous host that preclude parasitic infection, (2) conditions favoring a longer or shorter existence outside the body of the host, (3) the coexistence of the two hosts for a sufficient period, or (4) changes in the habits of the new host that render it susceptible to invasion.

The influence of the parasite on the evolution of the host ranges from no appreciable effect to local extermination of the species. Throughout the ages this mutual association has been a significant factor in modifying the biological equilibrium of animal life. Since the parasite lives at the expense of its host, its ultimate goal is to adapt its existence so that it will not shorten the life of its host. The well-adapted parasite that lives in a state of equilibrium with its host is likely to have had a much longer parasitic existence than the parasite that manifests a poorly adjusted relationship by injuring its host. As a parasite becomes better adapted it tends to cause less damage and to establish a more harmonious existence.

The host in turn tends to build up a gradually increasing immunity against the parasite. Susceptible hosts perish, leaving the more resistant. Thus natural selection raises the individual and collective immunity of the host species to such an extent that the parasite may be unable to attain its development. Similarly, the habits of the host undergo changes that tend to raise resistance to parasitic infection.

Life Cycles of Parasites. Parasites have developed more or less complicated life cycles through adaptation to their hosts and external environment. Most parasites except certain insects attain sexual maturity in their hosts. Some spend their entire lives within the host, one generation following another; others on leaving the host are exposed to the vicissitudes of an external environment. During their extracorporeal life they may remain quiescent in the form of resistant cysts, ova, or larvæ, or they may undergo active growth and metamorphosis. Furthermore, the larval parasite may pass through developmental stages in an intermediate host before it reaches a final host.

Hosts. The **final** or **definitive host** harbors the adult or sexually mature parasite. Every species of carnivorous or omnivorous animal at some time has sheltered one or more types of parasite. Indeed parasites may themselves be infested with smaller parasites. Man is not always the final host. He may be the only definitive host, the most important host in the spread of the disease, one of several animal hosts, or merely an incidental host of a parasite prevalent in other animals.

Animals that harbor the same species of parasites as man are known as **reservoir**

Table 3. PRINCIPAL HOSTS OF THE IMPORTANT PROTOZOAN AND HELMINTHIC PARASITES OF MAN

Parasite	Definitive Hosts	Intermediate Hosts
PROTOZOA		
Balantidium coli	Man, hog	
Endamœba coli	Man	
Endamœba histolytica	Man	
Giardia lamblia	Man	
Leishmania braziliensis	Man	*Phlebotomus* (sand-fly) (?)[1]
Leishmania donovani	Man, dog	*Phlebotomus* (sand-fly) (?)[1]
Leishmania tropica	Man	*Phlebotomus* (sand-fly) (?)[1]
Plasmodium falciparum	Mosquito	Man
Plasmodium malariæ	Mosquito	Man
Plasmodium vivax	Mosquito	Man
Trichomonas vaginalis	Man	
Trypanosoma cruzi	Man, armadillo, bat	Reduviid bugs[1]
Trypanosoma gambiense	Man, ruminants	Tsetse fly[1]
Trypanosoma rhodesiense	Man, ruminants	Tsetse fly[1]
NEMATHELMINTHES		
Acanthocheilonema perstans	Man	*Culicoides* (gnat)
Ancylostoma braziliense	Man, cat, dog	
Ancylostoma duodenale	Man	
Ascaris lumbricoides	Man, hog	
Dracunculus medinensis	Man, fur-bearing mammals	*Cyclops*
Enterobius vermicularis	Man	
Loa loa	Man	*Chrysops* (deer fly)
Mansonella ozzardi	Man	*Culicoides* (gnat)
Necator americanus	Man	
Onchocerca volvulus	Man	*Simulium* (black fly)
Strongyloides stercoralis	Man	
Trichinella spiralis	Man, hog, rat	Man, hog, rat
Trichuris trichiura	Man	
Wuchereria bancrofti	Man	Mosquito

[1] In trypanosomal and leishmanian infections, where sexual development is not defined, it is logically impossible to designate the final or intermediate host. For convenience the insect harboring the leptomonad stage is considered here to be the intermediate host.