MEDICAL ENTOMOLOGY

Arthropods and Human Disease

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Preface

This is a book about what arthropods may do to man directly and to degrade his health when acting in concert with microbes, worms, or even with other insects. While more than a layman's knowledge of arthropods and the associated parasites is presupposed, the student and thoughtful reader should find it comprehensible. The latter can explore any topic of special interest to him through the treatment here, supplemented by the suggested readings and the bibliography.

Medical entomology traditionally has made its contributions to human welfare in two ways: It has developed ways and means for the recognition of arthropods encountered in epidemiological practice, and it has provided information on the structure and habits of these insects. Parasitological texts are concerned primarily with pathogens particularly in their associations with vertebrates. There is now a considerable literature on the arthropod group as components of the environments of both men and pathogenic agents. Much of this literature is not readily available to students, medical men, and agencies concerned with the health of the public. This book, then, fills an intermediate need—a thorough exposition of the extrinsic ecology of arthropod and arthropod-borne vertebrate pathogens.

Material in this book is arranged to relate arthropods to human discomfort and disease in three ways: First, the habits, morphology, and relationships of the medically important categories are discussed; second, they are considered as causes of human distress; and last, pathogens depending wholly or in part on them for transport, sustenance, or both are discussed in their ecological frameworks. In order to show that transmission chains and annoyance from insects

and their relatives may be prevented or alleviated, the final chapter deals with the general aspects of control.

Chapters 2 through 5 deal with arthropods of medical importance according to the higher categories. Some morphological material is given together with information on distribution and habits as a basis for further inquiry through the literature cited. Students in the related disciplines of protozoology and helminthology should find the information and the point of view useful. The medical student and the practitioner can find enough to enable them to answer many of their own questions as well as those of patients. The sanitarian should get direct help from both the text and bibliography. Keys for identification are not included because recognition of species is of such a local nature that no combination of keys would be adequate. It is assumed that laboratory exercises at the option of the teacher will usually supplement the text in class use.

Chapter 6 will be useful to the medical practitioner who is confronted with identification of ailments induced by arthropods. There are few compendiums of this sort available to him. This text, together with cited literature, should offer ample information for complete understanding. Study of this chapter alone should make the clinician more aware of arthropodan causes of human discomfort and disease.

Chapters 7 through 13 are discussions of the ecology of numerous arthropod-borne pathogens. Separation into chapters is according to the larger taxonomic categories of parasites. Arrangement within chapters is often arbitrary. Most of the pathogens are directly related to human health, but some of veterinary significance are included for their historical value or because they illustrate specific transmission chains that differ from those of strictly medical significance. While every effort has been made to have the information up to date, parts of the field are changing so rapidly that even annual reviews are unable to keep abreast of developments. Chapter 8 lists names of viruses as if they were binomial with the word "virus" in the position of a genus name. This does not mean that the word virus has the status of genus; rather, it is done for uniformity in naming the parasites.

The last chapter presents a generalized discussion of principles of abatement and suppression of arthropods and the diseases caused by, or related to, them. It is in no sense a manual for control practices. Specific regulatory measures are seldom given because every

condition dictates its own practice. Any effort to give specific recommendations would demand much more space than is justified. An over-all comprehension of strategy in operations should be useful as a guide to the practitioner.

Many persons have contributed of their time and knowledge to make this volume possible. They aided in its conception and helped clear errors from its expression. For their efforts I am most grateful, but responsibility for the final form is solely my own. Dr. Norman Levine, a protozoologist, and Dr. Walter V. Balduf, an entomologist, both read the entire manuscript and offered many helpful suggestions. Dr. Francis Kruidenier, an helminthologist, examined Chapter 8 and made constructive suggestions; Mr. Lyle Bamber, our biology librarian, gave valuable assistance in finding innumerable elusive references. The ecological diagrams were prepared by Mr. C. H. Beiger through funds provided by a grant from the Graduate College, University of Illinois. For assistance in reading proof and for typing the manuscript, I am grateful to Mrs. William R. Horsfall and Mrs. Jerry Szumski.

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CHAPTER 1

Introduction

EARLY MAN AND ARTHROPODS

Man has encountered many stumbling blocks during his evolution toward a social creature. Certainly a major deterrent toward this progress has been the numerous pestilences resulting from his constant association with arthropods. For possibly a hundred centuries an escape from intimate contact with arthropodan pests was no more successful for humans than it is today for other large mammals. People, like other mammals, either accepted the annoyances, sought local situations where a tolerance level was attained, or moved to a more salubrious place. The latter became the accepted pattern for the vigorous of the species and nomadism became the rule.

A fragment of the human population drifted into southwestern Asia during the post-glacial period and found a climate there that was both dry and seasonably changeable. This became an eddy in the current of drifting humans because the salubrious features of this environment persisted. In this region man experienced a minimum of annoyance from arthropods. Food, shelter, and the necessities for existence were abundantly provided, and in time the settlements became permanent and finally gave rise to urban patterns of life. New problems that arose from the concentration of the human population were created in the new cities. During this formative period of community living the new kinds of plagues and pests were sometimes controlled to a degree by a return to the nomadic pattern. At times the sites of the cities were entirely abandoned in the quest for comfort and more abundant health.

Some time later the people pushed westward along the shores of the Mediterranean Sea, and new cities developed at those sites which provided a happy confluence of dry climate, arable soil, and a dependable supply of potable water. As groups settled in the places better suited to their agricultural practices, again they were subjected to devastating diseases, particularly those associated with arthropods. While a variable climate could be relied on to minimize hazards from a composite of diseases, the extremes imposed often meant repetitive droughts and attendant famine. Those areas dry enough to minimize disease hazards, and yet dependable enough to supply food for support of the settlements, were so rare that the population was held in constant check so that appreciable expansion was impossible. Thus urbanized man was ever caught between the forces of starvation and privation on the one hand and disease on the other. The best possibility for survival seemed to depend on the repeated abandonment of one habitation site and building on a new one, even as nomadic man moved his personal possessions at much shorter intervals.

At a very early date the people came to a degree of realization that insects in some mysterious way were thwarting their efforts toward a stable society. Wherever man went, pests always followed to plague him, while other pests new to him invariably made their appearance. At times he turned to insects in reverence in the vague hope that through his worship of them his burdens might be lifted. The Babylonians worshiped a god of pestilence which was represented as a two-winged fly. The Canaanites placated Baal-zebub, a vengeful god, also represented as a fly, while the early Egyptians considered as holy, the scarabs, a group of coprophagous beetles.

By the time of the sixth century B.C. two diseases of entomological import came to bear on the mushrooming population bordering the Mediterranean Sea. Both diseases became urban problems because cities became commercially interdependent. Malaria came because cities had to be located near mouths of rivers or on the coast. The high water table at such sites put the essential ecological complex, man and mosquitoes, in overlapping environments. Plague came because ships bore to all ports rats and fleas in their holds along with grain and other foodstuffs. Grain was the common bond that brought the essential biota for plague, rats and fleas, into concentrations of human suscepts. In the case of malaria man went to mosquitoes; for plague he brought rats and their attendant fleas to his quarters.

Here were two maladies that flourished wherever cities were established. For two millennia the populace reeled from these diseases and advancement was possible only when man could push northward into colder climates. Through the ages the only escape from these dread diseases was based on individual retreat. Medieval advice for those who could afford to move from a stricken city was to leave the city, stay away for a long time and return only after the outbreak had run its course. This practice was followed to avoid yellow fever until early in the twentieth century.

MODERN MAN AND ARTHROPODS

Late in the nineteenth century people began to reason systematically about arthropod-borne diseases. Pasteur and other workers gathered irrefutable evidence in support of the organismal causes of disease. Their immediate followers found a host of causative agents ranging from worms to protozoa and bacteria. Much later the existence of suboptical agents, the viruses, was demonstrated.

The bells which welcomed the twentieth century also sounded the knell for many arthropod-borne diseases. Ross, and coincidentally Grassi and his associates, had shown that malaria, the most devastating of all blood diseases, was carried by certain mosquitoes. Shortly afterwards, the Americans proved the validity of Finlay's culicine theory of transmission for the cause of yellow fever. At last these demon-diseases of the tropics could be controlled and the key for opening the tropical regions of the world to urbanization was finally possessed. Man ceased running from diseases of arthropodan origin as he became the master of his physical environment and was able to utilize the tropical regions of the world for human needs. The last half of this century should see both Africa and tropical South America achieve enormous progress as arthropod-borne diseases become little more than a memory over most of these regions.

The facts of the salient discoveries which lead to our present knowledge of arthropod-borne diseases should be recounted as an aid to our future efforts. Prior to the organismal theory of disease, humans were able to escape some of the ravages or to control them to the degree that only a few were catastrophic. Tribal or group lore often dictated the behavior of our prehistoric forebears just as today it determines some behavioral patterns in primitive cultures (Nuttall, 1900).[1] Urban man needed more reliable control of dis-

[1] References in this form in the text and in Additional Readings are to the Bibliography.

ease, and he was forced to modify his dwellings, change his sleeping habits, regularly cleanse his body, and finally develop artificial quarantines. He learned that the swamp was miasmatic and that rats in quantity meant epidemics of the black death. There was a slow and indeed hazy realization that animals both large and small were the sources of some of the most devastating maladies and annoying problems. Modern man has resolved the complex interrelations between the diseases of animals and humans, and today the people of a modern society may live virtually free of those diseases which actively depend on arthropods for their propagation.

Many specific examples of historical evidence of the theoretical relations between arthropods and human diseases are known. Early ideas were speculative and probably added little to our knowledge, while some of the later theories were basic to present concepts. By the middle of the eighteenth century some recognizable syndromes (agents of which are now known to be transmitted by arthropods) were thought to be arthropod-disease-related. At that time causes were not understood as evidence was indeed tenuous. Mercurialis (1530–1607) suggested that hordes of flies transmitted the cause of "black death" (a confused complex of cholera, typhoid, and bubonic plague). In 1769 Edward Bancroft wrote that yaws was related to flies. Early in the eighteenth century Lancisi and others published their beliefs that malaria was basically extrinsic and that it came to man as a poison which they related to geographical locality more than to any other factor. King (1883) observed that malaria was basically associated with seasons of high temperatures as well as specific localities, and furthermore disturbed topsoil seemed to have some responsibility. Finally he stated that the rate of malaria was definitely reduced if mosquito nets, gauze veils, or similar protective screens were consistently used by the potential victims. Nott, a physician living in Mobile, Alabama, wrote knowingly of yellow fever in the mid-nineteenth century and related the disease to hematophagous insects, but his commentary was only one among a welter of explanations, and it could not be adequately supported since it was made in advance of the development of the basic theory of causes of disease. Later Maull (1880) noted the effect from the use of screens during an epidemic of malaria that affected all families save two in the urban area under his observation. The two families which escaped attack slept in houses which had screened windows and doors, while all victims of the disease used no screens. Prior to

the knowledge of the transmission chain for the virus of yellow fever, H. R. Carter repeatedly noted that the time lag between the appearance of a primary case of yellow fever and the appearance of a secondary one was much longer than any lag between subsequent cases. He suggested that this was because the agent had an extrinsic existence.

Pasteur's elaboration of the organismal theory of causes of disease turned all eyes to the microscope as the reliable device for demonstrating this relationship. Within the next four decades all kinds of agents (except the viruses) were seen, and many of them were accurately associated with the proper syndromes. The extrinsic relations were less attended, though just prior to 1880 Manson had shown that a filariid parasite in the human blood lived part of its life in the body of a mosquito. A decade later, Smith and Kilborne demonstrated that a protozoan parasite in the blood of bovines lived in a common tick and furthermore depended on that tick for transport of the agent to another host. Ross and Manson collaborated to explode the first major shell in the final battle against ignorance of arthropods in epidemiology. They proved that plasmodia, the causative agents of malaria, did in truth depend on mosquitoes during part of their development. The need for entomologists to work in a specialized area of arthropod-borne diseases was immediately apparent as the clue to suppression shifted more from the parasite-human factor to the arthropodan link. The necessity for understanding the whole ecological complex was urgent. Public health agencies were established in time and knowledge basic to an integrated attack on diseases has been systematically brought to bear on control.

Bristowe (1946) gave excellent reasons for studying insects and their relation to human health when he stated that (1) historically more premature deaths have been brought about by direct and indirect attacks from arthropods than from any other cause; (2) the bites, stings, and general allergies inflicted by many arthropods still cause widespread discomfort; and (3) vast sums of money are spent in attempts to alleviate these distresses of man. Others have commented in similar vein. Plague, typhus, and malaria are said to have killed far more people than have been destroyed in all the armed conflicts since time began (see Frontispiece). As devastators of man the proboscises of the flea and the mosquito have proved to be sharper and surer than the sword. Disraeli, a prime minister of Britain during Queen Victoria's time, called attention to the truth

that the health of the public is the foundation on which rests the happiness and strength of a nation. If the people of any nation suffer for long from ill health or loss of vigor, the afflicted nation will surely perish. Those infectious diseases whose agents are borne by arthropods continue to be among the more devastating over much of the world, and their control will hasten the advancement of primitive cultures. Insects are a major cause of deficient health of many people; hence these potential enemies still require our most careful attention.

To the late W. B. Herms of California must go the credit for joining medicine and entomology in 1909 and for naming the union *Medical Entomology*. Since that time he and many others have helped those interested in this double-branched field to keep abreast of developments through the publication of books and numerous technical papers and bulletins. Historically, the practitioner of medical entomology has provided information on identification, made surveys, and studied the bionomics of vector-hosts of pathogens. More and more, the entomologist has provided basic information on transmission chains as well as extrinsic environments of the pathogens.

At one time ecological relationships between a parasite and its hosts were regarded as simple and in the manner of the observation credited to Maull above. Such relationships may be relatively uncomplicated in any one locality, but the variations in chains of transmission and the differences in basic environments of pathogens are almost endless. One object of this volume is to relate traditional entomological knowledge to the specific ecological situations which give reasons for (1) the absence of transmission or (2) propagation of arthropod-borne agents of diseases.

In our concern over their significance as hosts and vectors of vertebrate pathogens, we must never forget that arthropods still directly cause human discomfort, disease, and even death. Many of these animals sting, bite, irritate, and annoy people, while some provide allergens in hairs, scales, or body products which are responsible for discomfort or illness to sensitive persons. Some arthropods actually invade the human skin, subcutaneous tissue, sinuses, alimentary and urinary tracts, and even lymph nodes. Human reactions to these attacks are detailed in this book.

ADDITIONAL READINGS

HIRST (1953) provides us with an account of the evolution of the epidemiology of plague. In doing so he has traced the history of pandemics in the western culture.

KING (1883): "The animalcular, or insect, origin of disease is not a new idea. . . . Viewed in the light of our modern 'germ theory' of disease, the punctures of proboscidian insects, like those of Pasteur's needles, deserve consideration as probable means by which bacteria and other germs may be inoculated into human bodies so as to infect the blood and give rise to specific fevers. . . ."

NUTTALL (1900a) reviews some primitive reasoning about relationships between malaria and insects. Residents of Mindanao in the Philippines recognized as early as 1700 that mosquitoes were related to the disease. Africans in the Usambara Mountains of eastern Africa were aware that malaria was contracted in lowlands, and the word *mbu* means both malaria and mosquito in one tribal dialect.

RUSSELL (1955) has given an extensive account of the history of our knowledge of malaria and provides an example of how man moved from lore to reason in solving one of his greatest hazards.

CHAPTER 2

Arthropoda: Classes

GENERAL MORPHOLOGY

The phylum Arthropoda because of diversity of form is a morphologist's utopia. Its wealth of species and endless subspecific variants permit comparisons and relationships galore. The body structures have a direct bearing on the medical significance of the group. The appendages are modified in every conceivable way to permit insects to feed on a surface, below the surface, or even in tubular tracts of man and other animals. Mechanics of voiding their wastes and secretions provides the means for transferring pathogens to all animal hosts. The ease with which insects become hosts for agents of disease is intimately related to their morphology. It is the purpose of this book to draw attention to these morphological values, and the student is referred to any of the numerous compilations on morphology for further details.

Through a long evolutionary history, arthropods have come to be complex organisms. Their small size in relation to that of vertebrates may tend to belie the facts. For all of their smallness, they have evolved a complicated set of organ systems coordinated by an intricate nervous system. The size in turn enables arthropods to occupy microhabitats when survival is pressed. When conditions are favorable, they may expand their horizons because of high reproductive rates. In addition they are favored by having evolved jointed appendages, which enhance their capabilities for dispersal. The body covering of the terrestrial forms is capable of resisting desiccation. Thus we have small animals of high reproductive potential that may live in all sorts of limited environments and yet move easily and for great distances to new habitats.