

Infectious Disease

Series Editor: Vassil St. Georgiev

Jerome Goddard

Infectious Diseases and Arthropods

Third Edition

 Humana Press

Infectious Disease

Series Editor

Vassil St. Georgiev
National Institute of Health Department Health & Human Services,
Bethesda, MD, USA

The Infectious Disease series provides the best resources in cutting-edge research and technology.

More information about this series at <http://www.springer.com/series/7646>

Jerome Goddard

Infectious Diseases and Arthropods

Third Edition

 Humana Press

Jerome Goddard
Extension Professor of Medical Entomology
Mississippi State University
Mississippi State, MS, USA

Infectious Disease

ISBN 978-3-319-75873-2

ISBN 978-3-319-75874-9 (eBook)

<https://doi.org/10.1007/978-3-319-75874-9>

Library of Congress Control Number: 2018936128

© Springer International Publishing AG, part of Springer Nature 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Humana Press imprint is published by the registered company Springer International Publishing AG part of Springer Nature.

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

For Rosella, my inspiration

Preface

Infectious diseases aren't conquered. In fact, a good argument can be made that they are gaining ground in their long struggle with humankind. The ability of microbes to adapt to host immune responses and intense pressure from antibiotic use, combined with societal changes, has contributed to a resurgence of many infectious diseases. In addition, there are several "new" or emerging diseases, including Lyme disease, some forms of ehrlichiosis, Heartland and Powassan tick viruses, SARS, MERS, bird flu, Zika virus, Chikungunya, and Ebola hemorrhagic fever. In just the last 30 years or so we have seen the appearance of a virulent strain of avian influenza that attacks humans, a human variant of "mad cow" disease, and all manner of multiple drug-resistant bacteria such as *Staphylococcus aureus*. These new or emerging infectious diseases have raised considerable concern about the possibility of widespread and possibly devastating disease epidemics among human populations.

Many infectious diseases are vector-borne, i.e., carried from one host or place to another by an arthropod vector. It could be argued that at least some of the recent increase in vector-borne disease is the result of increased recognition and reporting. Specific disease and vector recognition is certainly made easier by newer technologies such as the polymerase chain reaction (PCR) and barcoding technologies. However, societal changes such as population increases, international travel, ecological and environmental changes, and especially suburbanization (building homes in tracts of forested lands) are contributing to an increase in the incidence of many of these vector-borne diseases.

In light of this vector-borne disease increase, information about these arthropod entities – their distributions, hosts, reservoirs, and vectors – is much needed. Thus, this third edition of *Infectious Diseases and Arthropods* is intended to provide physicians, as well as entomologists and other interested parties, with a reference on the biological and entomological aspects of infectious diseases. The primary approach has been to present readily accessible information on the major vector-borne diseases, with an emphasis on the relevant biology and ecology of each one. Since I am writing as an entomologist, the text obviously leans heavily to the organismal side of each disease, with, in some cases, less emphasis on clinical aspects. No effort has been made to present an in-depth review of each disease; instead, there is a middle-

of-the road consensus of current thought on each subject. It is the author's hope that *Infectious Diseases and Arthropods*, Third Edition, will prove a useful adjunct to the larger clinical texts employed by infectious disease specialists, public health and travel medicine physicians, epidemiologists, and others with duties encompassing vector-borne diseases. Treatments are mentioned (but without specific dosages) for the various diseases, but are only intended as general guidelines. They are in no way intended to be the sole, specific treatment for any particular patient. Physicians should consult clinical texts or drug package inserts for the most current recommendations.

Mississippi State University, MS, USA

Jerome Goddard

Acknowledgments

A substantial portion of this text was originally published (text, figures, and photos) as part of a series of medical entomology columns written for *Infections in Medicine*. For inclusion here, these were updated with new and current medical and scientific information. Specific credits for the columns are listed below. This material is kindly reprinted by permission of CMP Healthcare Media, Darien, CT, publishers of *Infections in Medicine*. Also, part of Chap. 1 was originally published as an article entitled “Arthropods and Medicine” in *Agromedicine*, and is reprinted here by permission from Hayworth Press, Inc., Binghamton, NY.

The following people read portions of the manuscript (either first, second, or third edition), supplied portions of text, and/or offered helpful advice: Michelle Allerdice (Centers for Disease Control), Rosella M. Goddard, Dr. Hans Klompen (Ohio State University), Dr. Bill Lushbaugh (formerly at the University of Mississippi School of Medicine), Dr. Chad P. McHugh (formerly at Brooks Air Force Base, San Antonio, TX), and Dr. Andrea Varela-Stokes (Mississippi State University). The following people allowed me to use their photographs and/or arthropod specimens for pictures contained in this book: Tom and Pat Baker (Oakdale, CT), Dr. Lorenza Beati (U.S. National Tick Collection), Dr. Kristine Edwards (Mississippi State University), Mallory Carter, Joseph Goddard (Alabama Department of Wildlife and Fisheries), Dr. Blake Layton (Mississippi State University), Joe MacGown (Mississippi State University), and Wendy C. Varnado (Mississippi Department of Health).

Rosella M. Goddard created the Third Edition worldwide distribution maps for the various arthropod vectors and diseases. I am especially grateful to her for that.

The following *Infections in Medicine Bug Vectors* columns were included in the First Edition of this book and serve as the basis for all subsequent editions:

- Arthropods and Medicine, 1996; 13: 543, 544, 557, © 1996, CMP Healthcare Media LLC
- Eastern Equine Encephalitis, 1996; 13: 670–672, © 1996, CMP Healthcare Media LLC

- St. Louis Encephalitis, 1996; 13: 747, 751, 806, © 1996, CMP Healthcare Media LLC
- Dengue Fever, 1996; 13: 933, 934, 984, © 1996, CMP Healthcare Media LLC
- Rocky Mountain Spotted Fever, 1997; 14: 18–20, © 1997, CMP Healthcare Media LLC
- Ehrlichiosis, 1997; 14: 224, 229, 230, © 1997, CMP Healthcare Media LLC
- Mosquitoes and HIV, 1997; 14: 353, 354, © 1997, CMP Healthcare Media LLC
- Malaria, 1997; 14: 520–522, 547, © 1997, CMP Healthcare Media LLC
- Lyme Disease, 1997; 14: 698–700, 702, © 1997, CMP Healthcare Media LLC
- Tick-Borne Viruses, 1997; 14: 859–861, © 1997, CMP Healthcare Media LLC
- Tick Paralysis, 1998; 15: 28–31, © 1998, CMP Healthcare Media LLC
- Imaginary Insect or Mite Infestations, © 1998; 15: 168–170, © 1998, CMP Healthcare Media LLC
- Tularemia, 1998; 15: 306–308, © 1998, CMP Healthcare Media LLC
- Murine Typhus, 1998; 15: 438–440, © 1998, CMP Healthcare Media LLC
- Lymphatic Filariasis, 1998; 15: 607–609, © 1998, CMP Healthcare Media LLC
- Yellow Fever, 1998; 15: 761, 762, 765, © 1998, CMP Healthcare Media LLC
- Plague, 1999; 16: 21–23, © 1999, CMP Healthcare Media LLC
- Chagas' Disease, 1999; 16: 23–26, © 1999, CMP Healthcare Media LLC
- Ticks and Human Babesiosis, 1999; 16: 319–320, © 1999, CMP Healthcare Media LLC
- Leishmaniasis, 1999; 16:566–569, © 1999, CMP Healthcare Media LLC
- Tick-Borne Relapsing Fever, 1999; 16: 632–634, © 1999, CMP Healthcare Media LLC
- Chigger Bites and Scrub Typhus, 2000; 17: 236–239, © 2000, CMP Healthcare Media LLC
- LaCrosse Encephalitis, 2000; 17: 407–410, © 2000, CMP Healthcare Media LLC
- Human Lice and Disease, 2000; 17: 660–664, © 2000, CMP Healthcare Media LLC
- Myiasis Confused with Boils, 2001; 18: 17–19, © 2001, CMP Healthcare Media LLC
- Black Flies and Onchocerciasis, 2001; 18: 293–296, © 2001, CMP Healthcare Media LLC
- Health Problems from Kissing Bugs, 2003; 20: 335–338, © 2003, CMP Healthcare Media LLC
- Bed Bugs Bounce Back – But Do They Transmit Disease? 2003; 20: 473–474, © 2003, CMP Healthcare Media LLC
- American Boutonneuse Fever, 2004; 21: 207–210, © 2004, CMP Healthcare Media LLC
- Fire Ant Attacks on Humans, 2004; 21: 587–589, © 2004, CMP Healthcare Media LLC
- Brown Recluse Spider Bites, 2005; 22: 205–210, © 2005, CMP Healthcare Media LLC
- Fleas and Human Disease, 2005; 22: 402–405, © 2005, CMP Health

Contents

Part I Arthropods and Human Health

1 Arthropods and Health	3
1.1 Classification of Arthropods	3
1.1.1 Insects	3
1.1.2 Spiders	4
1.1.3 Mites and Ticks	6
1.1.4 Scorpions	6
1.1.5 Centipedes and Millipedes.....	7
1.2 Identification Methods for Arthropods	9
1.2.1 Morphological Identification	9
1.2.2 Molecular Identification.....	12
1.2.3 Pros and Cons of Morphological Versus Molecular Identification	12
1.3 Medical Importance of Arthropods	14
1.3.1 Historical Aspects of Medically Important Arthropods	14
1.3.2 Direct Effects on Health.....	17
1.3.3 Indirect Effects on Health	19
References.....	24
2 Dynamics of Arthropod-Borne Diseases	27
2.1 Mechanical Versus Biological Transmission of Pathogens	27
2.1.1 Mechanical Transmission	27
2.1.2 Biological Transmission	29
2.2 Vector Competence	33
2.2.1 Incrimination of Vectors: A Complicated Issue.....	34
References.....	36

Part II Major Arthropod-Borne Diseases

3 Mosquito-Borne Diseases 39

3.1 Basic Mosquito Biology 39

3.2 Malaria 43

 3.2.1 Introduction 43

 3.2.2 The Disease and its Diagnosis 45

 3.2.3 The Causative Agent and Life Cycle 45

 3.2.4 Mosquito Vectors and Behavior 47

 3.2.5 Malaria Treatment and Control 48

3.3 Mosquito-Transmitted Encephalitis Viruses 53

 3.3.1 Introduction and General Comments 53

 3.3.2 Eastern Equine Encephalitis (EEE) 53

 3.3.3 St. Louis Encephalitis (SLE) 59

 3.3.4 West Nile Encephalitis (WNV) 61

 3.3.5 Other Mosquito-Borne Viruses 63

3.4 Dengue Fever 70

 3.4.1 Introduction 70

 3.4.2 Spread of the Virus 71

 3.4.3 Clinical and Laboratory Characteristics 71

 3.4.4 Treatment, Prevention, and Control 74

3.5 Yellow Fever (YF) 75

 3.5.1 Introduction and Medical Significance 75

 3.5.2 Brief History of Yellow Fever 77

 3.5.3 Jungle Vs Urban YF Cycles 79

 3.5.4 Treatment and Prevention 79

3.6 Lymphatic Filariasis 81

 3.6.1 Introduction and Medical Significance 81

 3.6.2 Clinical and Laboratory Findings 82

 3.6.3 Ecology of Lymphatic Filariasis 83

3.7 Other Human-Infesting Filarial Worms 86

References 87

4 Tick-Borne Diseases 91

4.1 Basic Tick Biology 91

4.2 Rocky Mountain Spotted Fever (RMSF) 95

 4.2.1 Introduction 95

 4.2.2 History 96

 4.2.3 Clinical and Laboratory Aspects of RMSF 98

 4.2.4 Ecology of RMSF 98

 4.2.5 Prevention and Treatment of RMSF 101

4.3 American Boutonnoise Fever (ABF) 101

 4.3.1 Introduction and Background 101

 4.3.2 Ecology of ABF 103

 4.3.3 Prevention and Treatment of ABF 105

- 4.4 Other Spotted Fever Group Rickettsioses 105
 - 4.4.1 Boutonneuse Fever. 105
 - 4.4.2 African Tick Bite Fever 106
 - 4.4.3 Siberian Tick Typhus 106
 - 4.4.4 Queensland Tick Typhus 107
- 4.5 Ehrlichiosis 107
 - 4.5.1 Introduction 107
 - 4.5.2 Clinical and Laboratory Findings 109
 - 4.5.3 Ecology of Ehrlichiosis 109
 - 4.5.4 Treatment and Control of Ehrlichiosis. 109
- 4.6 Anaplasmosis 111
 - 4.6.1 Introduction 111
 - 4.6.2 Clinical and Laboratory Findings 111
 - 4.6.3 Ecology of Anaplasmosis 112
 - 4.6.4 Treatment and Control of Anaplasmosis 112
- 4.7 Lyme Disease. 115
 - 4.7.1 Introduction 115
 - 4.7.2 Background and Historical Information 116
 - 4.7.3 Clinical and Laboratory Findings 117
 - 4.7.4 Ecology of LD 118
 - 4.7.5 Treatment 119
- 4.8 Tularemia 120
 - 4.8.1 Introduction and Medical Significance of Tularemia 120
 - 4.8.2 Clinical and Laboratory Findings 121
 - 4.8.3 Arthropod Transmission of the Tularemia Organism 122
 - 4.8.4 Treatment 123
- 4.9 Human Babesiosis 124
 - 4.9.1 Introduction and Medical Significance 124
 - 4.9.2 Clinical and Laboratory Findings 124
 - 4.9.3 Species of Babesia and Their Ecology. 125
 - 4.9.4 Treatment and Control 126
- 4.10 Viruses Transmitted by Ticks. 126
 - 4.10.1 Introduction 126
 - 4.10.2 Tick-Borne Encephalitis (TBE). 127
 - 4.10.3 Colorado Tick Fever (CTF) 128
- 4.11 Tick-Borne Relapsing Fever (TBRF). 130
 - 4.11.1 Introduction and Medical Significance 130
 - 4.11.2 Clinical and Laboratory Findings 130
 - 4.11.3 The Etiologic Agent and Its Relationship
to Louse-Borne Relapsing Fever 131
 - 4.11.4 Ecology of TBRF. 132
 - 4.11.5 Treatment and Control 133
- 4.12 Tick Paralysis. 133
 - 4.12.1 Introduction and Medical Significance 133
 - 4.12.2 Clinical Features 137

4.12.3	Ticks Involved and Mechanism of Paralysis	137
4.12.4	Prevention and Treatment	138
	References.	142
5	Flea-Borne Diseases	149
5.1	Basic Flea Biology.	149
5.2	Plague.	151
5.2.1	Introduction and Clinical Presentation.	151
5.2.2	History	152
5.2.3	Ecology of Plague	153
5.2.4	Diagnosis and Treatment	154
5.3	Murine Typhus	155
5.3.1	Introduction and Medical Significance	155
5.3.2	Clinical and Laboratory Findings	156
5.3.3	Ecology of Murine Typhus	157
5.3.4	Treatment	159
5.4	Cat-Scratch Disease (CSD)	159
5.4.1	Introduction and Clinical Presentation.	159
5.4.2	Reservoirs and Mode(s) of Transmission	159
5.4.3	Treatment	160
	References.	160
6	Sand Fly-Transmitted Diseases	163
6.1	Basic Sand Fly Biology	163
6.2	Leishmaniasis.	163
6.2.1	Introduction and Medical Significance	163
6.2.2	Clinical Manifestations and Diagnosis	165
6.2.3	Ecology of Leishmaniasis	168
6.2.4	Treatment and Control of Leishmaniasis.	170
6.3	Other Sand Fly-Transmitted Diseases	170
6.3.1	Bartonellosis (Carrion's Disease)	170
6.3.2	Sandfly Fever	171
	References.	171
7	Miscellaneous Vector-Borne Diseases	173
7.1	Chagas' Disease.	173
7.1.1	Introduction and Medical Significance	173
7.1.2	Clinical and Laboratory Findings	175
7.1.3	Ecology of Chagas' Disease and Its Vectors	177
7.1.4	Treatment, Prevention, and Control.	179
7.2	African Sleeping Sickness	180
7.2.1	Introduction and Medical Significance	180
7.2.2	Clinical and Laboratory Findings	181
7.2.3	Ecology of African Sleeping Sickness and Its Vectors	182
7.2.4	Treatment, Prevention, and Control.	183

- 7.3 Onchocerciasis 183
 - 7.3.1 Introduction and Medical Significance 183
 - 7.3.2 Clinical and Laboratory Findings 184
 - 7.3.3 Ecology of Onchocerciasis and Its Vectors 185
 - 7.3.4 Treatment, Prevention, and Control. 186
- 7.4 Scrub Typhus (ST) 186
 - 7.4.1 Introduction and Medical Significance 186
 - 7.4.2 Clinical and Laboratory Findings 187
 - 7.4.3 Ecology of ST and Its Vectors 188
 - 7.4.4 Treatment, Prevention, and Control. 188
- 7.5 Louse-Borne Infections 189
 - 7.5.1 General and Medical Importance of Body Lice 189
 - 7.5.2 Epidemic Typhus 191
 - 7.5.3 Trench Fever 192
 - 7.5.4 Louse-Borne Relapsing Fever (LBRF) 192
 - 7.5.5 Treatment, Prevention, and Control of Louse-Borne Diseases 192
- References. 194

Part III Other Arthropod-Caused or -Related Problems

- 8 Health Effects of Bed Bugs 199**
 - 8.1 Introduction and Bed Bug Biology 199
 - 8.2 Reactions to Bed Bug Bites 200
 - 8.3 Bed Bugs and Disease Transmission 203
 - References. 205
- 9 Why Mosquitoes and Other Arthropods Cannot Transmit HIV 209**
 - References. 210
- 10 Medical Conditions Caused by Arthropod Stings or Bites 211**
 - 10.1 Introduction and Medical Significance 211
 - 10.2 Pathogenesis. 211
 - 10.2.1 Mouthpart Types 211
 - 10.2.2 Sting Apparatus 212
 - 10.2.3 Direct Damage to Tissue 215
 - 10.2.4 Infectious Complications. 216
 - 10.3 Clues to Recognizing Insect Bites or Stings 217
 - 10.3.1 Diagnosis 217
 - 10.4 Summary and Conclusions 218
 - References. 218
- 11 Fire Ant Attacks on Humans 219**
 - 11.1 The Problem. 219
 - 11.2 Effects of the Venom 221
 - 11.3 Infectious Complications. 222
 - 11.4 Protecting Patients in Healthcare Facilities from Ant Attacks. 222
 - References. 223

- 12 Necrotic Arachnidism: Brown Recluse Bites** 225
 - 12.1 Introduction and Biology 225
 - 12.2 Facts and Fables About Brown Recluse Bites 227
 - 12.3 Differential Diagnosis 228
 - 12.4 Treatment of Bites 228
 - References. 230

- 13 Myiasis** 233
 - 13.1 Introduction and Medical Significance 233
 - 13.1.1 Accidental Myiasis. 233
 - 13.1.2 Facultative Myiasis. 236
 - 13.1.3 Obligate Myiasis 238
 - 13.2 Contributing Factors 240
 - 13.2.1 Accidental Myiasis. 240
 - 13.2.2 Facultative Myiasis 240
 - 13.2.3 Obligate Myiasis 241
 - 13.2.4 Myiasis in Clinical Practice. 242
 - 13.2.5 Differential Diagnosis 242
 - 13.3 Prevention, Treatment, and Control. 243
 - References. 244

- 14 Imaginary Insect or Mite Infestations.** 245
 - 14.1 Introduction and Medical Significance 245
 - 14.2 Clinical Aspects and Contributing Factors. 246
 - 14.3 Morgellons Disease 247
 - 14.4 Differential Diagnosis 247
 - 14.5 Treatment Strategies. 248
 - References. 249

- Appendix 1: Signs and Symptoms of Arthropod-Borne Diseases** 251

- Appendix 2: Diagnostic Tests Used in Arthropod-Borne Diseases** 257

- Appendix 3: Personal Protection from Arthropods.** 261

- References** 269

- Index.** 271

About the Author



Jerome Goddard is a medical entomologist currently located at Mississippi State University who is known for research on a number of medically important arthropods, most notably ticks, mosquitoes, and bed bugs. Prior to coming to Mississippi State, Dr. Goddard was an Air Force medical entomologist for 3 years and then state medical entomologist for the Mississippi Department of Health for 20 years. After Hurricane Katrina (2005), he was the health department official responsible for the mosquito and vector control program along the Mississippi Gulf Coast. He is the author of over 200 scientific articles and a medical textbook used by phy-

sicians, which won “Highly Commended” in 2003 in the British Medical Association’s Best Medical Book of the Year competition. Over the last two decades, he has served as an educational resource concerning medically important arthropods to a U.S. Congressional Committee, in various newspapers and magazines such as Reader’s Digest, and on television programs such as The Learning Channel (“Living with Bugs”) and the Colbert Report.

Part I
Arthropods and Human Health

Chapter 1

Arthropods and Health



1.1 Classification of Arthropods

The phylum Arthropoda includes insects, spiders, mites, ticks, scorpions, centipedes, millipedes, crabs, shrimp, lobsters, sow bugs (roly-polies), and other related organisms. Arthropods are characterized by segmented bodies; paired, jointed appendages (e.g., legs and antennae); an exoskeleton; and bilateral symmetry (Fig. 1.1) [1]. Arthropods display an amazing diversity and abundance. They make up more than 85% of all known animal species [2]. Arthropods are found on every continent, and a square meter of vegetation is literally teeming with them. For brevity, four classes of arthropods will be discussed in this chapter—insects, arachnids, centipedes, and millipedes. Table 1.1 discusses some key characteristics of these major arthropod groups.

1.1.1 Insects

Like other arthropods, insects possess a segmented body and jointed appendages. Beyond that, however, there is much variation: long legs or short legs; four wings, two wings, or no wings; biting mouthparts or sucking mouthparts; and soft bodies, hard bodies, etc. Despite the diversity, adult specimens can be recognized as insects by having three pairs of walking legs and three body regions: a head, a thorax (bearing legs and wings if present), and an abdomen. No other arthropods have wings. Although most adult insects have wings, several medically important species are wingless (e.g., lice, fleas, bed bugs).

Insects have different forms of development. In those with gradual metamorphosis (grasshoppers, lice, true bugs), the immatures are called nymphs and are structurally similar to the adults, increase in size at each molt, and develop wings (if present) during later molts (Fig. 1.2). In groups with complete metamorphosis

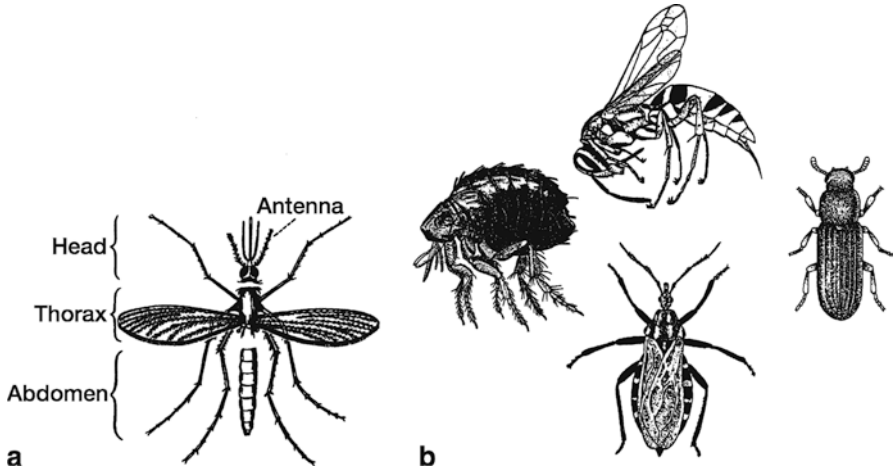


Fig. 1.1 (a) Generalized insect drawing with parts labeled; (b) several different insect types. (From US Department HEW [CDC] pictorial keys)

(e.g., beetles, flies, bees and wasps, moths and butterflies, and fleas), the immature stages are called larvae and pupae and look nothing like the adult (Fig. 1.3). Often, larvae are wormlike and are frequently called “worms” by lay people (Fig. 1.4). The three body regions are never as distinct as they are in adults, but generally three pairs of short walking legs are evident. Fly larvae (maggots) lack walking legs, and although some such as mosquitoes have three body regions, others (e.g., larvae of houseflies and blowflies) do not have distinct body regions. Caterpillars and similar larvae often appear to have legs on some abdominal segments. Close examination of these abdominal “legs” (prolegs) reveals that they are unsegmented fleshy projections, with or without a series of small hooks (crochets) on the plantar surface, and structurally quite unlike segmented walking legs on the first three body segments behind the head.

1.1.2 Spiders

Spiders have two body regions—an anterior cephalothorax and a posterior abdomen connected by a waist-like pedicle (Fig. 1.5). The anterior portion consists of the head with various numbers of simple eyes on the anterior dorsal surface and the thorax with four pairs of walking legs. The mouthparts, called chelicerae, are hollow, sclerotized, and fang-like and are used to inject venom into prey. Located between the chelicerae and the first pair of walking legs are a pair of short leglike structures called pedipalpi, which are used to hold and manipulate prey. Pedipalpi may be modified into copulatory organs in males. The spider abdomen is usually unsegmented and displays spinnerets for web production at the posterior end. Immatures look the same as adults, except smaller.

Table 1.1 Key characteristics of some arthropod groups

Arthropod group	Class	Characteristics	Remarks
Insects	Insecta or Hexapoda	Six legs	Mostly nonharmful (even helpful) to humans; some species bite/sting or transmit disease organisms
Spiders	Arachnida	Three body regions most with wings Eight legs	Most able to bite, but with little or no consequence
Mites and ticks	Arachnida	Two body regions: Cephalothorax, abdomen Eight legs (as adults) One globose or disk-shaped body region No true heads, mouthparts only	Brown recluse, widow spiders, hobo spider may be dangerous in the United States Ticks are essentially “large mites” Ticks transmit many different disease agents to humans and may cause paralysis while feeding
Scorpions	Arachnida	Eight legs	Only one dangerous species in the United States occurring in Arizona and New Mexico
Centipedes	Chilopoda	One pair of legs per body segment Often dorsoventrally flattened	Called “hundred-leggers” Painful bites but mostly harmless
Millipedes	Diplopoda	Two pairs of legs per body segment Often cylindrical	Called “thousand-leggers” Defensive fluids may cause burns or stains on the skin

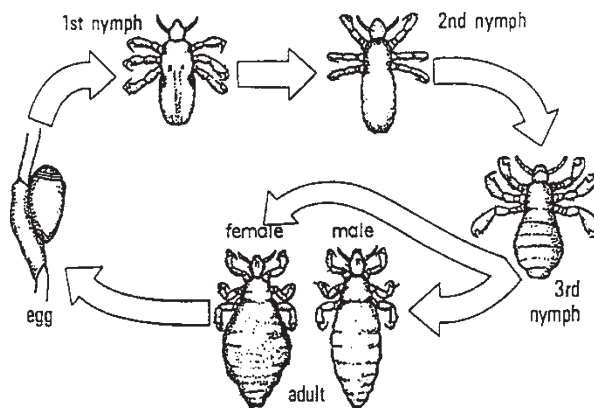


Fig. 1.2 Head lice life cycle, example of a gradual metamorphosis. (From US, DHHS, CDC, home study course 83–3297)

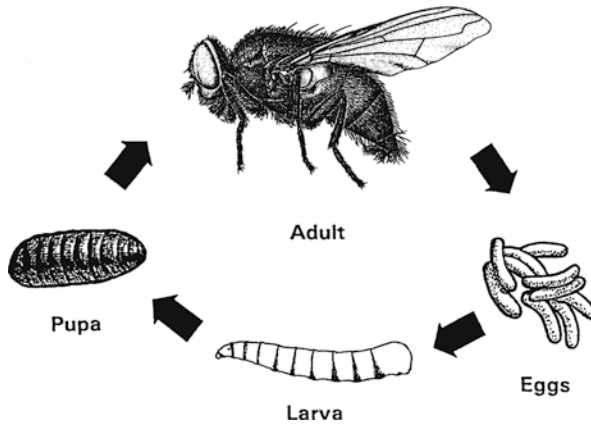


Fig. 1.3 House fly life cycle—example of complete metamorphosis. (From USDA, ARS, Agri. Hndbk. No. 655, Feb. 1991)

One note must be added about “daddy longlegs,” since most people erroneously call them spiders. Harvestmen, or daddy longlegs (order Opiliones), have many characteristics in common with true spiders; however, they differ in that the abdomen is segmented and broadly joined to the cephalothorax (not petiolate). Most species have extremely long, slender legs. Contrary to folklore, they are not venomous.

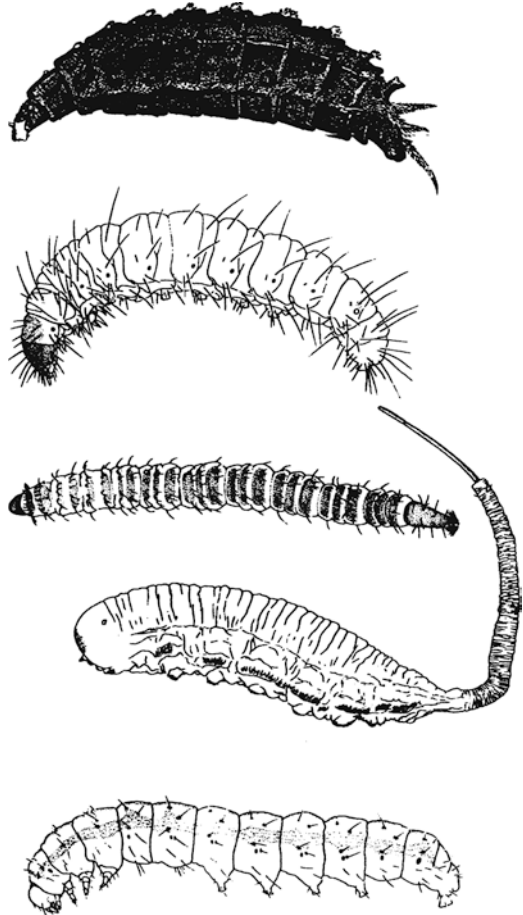
1.1.3 Mites and Ticks

These small arachnids appear to have only one body region (cephalothorax and abdomen fused), the overall appearance being globose or disk-shaped (Fig. 1.6). This general appearance quickly separates them from other arthropods. The body may be segmented or unsegmented with eight walking legs present in adults. Larvae, the first-stage immatures, have only six (rarely fewer) legs, but their fused cephalothorax and abdomen readily separates them from insects. They attain the fourth pair of legs at the first molt and thereafter are called nymphs until they become adults. As for spiders, immature ticks and mites are generally similar in appearance to adults. In general, ticks are considerably larger than mites. In fact, ticks are just large mites. Adult ticks are generally about the size of a pea; mites are about the size of a grain of sand (often smaller).

1.1.4 Scorpions

Scorpions are dorsoventrally flattened creatures with an anterior broad, flat area and a posterior segmented “tail” with a terminal sting (Fig. 1.7). Although these outward divisions do not correspond with actual lines of tagmatization, they do provide an

Fig. 1.4 Various types of insect larvae. (From US, DHEW, PHS, CDC, pictorial keys)

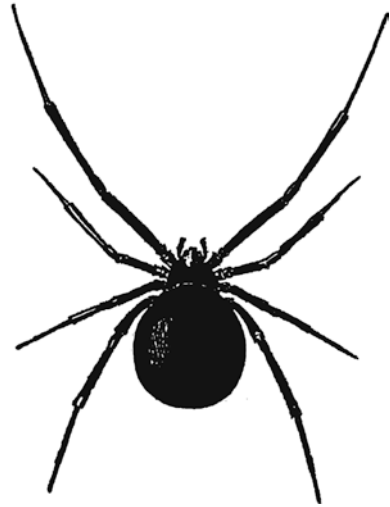
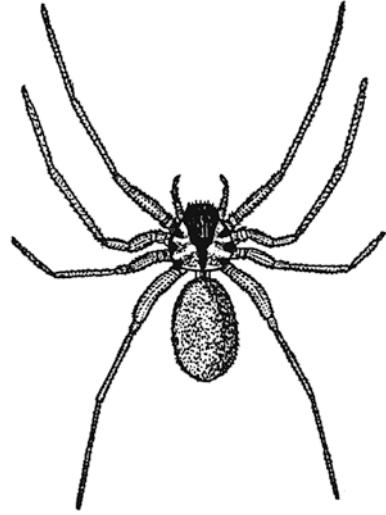


appearance sufficient to distinguish these arthropods from most others. Like spiders, they have four pairs of legs, the mouthparts are chelicerae, and the first elongate appendages are pedipalpi. Scorpion pedipalpi are modified into pinchers to capture prey. Immatures are similar to adults in general body form.

1.1.5 Centipedes and Millipedes

Centipedes and millipedes bear little resemblance to the other arthropods previously discussed. They have hardened wormlike bodies with distinct heads and multiple pairs of walking legs (Figs. 1.8 and 1.9). Centipedes are swift-moving, predatory organisms with one pair of long legs on each body segment behind the head. Millipedes, on the other hand, are slow-moving omnivores or scavengers that have two pairs of short legs on each body segment (after the first three segments, which only have one pair each). Immatures are similar to the adults.

Fig. 1.5 Various spiders:
top, tarantula; middle,
brown recluse; bottom,
black widow dorsal view
(not drawn to scale). (US,
DHEW, PHS, CDC,
pictorial keys)



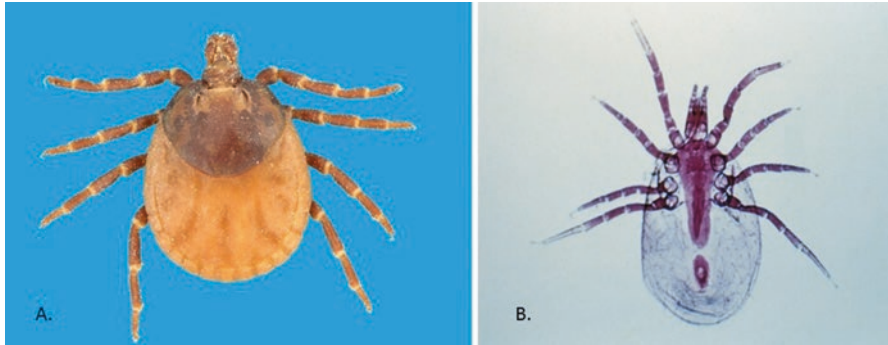


Fig. 1.6 Tick (a) and mite (b); not drawn to scale. (Tick photo courtesy Dr. Blake Layton, Mississippi State University and mite photo courtesy the CDC)



Fig. 1.7 Typical scorpion. (Photo copyright 2008 by Jerome Goddard Ph.D.)

1.2 Identification Methods for Arthropods

1.2.1 Morphological Identification

The historical method for identifying arthropods is performed by examining various structures (the morphology) on the specimens and making a classification based on size, shape, or number of those characters. This process often involves using published diagnostic keys wherein one follows a flowchart to arrive at the proper identification. Good-written keys include numerous high-quality photos or line drawings

Fig. 1.8 Centipedes and millipedes: (a) common house centipede, (b) giant centipede, (c) common millipede. (From US, DHEW, PHS, CDC, pictorial keys)

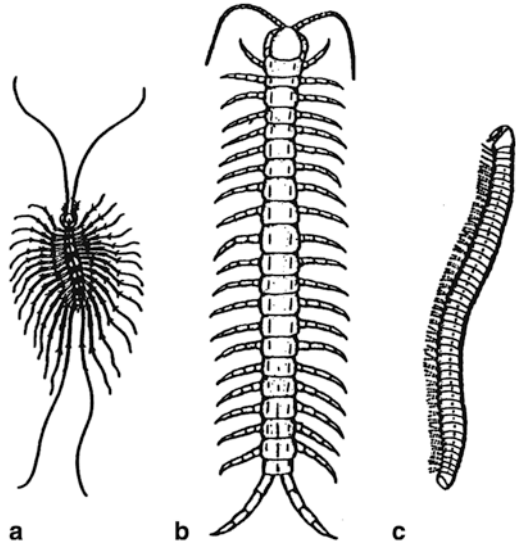


Fig. 1.9 Centipede. (Photo copyright 2016 by Jerome Goddard, Ph.D.)



of the structures mentioned (sometimes line drawing is actually better at showing detail than photographs). A written diagnostic key may look something like this:

1. Second antennal segment without a laterodorsal longitudinal seam . . .
Acalypteratae
- 1' Second antennal segment with a complete laterodorsal longitudinal seam . . .
go to 2
2. Hypopleuron (Meron) usually without hairs or bristles . . . Anthomyiaria
- 2' Hypopleuron (Meron) usually with hairs or bristles in one or more rows . . .
go to 3

On the other hand, a picture key may look something like the one presented in Fig. 1.10.

Identification keys may continue on like this for hundreds of choices or couplets comprising many pages. As is immediately obvious, keys can use complex

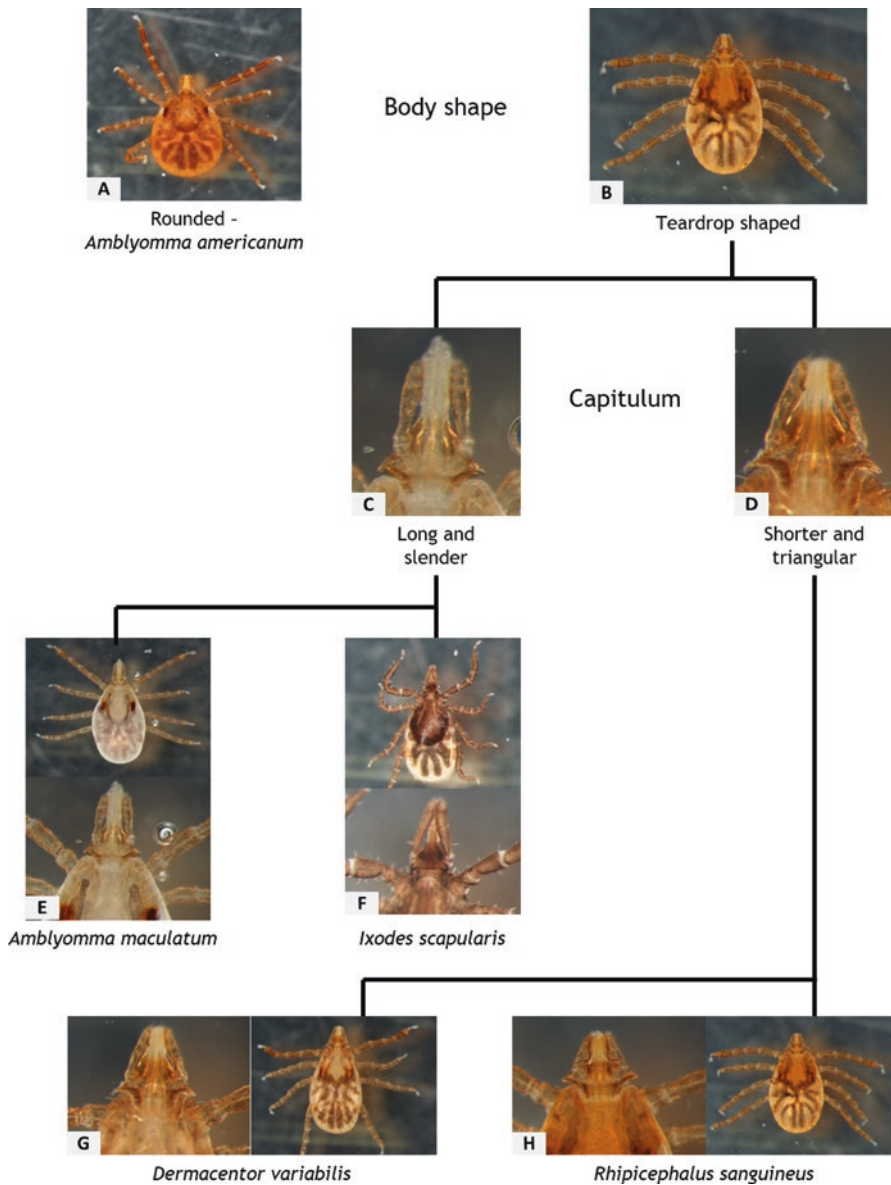


Fig. 1.10 Sample of a key for identifying nymphal ticks. (Photo courtesy Drs. Trisha Dubie and Bruce Noden, Oklahoma State University, used with permission)

terminology that lay people are not familiar with, making identification difficult. Well-written keys avoid jargon specific to any one group of arthropods and try to stay clear of couplets with vague phrases such as “such and such structure is longer.” If the person making the identification cannot see a specimen with the second option, they cannot make a decision. How long is longer? Therefore, morphological characteristics in a key should be quantitative whenever possible. Lastly, making a morphological identification does not harm the specimen, so voucher specimens can be deposited in a museum and kept for future examination if there is ever a question.

1.2.2 Molecular Identification

Molecular identification of arthropods involves looking at their genetic material by grinding up the arthropod in question (or pieces thereof), running a polymerase chain reaction (PCR) procedure to obtain DNA of portions of one or more key genes of that specimen and then comparing those gene sequences with known (published) sequences found in the National Center for Biotechnology Information, National Library of Medicine, and “GenBank.” Searching GenBank can reveal what the sequences most closely resemble. For example, if you did a PCR on an unidentified tick specimen using published primers for identifying ticks and then submitted your sequence to GenBank, you would get a result showing the closest matches. Your result may say “100% match with *Amblyomma americanum*.” If so, then that is the precise identification. If your result says “closest match is *Amblyomma parvum*, 86%,” then you can assume something went wrong with the analysis, or perhaps you have a specimen with no sequences in GenBank, or maybe you have found a new species. To improve the accuracy of molecular identifications, more than one gene should be used; the more the better.

In the last decade, there has been an effort to barcode all animal life using the cytochrome c oxidase gene. Use of these DNA barcodes has supposedly been validated [3], although not everyone agrees [4]. According to Will [4], people seeking an immediate panacea of molecular identification of species will encounter all sorts of constraints and inconsistencies in their work, most importantly, judgements about species boundaries. This problem is discussed in a paper by Sperling [5], wherein he discusses what DNA sequence or allozyme divergence number is the cutoff above which populations can be considered separate species. Based on his data from *Papilio* butterflies, Sperling says it is unreasonable to expect any kind of simple relationship between percent sequence divergence and the maintenance of genetic integrity [5].

1.2.3 Pros and Cons of Morphological Versus Molecular Identification

Some questions cannot be answered with a molecular analysis of an arthropod. The best example is developmental stage; in morphological identification, one can almost instantly determine the life stage of an arthropod. This determination is more difficult

using molecular methods. Certain arthropods contain different concentrations of mRNA at different time points in their development, in which case these genes can be amplified by PCR and analyzed for concentration; however, this is often not the case. If identification to developmental stage is required, morphological analysis is the best method to use. If developmental stage is not a point of concern and identification of species is the main concern, then maybe the more robust method is molecular analysis. However, genetic material is not always available, especially from historic collections. Additionally, molecular analysis is expensive and time-consuming; a laboratory needs access to DNA extraction kits, reagents for amplification, a thermal cycler to perform the amplification, access to sequencing capacity or electrophoresis, and the software required to analyze completed sequences. In addition to the expense, a complex understanding of the organism's genome is necessary to successfully use molecular analysis. For example, many hard ticks are closely related genetically, and some loci differentiate between species by only a few base pairs. If the targeted region of the genome is not informative between related species, this differentiation can be convoluted and inconclusive.

As mentioned, while molecular analysis can potentially provide clear distinction between species, these analyses are limited to the availability of genetic data. GenBank has a huge cache of genetic data with which to compare results, but there is no review process to submit genetic data to GenBank. This has allowed for at least a proportion of the data in GenBank to be not accurate, and how to determine what is and is not accurate is not simple. Studies have shown that up to 30% of the data publicly available in GenBank contains errors. If a BLAST search reveals numerous identical results from multiple sources, then chances are good the identification is correct; however, if only a few results are produced, confidence in the identification should be low. Another major point to consider when using molecular sequencing for species identification is that origin of all genetic data in GenBank is, in fact, morphological. Because GenBank is an open forum for submission, whoever submits the first sequence for an arthropod species designates it based on his own morphological identification. If the arthropod was misidentified, the data associated with it is incorrect. This can become a serious issue, as corrections may rarely be made if an original submission to GenBank was misidentified. No submissions to GenBank ever require publication, so submissions are thereby immune from peer review. Therefore, a misidentification could potentially persist unnoticed or uncorrected for decades.

Both morphological and molecular identification techniques have benefits and disadvantages, but a prudent decision to use one or the other must be made based on the available equipment, knowledge, and resources. In addition, the purpose of the identification must be considered; if the determination of developmental stage is required, or if physical characteristics or general fitness are a point of concern, morphological analysis will provide the best information. However, if a robust identification or secondary verification of a species is needed, molecular analysis will work well. Ideal situations employ both methods together and provide the most data; in this way, one can consider both physical characteristics and genetic information in tandem to make the most accurate determination. In either case, if identification seems to be an anomaly, further analysis is necessary.