The Influence of Cooperative Bacteria on Animal Host Biology

Ninety percent of the cells in the human body are bacteria, and humans may be host to many thousands of different species of bacteria. These striking statistics are part of a new paradigm in microbiology in which bacteria are no longer viewed as disease-causing killers but more as lifelong partners that are often essential for the survival of their host. This book brings together a group of diverse scientists – evolutionary biologists, immunologists, molecular biologists, microbiologists, pathologists, and mathematicians – to discuss the evolution and mechanisms of bacteria–host interactions at all levels of complexity, ranging from associations of one bacterium with its host to the many hundreds of bacteria normally associated with mammals. Chapters deal with the evolution of bacteria–host interactions over the last 60 years (since the introduction of antibiotics) to a period of 3.8 billion years (since the evolution of single-celled life) and discuss bacterial interactions with multicellular life forms such as coral reefs, insects, mice, and men. This book should be of interest to the widest range of biological scientists.

Margaret J. McFall-Ngai is Professor of Medical Microbiology and Immunology at the University of Wisconsin School of Medicine.

Brian Henderson is Professor of Cell Biology and head of the Cellular Microbiology Research Group in the Division of Microbial Diseases, Eastman Dental Institute, University College London. He is the co-editor of *Molecular Chaperones and Cell Signalling* (2005), *Bacterial Evasion of Host Immune Responses* (2003), and co-author of *Bacterial Disease Mechanisms* (2002).

Edward G. Ruby is Professor of Medical Microbiology and Immunology at the University of Wisconsin School of Medicine.

Published Titles

1. *Bacterial Adhesion to Host Tissues*. Edited by Michael Wilson 0521801079
2. *Bacterial Evasion of Host Immune Responses*. Edited by Brian Henderson & Petra Oyston 0521801737
3. *Dormancy in Microbial Diseases*. Edited by Anthony Coates 0521809401
4. *Susceptibility to Infectious Diseases*. Edited by Richard Bellamy 0521815258
5. *Bacterial Invasion of Host Cells*. Edited by Richard Lamont 0521809541
6. *Mammalian Host Defense Peptides*. Edited by Deirdre Devine & Robert Hancock 0521822203
7. *Bacterial Protein Toxins*. Edited by Alistair Lax 052182091X
8. *The Dynamic Bacterial Genome*. Edited by Peter Mullany 0521821576
9. *Salmonella Infections*. Edited by Pietro Mastroeni & Duncan Maskell 0521835046

Forthcoming Titles in the Series

Quorum Sensing and Bacterial Cell-to-Cell Communication. Edited by Donald Demuth & Richard Lamont 0521846382

Phagocytosis of Bacteria and Bacterial Pathogenicity. Edited by Joel Ernst & Olle Stendahl 0521845696

Cambridge University Press
0521834651 - The Influence of Cooperative Bacteria on Animal Host Biology
Edited by Margaret J. McFall-Ngai, Brian Henderson and Edward G. Ruby
Frontmatter
More information

Over the past decade, the rapid development of an array of techniques in the fields of cellular and molecular biology have transformed whole areas of research across the biological sciences. Microbiology has perhaps been influenced most of all. Our understanding of microbial diversity and evolutionary biology, and of how pathogenic bacteria and viruses interact with their animal and plant hosts at the molecular level, for example, has been revolutionized. Perhaps the most exciting recent advance in microbiology has been the development of the interface discipline of Cellular Microbiology, a fusion of classic microbiology, microbial molecular biology, and eukaryotic cellular and molecular biology. Cellular Microbiology is revealing how pathogenic bacteria interact with host cells in what is turning out to be a complex evolutionary battle of competing gene products. Molecular and cellular biology are no longer discrete subject areas but vital tools and an integrated part of current microbiological research. As part of this revolution in molecular biology, the genomes of a growing number of pathogenic and model bacteria have been fully sequenced, with immense implications for our future understanding of microorganisms at the molecular level.

Advances in Molecular and Cellular Microbiology is a series edited by researchers active in these exciting and rapidly expanding fields. Each volume focuses on a particular aspect of cellular or molecular microbiology and provides an overview of the area, as well as examines current research. This series will enable graduate students and researchers to keep up with the rapidly diversifying literature in current microbiological research.

CELLULAR MICROBIOLOGY

AMCM

ADVANCES IN MOLECULAR AND

Advances in Molecular and Cellular Microbiology 10

The Influence of Cooperative Bacteria on Animal Host Biology

EDITED BY
MARGARET J. McFALL-NGAI
University of Wisconsin, Madison

BRIAN HENDERSON
University College London

EDWARD G. RUBY
University of Wisconsin, Madison

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
40 West 20th Street, New York, NY 10011-4211, USA

www.cambridge.org
Information on this title: www.cambridge.org/9780521834650

First published 2005

Printed in the United States of America

A catalog record for this publication is available from the British Library.

Library of Congress Cataloging in Publication Data

The influence of cooperative bacteria on animal host biology / edited by
Margaret J. McFall-Ngai, Brian Henderson, Edward G. Ruby.
p. ; cm. – (Advances in molecular and cellular microbiology ; 10)
Includes bibliographical references and index.
ISBN 0-521-83465-1 (hardback)
1. Host-bacteria relationships. 2. Symbiosis.
[DNLM: 1. Immunity, Cellular. 2. Bacteria – genetics. 3. Bacteria – immunology.
4. Bacteria – pathogenicity. 5. Host-Parasite Relations. 6. Models, Animal.
7. Symbiosis. QW 568 I43 2005] I. McFall-Ngai, Margaret Jean. II. Henderson,
Brian, PhD. III. Ruby, Edward G. IV. Title. V. Series.
QR100.8.S9I546 2005
579.3'17852 – dc22 2005006653

ISBN-13 978-0-521-83465-0 hardback
ISBN-10 0-521-83465-1 hardback

Contents

Preface *page* **xi**
Contributors **xv**

I Evolutionary biology of animal host–bacteria interactions

1 How have bacteria contributed to the evolution of multicellular animals? 3
Carole S. Hickman

2 The interface of microbiology and immunology: A comparative analysis of the animal kingdom 35
Margaret McFall-Ngai

3 Co-evolution of bacteria and their hosts: A marriage made in heaven or hell? 57
Jörg Hacker, Ulrich Dobrindt, Michael Steinert, Hilde Merkert, and Ute Hentschel

4 Industrial revolution and microbial evolution 73
Fernando de la Cruz and Julian Davies

5 Bacteria evolve and function within communities: Observations from experimental *Pseudomonas* populations 83
Paul B. Rainey

II Bacterial ecology and the host as an environment

6 Coral symbioses: The best and worst of three kingdoms 103
Eugene Rosenberg

7 Interactions between inherited bacteria and their hosts: The *Wolbachia* paradigm 119
Zoe L. Veneti, Max Reuter, Horacio Montenegro, Emily A. Hornett, Sylvain Charlat, and Gregory D. Hurst

8 Microbial communities in lepidopteran guts: From models to metagenomics 143
Jo Handelsman, Courtney J. Robinson, and Kenneth F. Raffa

9 Commensal diversity and the immune system: Modelling the host-as-network 169
Robert M. Seymour

III Cellular interactions at the bacteria–host interface

10 Beneficial intracellular bacteria in the *Dryophthoridae*: Evolutionary and immunological features of a pathogenic-like relationship 203
Abdelaziz Heddi and Caroline Anselme

11 Type III secretion in *Bordetella*–host interactions 223
Seema Mattoo and Jeffrey F. Miller

12 Resident bacteria as inductive signals in mammalian gut development 249
Lora V. Hooper

13 Virulence or commensalism: Lessons from the urinary tract 265
Göran Bergsten, Björn Wullt, and Catharina Svanborg

IV Bacterial interactions with the immune system

14 Host responses to bacteria: Innate immunity in invertebrates 293
L. Courtney Smith

15 Bacterial recognition by mammalian cells 321
Clare E. Bryant and Sabine Tötemeyer

16 Moonlighting in protein hyperspace: Shared moonlighting proteins and bacteria–host cross talk 347
Brian Henderson

17 Cell signalling pathways as targets for bacterial evasion and pathology 375
Andrew S. Neish

18 Shaping of the the bacterial world by human intervention 399
Rino Rappuoli

Index 409

Preface

Bacteriology can be traced back to Anton van Leuwenhooek in the late seventeenth century, who first saw the magnitude of the bacterial colonisation of the planet Earth. However, it was in the nineteenth century that bacteriology, as we know it, was created by the towering figures of scientists such as Louis Pasteur and Robert Koch of bacterial disease fame and Serge Winogradsky, who pioneered the characterisation of the activity of bacteria in natural habitats. Bacteriology begat immunology, and the twentieth century saw the development of antibacterial vaccines and then the discovery of antibiotics. These naturally occurring drugs created the false illusion that we had "beaten the bugs," and bacteriology as a scientific discipline went into decline. Nevertheless, the study of bacteria, such as *Escherichia coli*, and of bacteriophage was at the foundation of modern molecular biology. The emergence of widespread antibiotic resistance in the late twentieth century was the spur to reactivate bacteriology, which is now a flourishing discipline in its many guises, such as molecular microbiology, cellular microbiology, and environmental microbiology.

Throughout the twentieth century, there was a growing realisation that bacteria did more than simply cause disease, and evidence began to mount that most animals contained their own populations of bacteria that were variously termed: commensal bacteria, indigenous microbiota, microflora, and so on. It was not until the advent of techniques allowing molecular phylogenetic analysis of the life forms in environmental samples (including those from animals) that the magnitude of the diversity of the prokaryotic world became realised. We now understand that microbial life forms, particularly bacteria, are the predominant organisms on our planet, with a staggering diversity. What has been even more astonishing is the discovery that the

majority of multicellular creatures on our planet live with many specific bacterial partners. In this volume, we describe these organisms as cooperative bacteria. Humans, most of whom fear bacterial infection, may be the acme of bacterial cooperation as ninety percent of the cells in the average human are bacteria, and the number of bacterial species living happily with us is estimated to be between 1,000 and 3,000. Compare this with the 50 or so bacteria (many of which form part of the cooperative assembly) that have the potential to cause human disease. This suggests that for the last century or more, we have been looking at bacteria through the wrong end of the telescope.

This volume arose from a meeting held in the beautiful lake resort of Bellagio, Italy, and funded by the Rockefeller Foundation. Scientists from diverse disciplines but with a common interest in bacteria–host interactions came together to discuss the biology of animal–bacterial cooperation and what it means for both partners.

This volume is divided into four sections. Part I discusses the evolution of cooperation and addresses key questions about the role of cooperation as an evolutionary pressure on both prokaryotes and eukaryotes, as well as the influence of bacterial cooperation in the evolution of the complex vertebrate acquired immune response. Biological evolution is generally viewed on the scale of millions of years. However, as the last two chapters in this section describe, rapid changes in phenotype can arise in bacterial populations in response to selection factors in their environment, such as antibiotics. In Part II attention focuses on the ecological interactions between bacteria and their multicellular hosts, and the reader is introduced to the roles of bacteria in such diverse activities as coral bleaching and the control of insect reproduction. A major problem in the study of cooperative bacteria is the complexity of the "system" that is created between bacteria and their hosts. The final chapters in this section deal with methods of analysis of cooperative systems using metagenomics and mathematical modelling. Part III discusses our emerging knowledge of how cooperative bacteria interact with their hosts at the molecular level in a variety of systems ranging from intracellular bacteria in insects to the complex systems found in mammalian tissues such as the gut, genitourinary system, and respiratory tract. The final section, Part IV, considers how cooperative bacteria interact with innate and acquired immunity, and discusses our rapidly advancing knowledge of the innate immune responses of invertebrates and the mechanisms by which vertebrates immunologically recognise and cope with bacteria, including their cooperative partners. The final chapter reviews how much we have gained control over our cooperative bacteria in the last 50 years.

This volume will be of interest to a wide range of biological scientists, including basic microbiologists, medical microbiologists, epidemiologists, cell biologists, virologists, parasitologists, ecologists, and zoologists, and should be useful to undergraduate, postgraduate, and postdoctoral scientists working at the frontier of a new understanding of the role of cooperative bacteria in animal host biology.

Contributors

Caroline Anselme
Laboratoire de Biologie
Fonctionnelle Insectes et
Interactions
URM INRA/INSA de Lyon
Bât. Louis Pasteur
20 Avenue Albert Einstein
69621 Villeurbanne Cedex
France
anselme@insa-lyon.fr

Göran Bergsten
Department of Microbiology,
Immunology and Glycobiology
Institute of Laboratory Medicine
Lund University
S-223 62 Lund
Sweden
Goran.Bergsten@mig.lu.se

Clare E. Bryant
Department of Clinical Veterinary
Medicine
University of Cambridge
Madingley Road
Cambridge CB3 OES
United Kingdom
Ceb27@cus.cam.ac.uk

Sylvain Charlat
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
s.charlat@ucl.ac.uk

Julian Davies
Department of Microbiology and
Immunology
University of British Columbia
Vancouver
British Columbia
Canada V6T 1Z3
JED@UNIXG.UBC.CA

Fernando de la Cruz
Departmento de Biologia Molecular
(Unidad Asociada al CIB)
Universidad de Cantabria
Spain
delacruz@medi.unican.es

Ulrich Dobrindt
Institut für Molekulare
Infektionsbiologie
Röntgenring 11
Würzburg D-97070
Germany
u.dobrindt@mail.uni-wuerzburg.de

Jörg Hacker
Institut für Molekulare
Infektionsbiologie
Röntgenring 11
Würzburg D-97070
Germany
j.hacker@mail.uni-wuerzburg.de

Jo Handelsman
Department of Plant Pathology
University of Wisconsin
1630 Linden Dr.
Madison
Wisconsin 53706-1598
USA
JOH@PLANTPATH.WISC.EDU

Abdelaziz Heddi
Laboratoire de Biologie
Fonctionnelle Insectes et
Interactions
URM INRA/INSA de Lyon
Bât. Louis Pasteur
20 Avenue Albert Einstein
69621 Villeurbanne Cedex.
France
Abdelaziz.heddi@insa-lyon.fr

Brian Henderson
Division of Microbial Diseases
Eastman Dental Institute
University College London
256 Gray's Inn Road
London WC1X 8LD
United Kingdom
b.henderson@eastman.ucl.ac.uk

Ute Hentschel
Institut für Molekulare
Infektionsbiologie
Röntgenring 11
Würzburg D-97070
Germany
u.hentschel@mail.uni-wuerzburg.de

Carole S. Hickman
Department of Integrative Biology
University of California Berkeley
Berkeley
California 94720-3140
USA
caroleh@socrates.berkeley.edu

Lora V. Hooper
Center for Immunology
The University of Texas
Southwestern Medical Center
at Dallas
5323 Harry Hines Blvd.
Dallas
Texas 75390
USA
Lora.hooper@utsouthwestern.edu

Emily A. Hornett
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
e.hornett@ucl.ac.uk

Gregory D. Hurst
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
g.hurst@ucl.ac.uk

Seema Mattoo
Department of Pharmacology
University of California, San Diego
School of Medicine
Leich tag Biomedical Research Building
Rm 249, Bay M
9500 Gilman Drive
Dept 0721
La Jolla
California 92093-0721
smattoo@ucas.edu.

Margaret McFall-Ngai
Department of Medical Microbiology and Immunology
University of Wisconsin
1300 University Avenue
Madison
Wisconsin 53706
USA
mjmcfallngai@wisc.edu

Hilde Merkert
Institut für Molekulare Infektionsbiologie
Röntgenring 11
Würzburg D-97070
Germany
h.merkert@mail.uni-wuerzburg.de

Jeffrey F. Miller
UCLA School of Medicine
10833 LeConte Avenue
43-46CHS
Los Angeles
California 90095
USA
jfmiller@ucla.edu

Horacio Montenegro
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
h.montenegro@ucl.ac.uk

Andrew S. Neish
Department of Pathology
Emory University School of Medicine
105-F Whitehead
615 Michaels St.
Atlanta
Georgia 30322
USA
aneish@emory.edu

Kenneth F. Raffa
Department of Entomology
University of Wisconsin
1630 Linden Dr.
Madison
Wisconsin 53706-1598
USA
raffa@entomology.wisc.edu

Paul B. Rainey
School of Biological Sciences
University of Auckland
Private Bag 92019
Auckland
New Zealand
p.rainey@auckland.ac.nz

Rino Rappuoli
Chiron Vaccines
Via Fiorentina 1
53100 Siena
Italy
RINO.RAPPUOLI@CHIRON.COM

Max Reuter
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
m.reuter@ucl.ac.uk

Courtney J. Robinson
Department of Plant Pathology
University of Wisconsin
1630 Linden Dr.
Madison
Wisconsin 53706-1598
USA
cjr@plantpath.wisc.edu

Eugene Rosenberg
Department of Molecular
Microbiology and Biotechnology
Tel Aviv University
Ramat Aviv 69978
Israel
eros@post.tau.ac.il

Edward N. Ruby
Department of Medical
Microbiology and Immunology
University of Wisconsin
1300 University Avenue
Madison
Wisconsin 53706
USA
egruby@wisc.edu

Robert M. Seymour
Department of Mathematics
University College London
Gower Street
London WC1E 6BT
United Kingdom
r.seymour@math.ucl.ac.uk

L. Courtney Smith
Department of Biological Sciences
George Washington University
Lisner Hall 334
2023 G St. NW
Washington, DC 20052
USA
csmith@gwu.edu

Michael Steinert
Institut für Molekulare
Infektionsbiologie
Röntgenring 11
Würzburg D-97070
Germany
m.steinert@mail.uni-wuerzburg.de

Cambridge University Press
0521834651 - The Influence of Cooperative Bacteria on Animal Host Biology
Edited by Margaret J. McFall-Ngai, Brian Henderson and Edward G. Ruby
Frontmatter
More information

Catharina Svanborg
Department of Microbiology,
Immunology and Glycobiology
Institute of Laboratory Medicine
Lund University
S-223 62 Lund
Sweden
Catharina.svanborg@mig.lu.se

Sabine Tötemeyer
Department of Clinical Veterinary
Medicine
University of Cambridge
Madingley Road
Cambridge CB3 OES
United Kingdom
st2b2@cam.ac.uk

Zoe Veneti
Department of Biology
University College London
4 Stephenson Way
London NW1 2HE
United Kingdom
z.veneti@ucl.ac.uk

Björn Wullt
Department of Urology
Lund University
22185 Lund
Sweden
bjorn.wullt@urokir.lu.se