Advances in Environmental Microbiology 4

Christon J. Hurst *Editor*

Modeling the Transmission and Prevention of Infectious Disease

Springer

Advances in Environmental Microbiology

Volume 4

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More information about this series at http://www.springer.com/series/11961

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ISSN 2366-3324 ISSN 2366-3332 (electronic)
Advances in Environmental Microbiology
ISBN 978-3-319-60614-9 ISBN 978-3-319-60616-3 (eBook)
DOI 10.1007/978-3-319-60616-3

Library of Congress Control Number: 2017948674

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The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Dedication

I dedicate this book to my doctoral advisor and dear friend Charles Peter Gerba. When I started working in Chucks laboratory at Baylor College of Medicine in Houston, Texas, I was his first graduate student and he said that he kept me around because my mother periodically mailed homemade cookies to the laboratory. Usually those were chocolate chip cookies that contained chow mein noodles which my mother added as reinforcement against the cookies breaking during handling by the postal service. Both Chuck and I did of course manage to survive those years together at Baylor. I learned a lot about science and performing research. The cookies from my mother were good, and Chuck defended me against the departmental politics. Chuck still keeps going at the task of training new generations of scientists and has advised more than 129 additional graduate students. His wife Peggy keeps him grounded as he navigates the frustrating path of research and advising. I owe Chuck an appreciative "Thank you".

Charles P. Gerba

Series Preface

The light of natural philosophy illuminates many subject areas including an understanding that microorganisms represent the foundation stone of our biosphere by having been the origin of life on Earth. Microbes therefore comprise the basis of our biological legacy. Comprehending the role of microbes in this world which together all species must share, studying not only the survival of microorganisms but as well their involvement in environmental processes, and defining their role in the ecology of other species, does represent for many of us the Mount Everest of science. Research in this area of biology dates to the original discovery of microorganisms by Antonie van Leeuwenhoek, when in 1675 and 1676 he used a microscope of his own creation to view what he termed "animalcula," or the "little animals" which lived and replicated in environmental samples of rainwater, well water, seawater, and water from snow melt. Van Leeuwenhoek maintained those environmental samples in his house and observed that the types and relative concentrations of organisms present in his samples changed and fluctuated with respect to time. During the intervening centuries we have expanded our collective knowledge of these subjects which we now term to be environmental microbiology, but easily still recognize that many of the individual topics we have come to better understand and characterize initially were described by van Leeuwenhoek. van Leeuwenhoek was a draper by profession and fortunately for us his academic interests as a hobbyist went far beyond his professional challenges.

It is the goal of this series to present a broadly encompassing perspective regarding the principles of environmental microbiology and general microbial ecology. I am not sure whether Antonie van Leeuwenhoek could have foreseen where his discoveries have led, to the diversity of environmental microbiology subjects that we now study and the wealth of knowledge that we have accumulated. However, just as I always have enjoyed reading his account of environmental microorganisms, I feel that he would enjoy our efforts through this series to summarize what we have learned. I wonder, too, what the microbiologists of still future centuries would think of our efforts in comparison with those now unimaginable discoveries which they will have achieved. While we study the many wonders of microbiology, we also further our recognition that the microbes are our biological critics, and in the end they undoubtedly will have the final word regarding life on this planet.

Christon J. Hurst in Heidelberg

Indebted with gratitude, I wish to thank the numerous scientists whose collaborative efforts will be creating this series and those giants in microbiology upon whose shoulders we have stood, for we could not accomplish this goal without the advantage that those giants have afforded us. The confidence and very positive encouragement of the editorial staff at Springer DE has been appreciated tremendously and it is through their help that my colleagues and I are able to present this book series to you, our audience.

Cincinnati, OH Christon J. Hurst

Volume Preface

This volume addresses two of the principle subject areas that must be considered as we research the goal of eliminating infectious diseases, those are blocking environmental transmission and understanding the ecological perspective of pathogens and their pathogenic processes. The first section of the book addresses environmental transmission and contains chapters that discuss the procedures used to assure microbiological safety of space flight habitats, a review of biocides and biocide resistance mechanisms, plus health and safety requirements for preventing aerosol related transmission of infections within health care treatment facilities. The second section of the book contains chapters which offer insight regarding ecological aspects of infectious disease. These ecological insights introduce us to the role of indigenous gut microbiota in maintaining human health; present discussion on environmentally ecountered bacterial and fungal pathogens associated with soil and water including those species which variously cause the necrotizing skin disease Buruli ulcer and coccidioidomycosis; and consider influenza A virus as an example for understanding how zoonoses, those infectious illnesses typically affecting other animals, spillover into human populations.

Cincinnati, OH Christon J. Hurst

Contents

Part I
Preventing the Environmental Transmission of Infections

Chapter 1
Preventing Infectious Diseases in Spacecraft and Space Habitats

Wing C. Wong, Cherie Oubre, Satish K. Mehta, C. Mark Ott, and Duane L. Pierson

Abstract Spacecraft crewmembers live and work in a closed environment that is monitored to ensure health and safety. Lessons learned from previous spaceflight missions have been incorporated into the design and development of the International Space Station (ISS). The microbial control actions on the ISS include engineering designs, such as high efficiency particulate air filtering of the air, microbial monitoring of the air, surfaces, and water, as well as remediation procedures when needed. This chapter will describe an overview of microbial risks of spaceflight focusing on measures to prevent infectious disease. The information discussed in this chapter is focused on the microbial monitoring activities in United States Operating Segment (USOS) of the ISS and experimental data obtained on USOS crewmembers.

1.1 Introduction

Spaceflight creates a unique environment where humans live and work for extended periods in a crowded spacecraft breathing reconditioned air and using reconditioned water. This closed environment creates difficult challenges for sustained human habitation. Early spaceflight missions, including Apollo, Skylab, NASA-Mir, and Space Shuttle missions, provided valuable knowledge about human spaceflight that is used to develop future spacecraft and habitats. In particular, the cumulative

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C.J. Hurst (ed.), *Modeling the Transmission and Prevention of Infectious Disease*, Advances in Environmental Microbiology 4, DOI 10.1007/978-3-319-60616-3_1

lessons learned from these early programs were applied to the ISS resulting in the most sophisticated and safe space habitat yet.

There are many physical impacts to humans living and working in space habitats. Spaceflight research has documented microgravity-related physiologic changes (Nicogossian et al. 1994) including bone mineral density and muscle mass loss (Trappe et al. 2009; Nagaraja and Risin 2013; Whitson et al. 1997; Aubert et al. 2005; Schneider and LeBlanc 1995), cardiovascular deconditioning (Aubert et al. 2005), neurovestibular imbalances (Bacal et al. 2003; Clément and Reschke 2008), and dysfunctional immunity (Crucian et al. 2013; Mehta et al. 2013).

In addition to documented physiologic effects, spaceflight introduces a variety of stressors including isolation, containment, psychosocial, physical exertion, anxiety, variable acceleration forces, elevated radiation, sleep deprivation, environmental contaminants, and others (De la Torre 2014). Further confounding the effects of these stressors is the subjective nature of individual crewmember's responses.

As future spaceflight missions expand outside of low-Earth orbit and increase in duration, these physiologic challenges will potentially increase in severity. During the extended duration multi-year missions, communication delays of up to 40 min roundtrip from Earth to Mars are anticipated, and there is a limited potential to return a crewmember to Earth for emergency treatment. Current research is identifying ways to prevent or minimize the impacts of the microgravity environment on the human.

1.2 Microbiological Risks and Their Adverse Effects

Infectious diseases are perhaps the best recognized adverse effects of microbial contamination affecting crew health and performance. Microorganisms accompany all spacecraft and habitats occupied by humans. The closed environments of these spacecraft increase the importance of infection control measures to keep crewmembers healthy, safe, and productive. Major potential microbiological routes of infection to crewmembers include food, surfaces, water, payloads, air, other crewmembers, animals, and biohazardous materials (Fig. 1.1).

Evidence gained from previous human spaceflight programs suggests that infectious diseases and allergic responses may increase on long-duration missions due to sustained immune dysfunction (Kaur et al. 2004, 2005; Mehta et al. 2001; Ott et al. 2004; Stowe et al. 2001; Crucian et al. 2013) and increased virulence of some microorganism (Wilson et al. 2007, 2008; Crabbe et al. 2011). In combination, a dysfunctional immune response and a potential for increased virulence could lead to an increased risk for infection of crewmembers during longer-duration missions. Other environmental contaminants, such as mold spores and animal dander, may

Fig. 1.1 Crewmembers gathering and eating in confined spaces in ISS

lead to allergic responses that can also jeopardize mission objectives. The release of volatile compounds from microorganisms can produce objectionable odors or, in the worst case, a toxic environment. Production of nonvolatile toxins, such as aflatoxins from fungi, can result in acute or delayed toxin effects. In addition, microbes can cause food spoilage that could affect the sustainability of a closed environment. Some viruses, such as cytomegalovirus, can diminish cell-mediated immune defenses. Cytomegalovirus (CMV) is a double-stranded DNA virus and is a member of the *Herpesviridae* family that has been associated with immunosuppression. Reactivation of CMV from latency results in serious morbidity and mortality in immunocompromised transplant recipients (Cook 2007; Hummel and Abecassis 2002).

Adverse effects of microorganisms vary in severity and can range from simple skin irritations to illnesses that can jeopardize either crewmember health and safety or mission objectives. Not all adverse effects of microorganisms result in crew illness. Microorganisms can cause biodegradation of critical materials, including system components and space suits, that can result in system failures, thus endangering crewmembers (Fig. 1.2).

Medical incidents in crewmembers have occurred since the onset of the US human space program. Reported illnesses and symptoms related to immune function during the Space Shuttle and ISS programs are listed in Table 1.1. Common infectious diseases and immune-related symptoms including allergic reactions, ear