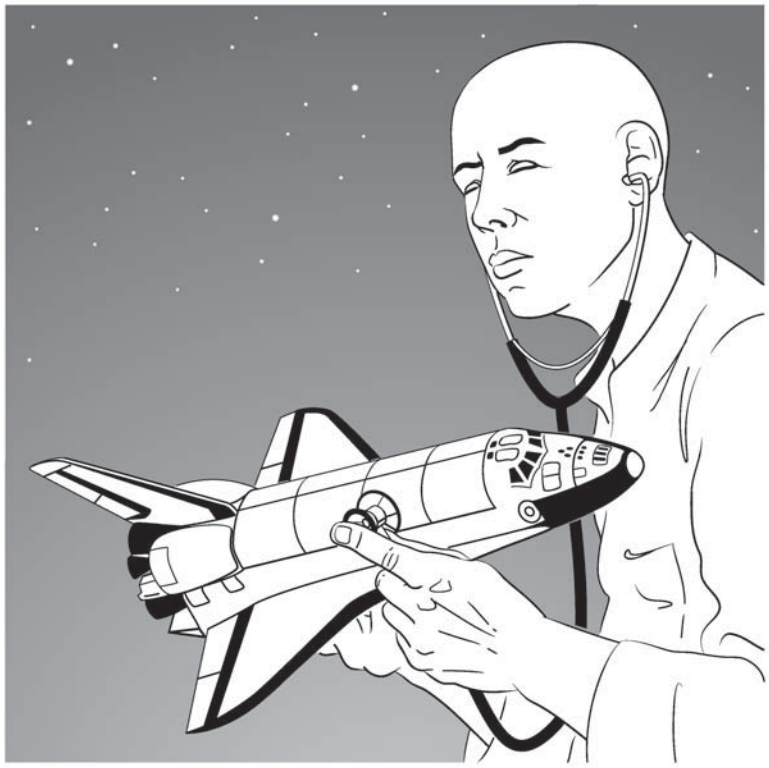
FUNDAMENTALS OF SPACE MEDICINE



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Fundamentals of Space Medicine

by

Gilles Clément

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Cover photo of Earth from Space: View of Africa and the Indian Ocean taken in Dec. 1972, by Apollo 17, the last of the Apollo missions to explore the Moon, Photo courtesy of NASA.

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Printed on acid-free paper

Printed in the Netherlands.

To my parents,
To my brother and sister,
To Josiane, Guillaume, and Jean-Loup

Contents

PREFACE

Didier Schmitt, M. D., Ph. D.
Head, Space Life Sciences
European Space Agency

Even before the actual beginnings of spaceflight people were interested in the question of what happens to human beings when they enter the extreme and fascinating environment of space. Decades of experimentation with biosatellites and more than 240 crewed spaceflights with about 450 astronauts from various countries have led to a solid knowledge base on many effects that the space environment has on living organisms. In many cases, many of which are mentioned in this book, the results obtained have significantly changed our concepts of physiological mechanisms. While advance in knowledge, as always, leads to further questions and yet some basic mechanisms are still unknown, the field of space life sciences has reached a maturity which allows to add on top of basic research the aspect of applying "space" knowledge for the benefit of the citizen on the ground. In Europe, where traditionally the majority of (physiological) space life sciences research is carried out by researchers who are also involved in "normal" physiological or clinical research on the ground, this application and transfer of "space knowledge" is a constant characteristic that defines our work.

At the same time, as in any field that matures, complexity is rising and specialists develop new experiments in order to make further progress. However, the need for "the big picture" regarding the various physiological systems and their interactions and interdependencies is growing at a similar rate. This book is remarkable in providing exactly this vast overview. In spanning an arc from cell biology via plants, and human physiology up to psychology the author collects a vast amount of information that will serve as fountain of knowledge and motivation to students in the life sciences with an interest in space and extreme environments. Also, the very practical advices on the preparation of space experiments, which builds on many years of first hand experience by the author, will prove invaluable to future space life science experimenters.

With the International Space Station providing for continuous international presence of human beings in space since October 2000, we have a unique tool at hands to perform further research. When thinking about the future of human spaceflight, one of the most exciting challenges is posed by a planetary mission that will carry human beings to the surface of our neighbor

planet, Mars. While naturally the knowledge and understanding that we have accumulated so far will provide a solid basis for the preparation of a mission to Mars, such a mission will be very different in nature compared with the experience in low Earth orbit.

Factors like the interplanetary radiation environment or the psychological effects of prolonged isolation and confinement will necessitate very different measures than what is currently used to counter spaceflight effects. Thus, space life sciences research continues to expand and has gained an additional third layer, which is the targeted preparation of mankind's future in space.

Didier Schmitt, M. D., Ph. D.
Head, Space Life Sciences
European Space Agency

28 May 2003

PREFACE

Douglas R. Hamilton, M. D., Ph. D.
Flight Surgeon

I am writing this preface on February 2nd, 2003 at 2am, because I can't sleep. My 7-year old daughter, Keltie, is sleeping beside me on the sofa and won't go to bed. She understands that today something very bad has happened to Iain Clark's mom, Laurel, and senses that I am very distraught. I have to tell her that "Miss Laurel" has gone away and that her schoolmate, Iain, will be without a mother. Just a few days ago, I was in the NASA Mission Control Center sitting at the SURGEON console with Laurel's husband, Jon, who also is a flight surgeon. We were supporting the Space Shuttle flight STS-107, laughing and joking around while we watched Laurel on a television monitor. She was living an experience that Jon and I could only dream about. I remember our biomedical engineers on our support console joking over the intercom that Jon should allow the Flight Activities Officer to remove the private family videoconference with Laurel from the timeline since he already had watched her for 12 hours during the previous shift. Thank goodness, Jon and Iain had that special private time with Laurel.

I was in the Mission Control Room helping execute the emergency procedures after the breakup of STS-107 earlier today. The Shuttle flight and payload controllers were working the issues like we had trained so many times before. I want you to know how proud I am of those remarkable men and women who stood at their consoles and remained calm and professional throughout the whole day. They knew when to run and when to walk. It was indeed an impressive sight.

Having been an attending physician in a hospital, I have felt the emotional hardship of escorting a patient's family out of the hospital after the death of a loved one, …only to turn around, walk back into the hospital and onto the ward, face your medical team with a calm demeanor, and with a steady hand, reach for the next patient's chart off the rack in the nursing unit. Rick, Willie, Mike, KC, Dave, Ilan, and Laurel will be sorely missed. The real measure of the space community will be how we pick ourselves up after being knocked down so hard.

If anyone knows how to take science from the bench and perform it in space, it is Gilles. He has been performing research with crewmembers in space and on the ground for more than 20 years. He knew Jon and Laurel because of their participation in science experiments and also because Jon is a board certified neurologist who, along with Gilles, has a passion for the

neurological aspects of space travel. I know that Gilles did not just lose science today but also very close friends.

I first met Gilles in 1992 when I was attending the International Space University (ISU) summer session in Kitakyushu, Japan. He taught us all about the neurological aspects of space travel. Since then, he and I have lectured together for the Space Life Sciences department at summer sessions from 1997 until the present (Vienna, Houston, Cleveland, Ratchasima, Valparaiso, Bremen, and Pomona). During this time, I have been able to familiarize Gilles with the operational aspects of space medicine and he acquainted me with the challenges facing scientific investigators such as himself. Together, we designed a series of space life sciences lectures which are intended for a multi-cultural audience who is not educated in life sciences. The magic of International Space University is that it uses this pedagogical approach for all aspects of space. To communicate the complex issues associated with space to such a diverse audience requires the natural teaching ability of educators like Gilles and many of the other department lecturers at ISU.

Right after this tragic event, I thought a document that describes how we medically support a crew like STS-107 and what they were trying to scientifically accomplish needs to be written. Serendipitously, Gilles emailed me his initial manuscript for this book just a few weeks ago and asked me to write a preface. Hence I find myself writing this preface at 2am in the morning, after one of the saddest days of my life. Laurel and Jon Clark are both flight surgeons and pilots. They represent the "pointy end of the spear" when it comes to medical support in space. Laurel as a physician astronaut and Jon as a console flight surgeon. The medical issues they and others need to deal with and the scientific questions behind these complex problems are clearly represented in Gilles marvelous book. I have read many books and articles about physiology and space life sciences, but none of them successfully make the connection between space life sciences and medical operations. When you read this book, you will understand what the space medical community is all about and the real challenges that face the flight surgeon and life science investigator.

Gilles, thank you for writing this book and allowing me to be part of it.

Now, I must put my daughter back into bed…and say goodbye to some close friends.

Douglas R. Hamilton
M. D., Ph. D., M. Sc. E. Eng
P. E., P. Eng., ABIM, FRCPC
Flight Surgeon / Electrical Engineer

FOREWORD

When preparing my courses for the International Space University (ISU), where I teach in the Department of Space Life Sciences since 1989, I realized it was difficult to get the information I needed regarding the effects of spaceflight on humans. Looking for this information into the original papers published in scientific journals, finding the essential, and making clear presentations for students (with often limited background in biology) requires a lot of time and effort. Most reviews on this topic are either addressed to specialists (Churchill 1997, Colin 1990, DeHart 1985, DeHart and Davis 2002, Moore et al. 1996) or to laymen (Lujan and White 1994, Nicogossian and Parker 1982, Oser and Battrick 1989, Stine 1997). Other reviews are hard to get or most of their content is outdated (Clavin and Gazenko 1975, Johnston and Dietlein 1977, Link 1965, Nicogossian 1977, Nicogossian et al. 1993, Parker and Jones 1975). Lastly, most of these reviews are lacking the basic principles of human physiology and a structured presentation directly useful for educational lectures.

Thus, I decided to write "Fundamentals of Space Medicine" as a textbook for professors and undergraduate or graduate students. Why this title? *Space Medicine* and *Space Physiology* are often viewed as two aspects of space life sciences, with the former being more operational, and the latter being more investigational. *Space Medicine* tries to solve medical problems encountered during space missions. These problems include some adaptive changes to the environment (microgravity, radiation, temperature, and pressure) and also some non-pathologic changes that become mal-adaptive on return to Earth (e.g., bone loss). *Space Physiology* tries to characterize body responses to space, especially microgravity. It provides the necessary knowledge, hence the "fundamentals", required for an efficient space medicine.

As a neurophysiologist participating in space research since 1982, with experiments manifested on Salyut-7, Mir, and 31 Space Shuttle flights, I know what it takes to collect data during relatively simple space experiments, and then try to make sense of the sparse, often contradictory, results in a scientific paper. Many articles in space life sciences include a discussion which goes far beyond the results actually obtained. The interpretations proposed by one author may some day prove incorrect as new data are collected. In this textbook, I have tried to compile these scientific facts, and apologize to the authors if all their interpretations are not included.

Now that the International Space Station (ISS) is being assembled, the opportunities for conducting biomedical research in orbit are reduced because of the limited crew time. Until the laboratories in the ISS are fully operational,

this is a good time to review what we learnt from previous studies. This book reflects *what we do know* in space life sciences at the beginning of the 21st century. It also points to the missing data, i.e., *what we don't know* and *what we should know* before committing to a larger access for humans (i.e., space tourists, by contrast with the current, professional astronauts) in space and for longer duration exploratory missions.

The structure of this book is such that it reviews step by step the changes in the major body functions during spaceflight, from the cellular level to the behavioral and cognitive levels:

Chapter 1 starts with an introduction to the environmental challenges that spaceflight poses to the human body, and continues with a short history of space life sciences research.

Chapter 2 reviews the effects of microgravity and radiation at the cellular level on bacteria, animals, plants, and humans, including the issues of reproduction and development.

The following chapters each review the effects of spaceflight on the major human body functions: Chapter 3: Neuro-sensory function (the brain in space); Chapter 4: Cardio-vascular function (the heart in space); Chapter 5: Musculo-skeletal function (the muscle and bone in space); Chapter 6: Psycho-sociological issues (the mind in space).

However, every system or process must ultimately be viewed in the context of the entire body. The consequences of the fore mentioned changes at a function level on the health and well being of the astronauts are therefore described in the Chapter 7: Operational Space Medicine.

Chapter 8 concludes this review with some tips from the author of this book on how to proceed for proposing and planning a space experiment which utilizes humans as test subjects, given the available resources and constraints of space missions.

Each of these chapters corresponds to one core lecture of the ISU Space Life Sciences Department. These lectures were developed with the help of many people from all over the world in a collegial and collaborative environment. In particular, the areas related to the medical effects of spaceflight are significantly due to the contribution of Doug Hamilton.

Some space-related changes and interpretations for these changes are sometimes described in the text in greater details than what is required for a plenary lecture. For this reason, a PowerPoint version of each of these lectures with the key concepts presented in bullet-form is included on the CD-ROM bound to this book. These PowerPoint presentations also include related colorful illustrations and video clips.

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ACKNOWLEDGMENTS

[Sitting atop the Saturn V rocket] I am everlasting thankful that I have flown before, and that this period of waiting atop a rocket is nothing new. I am just as tense this time, but the tenseness comes mostly from an appreciation of the enormity of our undertaking rather than from the unfamiliarity of the situation. […] I am far from certain that we will be able to fly the mission as planned. I think we will escape with our skins, or at least I will escape with mine, but I wouldn't give better than odds on a successful [Moon] landing and return. There are just too many things that can go wrong.

—Mike Collins, July 16, 1969 (Carrying the Fire: An Astronaut's Journeys. New York, NY: Farrar, Strauss, Giroux, 1989)

I was finishing up this book when I learned about the Space Shuttle *Columbia* accident of 1 February 2003 and the loss its seven astronauts. STS-107 was a life and material sciences mission, so this was clearly a tragic event in the history of human spaceflight and for space research in particular.

Although I am convinced that space research is and will be helping in many ways our daily life, the price of giving the lives of brave men and women for science is too much to pay. I had personally met one of the STS-107 crewmembers, when he kindly volunteered to participate in one of my experiment, so I am even more saddened by this tragedy. *Columbia* has also a special place in my own memories. It was the ship that carried aloft the Spacelab from 1983 until 1998. I was the principal or co-investigator of several experiments that flew aboard this remarkable spacecraft (IML-1, LMS, and more recently, Neurolab). This Space Shuttle in particular was the proud focus of not only my life but that of hundreds of scientists around the world for many years. *Columbia*, you served us well!

This book is dedicated to the astronauts and cosmonauts, without whom the work reported here would have been impossible.

I would like to give my sincere thanks to the 73 astronauts and cosmonauts who have participated as test subjects in my own space experiments aboard Salyut-7, Mir, and the Space Shuttle, and the hundreds of volunteers who served as ground-based control subjects for these experiments.

I would also like to take this opportunity to thank my space mentors (Millard Reschke, Francis Lestienne), my long-term friends and collaborators in these experiments (Scott Wood, William Paloski), and my former students (Corinna Lathan and Claudie Haigneré—the latter is now the French Minister of Research and High Technologies), with whom I have shared exciting moments of space exploration. On a broader scale, acknowledgments are due to CNES, CNRS, ESA, and NASA for their continuous support in my research activities.

As mentioned earlier, my knowledge in certain areas of the book is significantly due to the contributions of Doug Hamilton. His experience in the Medical Division Branch at the NASA Johnson Space Center as a flight surgeon (the second best job at NASA, just after the astronaut one) was priceless. As my partner in crime at ISU since many years, Doug has helped me to put together all this material in an easily accessible format. He should be recognized as the author of the PowerPoint lectures on the "Cardio-Vascular System in Space" and on "Operational Space Medicine".

Thanks to many people for their help in providing content for this book, and in particular Elisa Allen, Oliver Angerer, Oleg Atkov, Mike Barratt, Alain Berthoz, Sheryl Bishop, Susanne Churchill, Guillaume Clément, Bernard Comet, Jan Cook, Susan Doll, Elena Grifoni, Michel Imbert, Sonya Japenga, Corrie Lathan, Patricia Santy, Barbara Ten Berge, and Michel Viso.

I am grateful to Mr. Philippe Tauzin, from the Service Commun Multimédia of the Université Paul Sabatier in Toulouse, for his help with some of the illustrations, including the book cover. I also appreciate the great work done at NASA to document, catalogue, and give access to its archives, and video and pictures gallery. Many photographs in this book come from this gallery, and most of them were taken by the astronauts themselves during their space missions.

My deep appreciation to those who have kindly accepted to review this book, and to Drs. Didier Schmitt and Douglas Hamilton for writing the Preface.

Last but not least, I thank Dr. Harry (J.J.) Blom, my editor, who offered me the opportunity to disseminate the legacy of space life sciences research in the Space Technology Library series.

Gilles Clément, Ph. D.

Toulouse, 28 May 2003