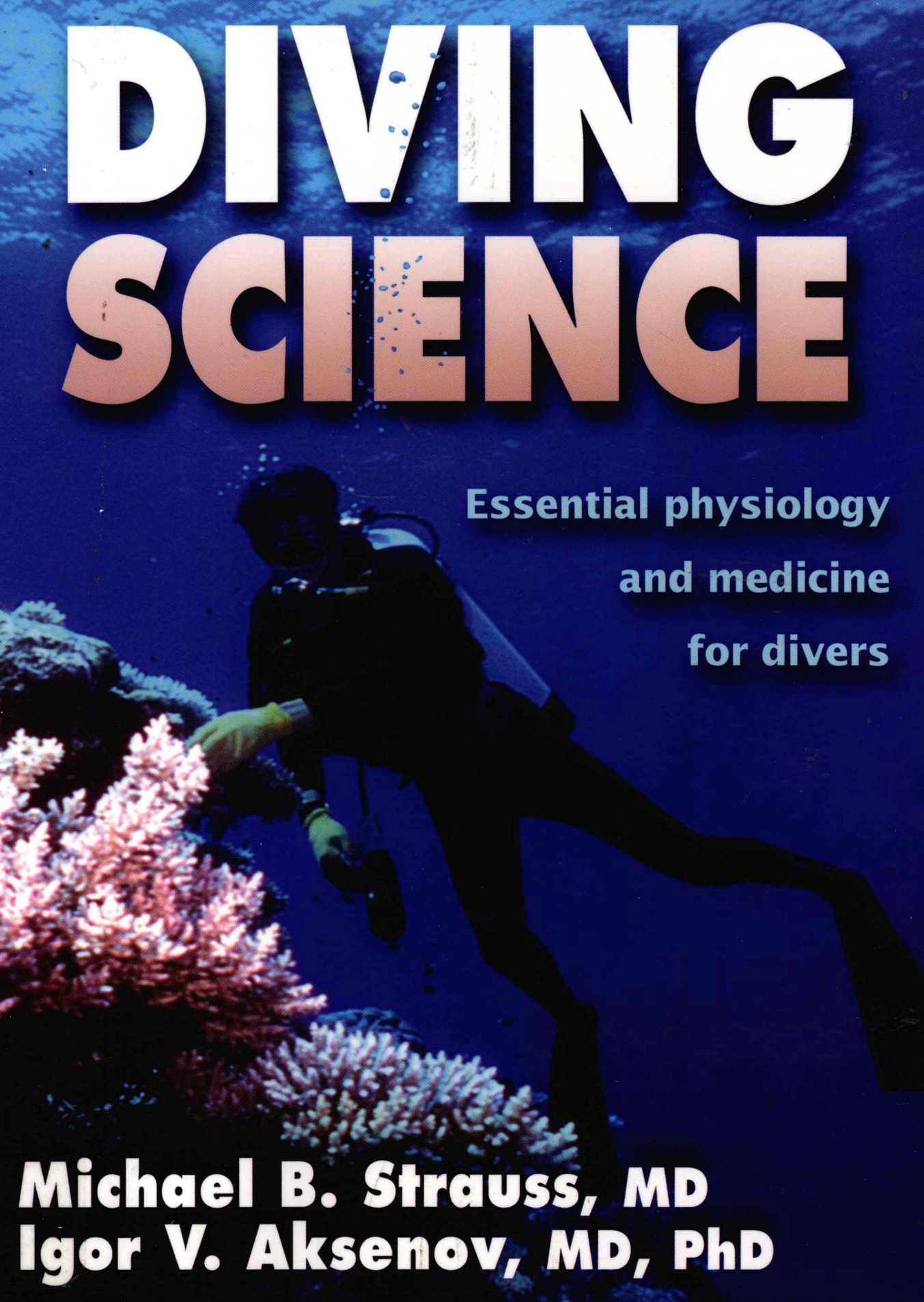
DIVING SCIENCE



Essential physiology and medicine for divers

Michael B. Strauss, MD
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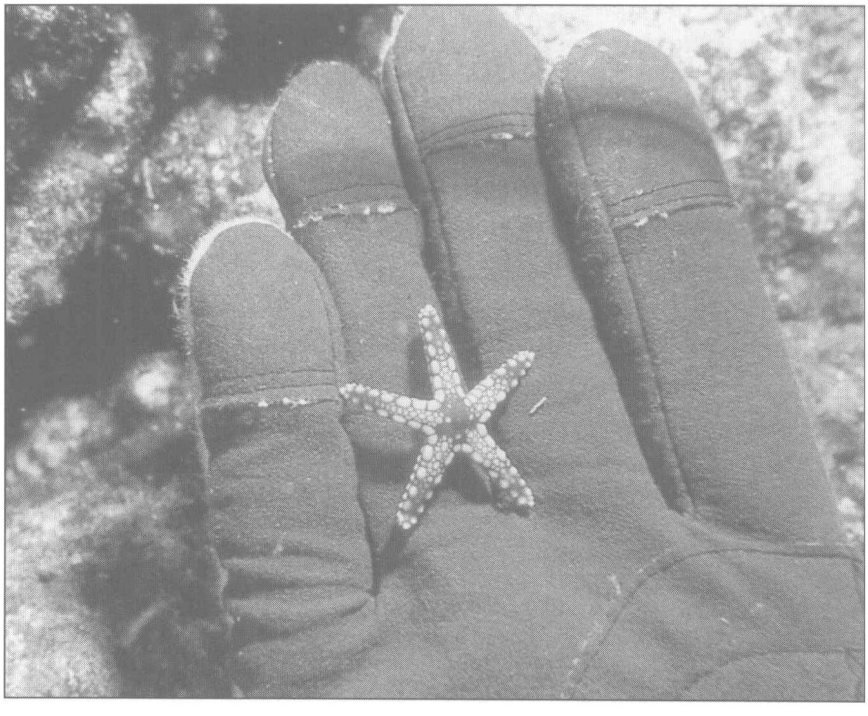
PREFACE

The underwater environment is a special place, full of mystery and excitement. It is responsible for climate, commerce, ecological habitats, dispersion of pollutants, food, recreation, travel, weather, and more. The biblical statement "Dust thou art, and unto dust shalt thou return" is almost a metaphor for the relationship of the water environment to all life on earth. Life on earth, as well as the embryological development of every individual life form (ontology), has its origin in a water environment. It is no coincidence that the mineral composition of seawater is remarkably similar to that of our blood. Eventually, perhaps over hundreds of thousands of years, everything returns to the sea through the mechanisms of erosion and geological changes. Consequently, the aquatic version of the biblical statement might read "From the sea thou ariseth, and to the sea thou shalt return." Of the 37 phyla of life forms so far identified, 34 (92 percent) can be found in the sea. In contrast, 17 phyla (47 percent) can be found on land. About one-third (39 percent) of the phyla are found on both land and water.



The underwater environment attracts a variety of audiences, from the marine biologist to the seashell collector.

The diver's entrée to the underwater environment is wide-ranging. Through adaptations, acclimatizations, technology, and understanding, the diver can participate in the underwater environment at almost any level of activity. This text is divided into three parts. Each focuses on a different aspect of the underwater environment, but each complements the others. Part I concerns the underwater environment—its challenges, the types of diving with respect to breathing equipment, and the ways in which the diver copes with the inert gas load. Part II explores specific challenges of the underwater environment (e.g., cardiovascular, respiratory, and thermal), the adaptations diving mammals have for meeting these challenges, the counterparts of these adaptations in human divers, and the specific equipment used to meet each challenge. Part III is a synopsis of the medical problems of diving. The synopsis is uniquely organized such that the problems are presented in the order in which they would most likely occur during a dive. This organization makes it easy to focus in on a medical problem of diving without using the table of contents.

Coauthorship can produce a continuity in style and organization that is difficult to achieve with edited texts. The figures and tables in this book contain information that we have used as study aids in over three decades of teaching diving medicine and physiology to a variety of audiences. For many of the subjects we have generated papers and formulated new ideas. We apply physics (gas laws), physiology (how the body works), and anatomy (the structure of the body) to divers and their interaction with the underwater environment. The "Chapter Preview" section in each chapter alerts the reader to the objectives of that chapter. Another feature of out text is the consistent use of case reports and comments for the "Bringing It All Together" sections in the chapters of part III. Text citations have been kept to a minimum and by and large are used only to give credit to scientists who have done the classical research on mammalian adaptations to diving. For readers who seek further information, specially selected recommended readings are listed by chapter at the end of the book.

Our aim is to explain how the diver interacts with the underwater environment in positive as well as undesirable ways, especially for those who wish to know the first-response interventions for medical problems of diving, study the physiological responses to the aquatic environment, teach diving, prepare for missions requiring diving, or simply have the satisfaction of knowing as much about this subject as possible.

ACKNOWLEDGMENTS

In one sense our dive text began 57 years ago with my father, Max B. Strauss. For lack of a better title, he was "Mr. Aquatics" for a small town in western Oregon. Although he was a purported furniture dealer, his true passion was to teach others to love the water. He used any excuse to lock up the furniture store, put a "Gone Swimming" sign on the door, and transport the town kids in his furniture truck to the nearest swimming pool. This evolved to coordinating the county's Red Cross swimming programs and becoming the father of competitive swimming in the county. The "Gone Swimming" sign got a lot of use. From my father I not only gained a great fondness for water-related activities but also learned about managing panic in the water. Many of his admonitions and techniques for the management of panic in the water are as valid today as when he first taught them to me in 1946. This information was the starting point for my papers on diver panic and for the inclusion of this subject in chapter 11.

My second acknowledgment is to the U.S. Navy. Over a 33-year period I received training in and dove with almost every type of equipment discussed in the text. I am especially proud of my 25-year medical association with the Navy Frogmen and SEALS. They reaffirmed my belief that divers can be swimmers as well and were a significant motivating factor for part II of this text concerning the physiological responses to the underwater environment. A third acknowledgment is to retired naval Captain George B. Hart, MD, director emeritus of the department of hyperbaric medicine, Long Beach Memorial Medical Center, Long Beach, California. In 1977, at his invitation and after completion of undersea medicine, orthopedic training, and operational billets in these specialties in the navy, I began working under his auspices as associate director of his department with the mission to define the orthopedic uses of hyperbaric oxygen. Dr. Hart not only helped me to meet this goal, but he encouraged me to maintain my interests in diving. I have collaborated with him in the management of medical problems of diving, and with his support traveled around the world to conduct medical diving seminars and continue my affiliation with the Navy Reserve SEAL teams.

Another person who requires acknowledgment is my Junction City, Oregon, high school classmate, Gary Mortensen. He was the person who rescued me from the episode of breath-holding blackout presented as a case study in chapter 11. Recently, we reminisced at our high school class reunion. Had it not been for Gary's prompt action, the past 45 years could have been very different for me. This experience stimulated my interest in the subject of

blackout, resulting in what is now the most complete listing of the no-panic blackout conditions to be found in a diving text.

Finally, I want to acknowledge those who have helped me with the actual production of this text: first, Mike Bahrke, PhD, of Human Kinetics for his invitation (based on his review of one of my dive papers) to submit a proposal to write a dive text. This invitation led to the opportunity to work with many of the Human Kinetics staff, and I sincerely appreciate their constructive criticisms, professionalism, and contributions to the mutual goals of this dive text. Second, for content review, many colleagues helped me, including Marvin Appel, MD; Thomas Asciuto, MD; Andrew Choy, MD; Eknath Deo, MD; Debbie Meeks, Certified PADI instructor; Jon Pegg, MD; Ralph Rozenek, PhD; Ronald Samson, MD; and Donald Winant, MS. Excellent editorial help was received from Zarah Maginot, Julia Ayzenberg, my older son Ari (an electrical engineer), and my younger son Sasha (a brand strategist). The latter I thank especially for his preparation of the illustrations. Finally, my wife, Wendy Groner Strauss, PharmD, deserves special thanks as she was always there to help answer a word or grammar question and to encourage my work on this yearlong project. She substantially contributed to my decision to invite Dr. Aksenov to be the coauthor. With his computer skills, Dr. Askenov made communications between us a "snap." His substantial contributions to part III, the appendixes, and the reference portions of this book made it possible to meet our submission deadlines.

Michael B. Strauss, MD

The writing of this book has been an honor and pleasure for me. Many people have supported me in this endeavor. First of all, I acknowledge my parents, Viktor G. Aksenov and Natalia L. Koustova, who encouraged me to become a physician and attend the St. Petersburg Military Medical Academy. I feel privileged to have received my medical training at one of the oldest and most prestigious medical institutions in Russia. It was there that I was trained as a navy physician and was introduced to diving physiology and medicine. Later, in my capacity as an intensive care physician, I was able to complete postdoctoral studies in diving and hyperbaric medicine at the Academy. More recently, I directed the hyperbaric medicine program at the Saba University School of Medicine and held the position of medical director of the Saba National Marine Park Hyperbaric Facility on the island territory of Saba in the Netherlands Antilles. In this capacity I had extensive experiences in treating medical problems of diving with the able assistance

of David Kooistra, park manager, and Janine le Sueur, Hyperbaric Medicine Program Administrator.

For their careful review of selected chapters and their constructive suggestions I give special thanks to Saba University School of Medicine faculty members Angel Kurtev, MD, PhD; Nick Macri, PhD; and Jim Stewart, PhD. Another thanks goes to Ella France, MD, my sister and fellow faculty member at Saba University Medical School. She spent innumerable hours with me discussing issues, shaping ideas, and providing encouragement for this project. Likewise, my wife, Natalya I. Stoyanova, deserves a special acknowledgment for her constant emotional support, patience, understanding, and ability to create a working environment for me while caring for our two sons. Finally, I extend my gratitude to Dr. Michael Strauss, who invited me to coauthor this book. It was a pleasure to work with someone so full of ideas and energy.

Igor Aksenov, MD, PhD

CONTENTS

PART I

The Underwater Environment

This part of the book focuses on the underwater environment from the perspective of challenges to the diver. One of the fascinations of the underwater environment is that it is so different from our usual terrestrial environment. A diver can literally soar through the underwater environment as a bird flies through a forest. But this freedom from the effects of gravity does not come without costs. The costs are due to the physical properties of water. Water is several hundredfold denser than air and contains about 1/40 the amount of oxygen that air at sea level does. It imposes special considerations relating to the effects of on-gassing of nitrogen or other inert gases to the tissues of the diver's body as the diver descends using a compressed gas supply.

The three chapters in part I address each of these challenges. Chapter 1 covers the physical, physiological, and psychological stresses imposed on the diver underwater. This chapter provides the background for understanding human divers' and diving mammals' adaptations and acclimatizations to the underwater environment as presented in part II. It also provides the basis for understanding what happens when the body's positive feedback responses—used to meet the challenges of the underwater environment—are exceeded, become negative feedback mechanisms, and cause harm to the diver as discussed in part III. Chapter 2 describes the types of diving, dive profiles, and phases of the dive. Chapter 3 deals with the inert gas load. Although this

is a complex subject, our aim was to present the material in a manner that would be understandable to our target audiences. This chapter includes a thorough discussion of the advantages and disadvantages of dive tables and the diving computer. Our method of presentation and the thoroughness with which we discuss the subjects in part I are unique to our dive text.

CHAPTER 1

CHALLENGES OF THE UNDERWATER ENVIRONMENT

Chapter Preview

- Principal stresses that the underwater environment imposes on the human diver
- Gas laws and how they help to explain the physical stresses of the underwater environment
- Pressure and how it affects the three pressure-related body compartments
- Physiological stresses of the underwater environment and how they affect the human diver
- Psychological (orientation) stresses of the underwater environment

Both **commercial** (diving for pay) and **sport diving** (diving for enjoyment without consideration for remuneration) expose divers to stresses that are unique to the underwater environment. That is, terrestrial counterparts of the stresses do not exist, or they are ordinarily so minimal that they go unnoticed while a person is on land. **Stress** is a challenge, stimulus, or other signal that initiates a response in an organism. Three main categories of stresses are encountered in the underwater environment: physical, physiological, and psychological (see figure 1.1). In almost all circumstances the diver resolves the stresses of the underwater environment through positive feedback mechanisms.

Stresses themselves are not all undesirable. Most are physiological; that is, they induce responses in the organism that maintain life, protect from injury, or cause the organism to change. These responses are examples of positive feedback. For example, the fundamental physiological stress that initiates breathing is the imperceptible rise in carbon dioxide in the blood that occurs before each breath. Part II of this book deals largely with the physiological stresses of the underwater environment and how they are resolved. When stresses cause harm to the organism, they are labeled pathological. Part III describes the pathological stresses the diver may encounter in the underwater environment, such as the ear squeeze. Underwater, the transition between a physiological stress and a pathological stress is often minimal. Pathological stresses cause negative feedback—responses that are unphysiological and lead to injury.

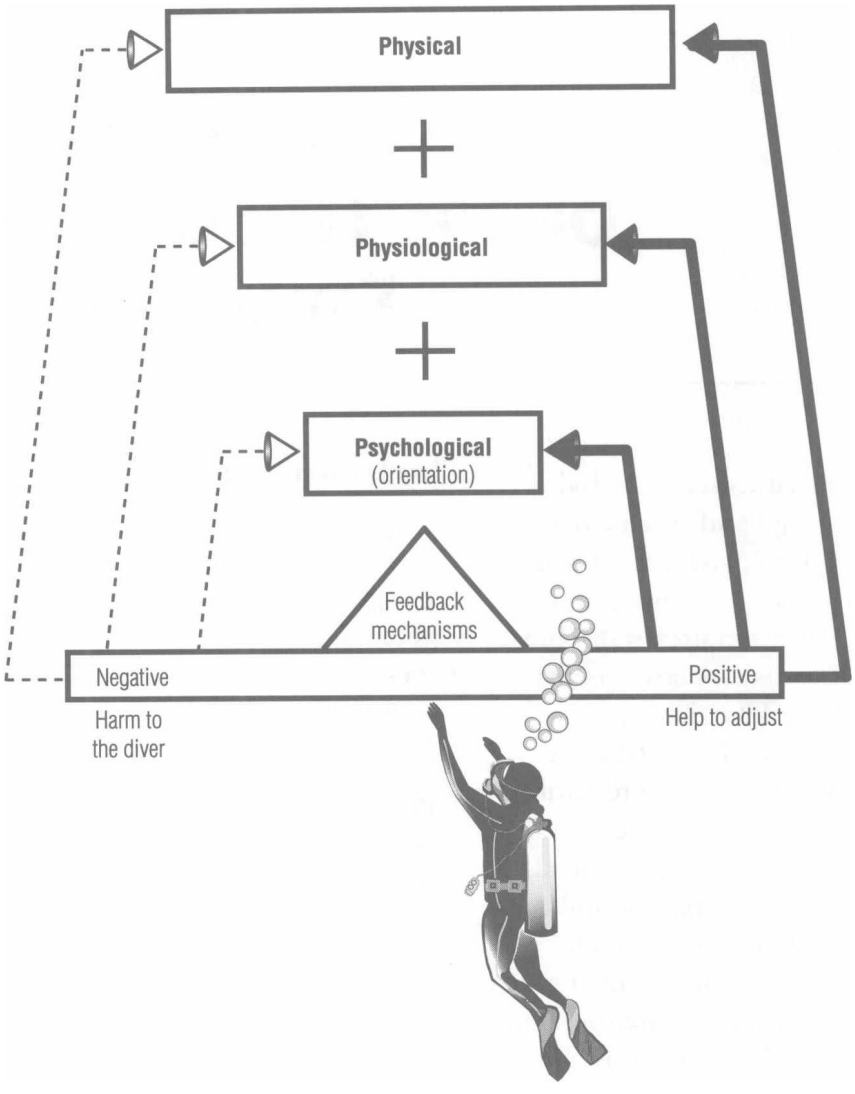


FIGURE 1.1 Stresses in the underwater environment.

Physical Stresses

Physical stresses arise from the physical properties of water. These include the effect of the density of water. Since water is 775 times more dense than air, a few feet of descent in water is equivalent to many hundreds of feet of descent in the atmosphere. Other physical stresses related to the density of water include those from currents and movement through the water. The thermal properties of water are another source of significant physical stress for the diver.

Pressure

The main physical stress of the underwater environment is the effect of hydrostatic (the weight of the water column) pressure. From a mathematical perspective, **pressure** is defined as force per unit area. Two observations cause confusion regarding the concept of pressure. First, multiple units are used to define pressure. Most people are familiar with the designation of pounds per square inch (PSI), used for measuring the amount of air pressure in tires, or millimeters of mercury (mmHg), used for measuring blood pressure. Pressure units like kilopascals and BAR may seem foreign. At least nine different units are used for measuring pressure as enumerated in table 1.1.

Each pressure unit has its own special usage. At least half of the units relate to the underwater environment in one way or another. Fortunately, knowing the equivalent for each unit, based on one-for-one atmosphere of pressure, makes it easy to calculate what a pressure would be in a different unit using simple algebraic principles. Depth is measured in feet of seawater (FSW) (or meters of seawater, MSW). For convenience, unit area is not included among these terms.

For SCUBA (Self-Contained Underwater Breathing Apparatus) diving tanks, PSI is used to designate how full the tanks are, while in mixed-gas diving the tank pressures are measured in BAR. If the diver should be so unfortunate as to develop **decompression sickness** (i.e., a wide spectrum of conditions, from skin itches, to joint pains, to breathing problems, to paralysis, following reductions in ambient pressure), he or she may require treatment in a **recompression chamber** (a vessel that can safely withstand pressurization; it is used to treat diving problems and other medical conditions) where atmospheres absolute (ATA) or feet (meters) of seawater will be used as the pressure unit. Although the use of so many different units to designate pressure may be confusing initially, each particular unit is selected for and determined by convenience and convention, and one unit can be easily converted to another.

Diving Physics: Pressure Conversion

Q: What would the maximum theoretical height (in feet of seawater) be for blood backing up in a line connected to an artery for someone with a systolic blood pressure of 120mmHg? (Hint: Convert mmHg pressure to feet of seawater.)

A: *5.2 feet (1.6 meters)*

The second source of confusion associated with pressure is the ubiquitous nature of pressure itself. The surface of the earth is surrounded by the earth's **atmosphere,** the gaseous mass or envelope surrounding the earth and retained by the earth's gravitational field. In essence, at sea level, we live at the bottom of an "ocean of air." This is equivalent to one atmosphere of pressure. As we