The physiology and pathophysiology of the hyperbaric and diving environments

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HUMAN EXPOSURE to the challenges of the underwater world has been traced back thousands of years (e.g., the diving women of Japan). However, the last century has seen an acceleration of activities with disparate foci on the “Silent World.” The variety and beauty of marine life attract growing numbers of recreational divers, and the pressing need for exploitation of new energy sources has led to technical development and physiological research allowing divers to work at over 500 m of depth. The physical properties of water favor stealth military operations but have also inspired competitive diver-athletes to compete in overcoming enormous challenges (the current world record in deep breath-hold diving subjected the diver to a pressure of 21 atm). The severity of these challenges is greater than for any other human activity and are due to pressure (depth), temperature extremes, and the unbreathable ambient medium. They affect locomotion, respiration, circulation, renal and nervous systems, and water and thermal balance due to the physical properties of water. Direct hydrostatic effects have been demonstrated, as well as physical and pharmacological or toxic actions of respired gases at increased pressures. Physiological adaptations to the strains caused by the underwater environment are achievable, sometimes to an amazing degree, while other challenges require an artificially created “microenvironment” (breathing gear, diving suit, etc.), and yet, adjustment is not always sufficient, resulting in injury and even death.

Some insights into the physiology and medicine of diving have had marked impacts on the theory and practice of traditional medicine. The application of increased ambient pressure, typically in a surface-based pressure chamber, has been used for over a century to eliminate the gas bubbles causing decompression sickness in divers but has more recently been applied, preferably in combination with oxygen breathing, to treat nosocomial gas embolism in the clinic. A further development of this methodology is the application of hyperbaric oxygen, currently available at over 900 facilities in this country, to treat a variety of conditions that might benefit from enhanced tissue oxygenation, or other pressure-mediated effects. These conditions include, among others, carbon monoxide poisoning, gas gangrene, crush injury, poorly healing wounds, necrotizing soft tissue, osteomyelitis, ischemic skin grafts and retinal vascular occlusion, and, in promising pilot studies, stroke. The current list of indications paid for by insurers numbers 13 and is growing. It is only to be expected that the results of ongoing research concentrating on evidence-based and mechanistic studies of the physiology and medicine of diving and clinical hyperbaric medicine are intensely cross fertilizing.

This series on “The Physiology and Pathophysiology of the Hyperbaric and Diving Environments,” although for space reasons not entirely comprehensive, offers reviews dealing with topic areas that are central to the general theme of the series. The review entitled “The underwater environment: cardiopulmonary, thermal, and energetic demands” (6) gives an overview of effects of water surrounding the body. Another study will deal with simplest form of diving, i.e., breath-hold diving, and is entitled “The physiology and pathophysiology of human breath-hold diving” (4). A subsequent paper in the series will be “Pulmonary gas exchange in diving” (5), dealing with the effects of depth, including immersion and pressure, on respiration. Increased pressure of the respired gas typically exposes the diver to high partial pressures of oxygen and nitrogen during air breathing or other inert gases when special breathing mixtures are used.

Increased nitrogen pressure in the lungs generates higher tissue nitrogen pressure, and during ascent, this leads to an excess of nitrogen that must be eliminated via the lungs. If this elimination does not keep pace with the reduction in depth, decompression sickness might ensue. Various aspects of how to prevent this outcome and some of the insights into decompression physiology gained in studies of decompression to altitude, which has applications also to decompression in diving, are dealt with in “Decompression to altitude: assumptions, experimental evidence, and future directions” (3).

Recent advances in physiological research methods are now allowing much improved understanding of the mechanisms of action of oxygen and oxygen toxicity and the so-called inert gases as illustrated by the following two papers: “Two faces of nitric oxide: implications for cellular mechanisms of oxygen toxicity” (1) and “Effects of hyperbaric gases on membrane nanostructure and function in neurons” (2). The advances in hyperbaric oxygen therapy will without doubt be much furthered by the deepening insight in the mechanisms of action of high oxygen tensions on important pathological processes as discussed in “Oxidative stress is fundamental to hyperbaric oxygen therapy”
Finally, a relatively recent advancement in medical technology, namely the development of perfluorocarbon emulsions with high gas-dissolving capacity, for intravenous administration, shows promise, not only in enhancing inert gas elimination in divers, but also for relief of tissue hypoxia in a host of clinical conditions unrelated to diving, as described in “Perfluorocarbon emulsions as a promising technology: a review of tissue and vascular gas dynamics” (7).

Despite modest public funding support for research related to human productivity and safety in undersea activities (mostly from the US Navy) and for the use of hyperbaric oxygen treatment in terrestrial medicine, very important gains in these areas have been made and are accelerating, especially in the latter field. For instance, the exploitation of oil and natural gas fields under the sea bottom is critically dependent on divers, and there is a rapidly growing application of hyperbaric oxygen that now, supported by sound mechanistic research, is setting its sights on some of the major public health challenges, such as stroke and the sequelae of diabetes.

REFERENCES