HYPERBARIC OXYGENATION

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A concise introduction to a complex subject . . .

The information presented here has been culled from widely scattered sources and compiled to provide new insight into the history, theory, scientific investigation, and clinical application of hyperbaric oxygenation as well as appreciation of attendant problems and complexities. The bibliographies which follow each chapter extend the usefulness of the text through direction to widely scattered sources of more profound and comprehensive treatment.

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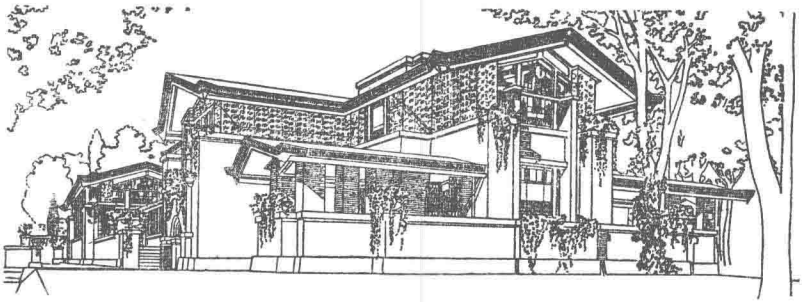

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DEDICATION

To my wife, Gertrude, and our children, Suzanne, Charley and Katy

Preface

THIS MONOGRAPH HAS been prepared to provide a concise introduction to the various aspects of hyperbaric oxygenation. The scope is broad in order to satisfy diversified interests and to provide to each a balanced view of the basic scientific and clinical implications of the subject.

Four categories of readers were considered: (1) those desiring merely a conversational acquaintance with the currently popular subject; (2) those with research inclinations voluntarily committed to its laboratory or clinical investigation; (3) clinicians, who perforce are confronted with its application or problems associated with it; (4) students for whom the subject deserves to be a part of a progressive medical education.

The information offered has been culled from widely scattered sources and compiled to provide a concise insight to the history, theory, scientific investigation and clinical application of hyperbaric oxygenation, and appreciation of the attendant problems and complexities.

A broad survey of a subject which offers neither suggestions for progressive reading nor escape from the subjective interpretation of the author would be of limited value. To circumvent such limitations and to extend the practicality of the monograph, selected references are provided for those who wish to pursue various phases in depth. The comprehensiveness of the bibliographies was intentional in an effort to provide within a single volume references to the scattered sources of pertinent information. Such further pursuit is essential for intelligent experimentation or clinical application of hyperbaric oxygenation. Since the monograph is not a manual of procedures, those seeking such direction will also find the bibliographies helpful.

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C. B. P.

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Historical Development

HYPERBARIC OXYGENATION (H.O.) is oxygen therapy applied within a pressure chamber under circumstances which provide alveolar partial pressures of the gas exceeding those possible from the inhalation of pure oxygen at atmospheric pressure. The resultant hyperoxemia is intermediate in the production of elevations in tissue tensions of oxygen. The objective of the therapeutic regimen is the development of elevated tensions of the gas within mitochondria, the presumed site of its most significant cellular activity.

Current medical interest in H.O. originated with the encouraging report of Churchill-Davidson and his associates[10] in 1955 pertaining to its application in radiotherapy and that of Boerema and coworkers[7] in 1956 regarding its use as an adjunct to cardiac surgery. Interest was enhanced subsequently by the dramatic demonstration by Boerema[8] of the possibility of sustaining life in a bloodless pig perfused with saline solution while the animal breathed oxygen at three atmospheres absolute.

The designation of pressure in terms of atmospheres absolute represents conventional hyperbaric terminology. Its consistent use in relation to H.O. is urged to avoid ambiguity. Ambient pressure at sea level is regarded as one atmosphere absolute, or approximately fifteen pounds per square inch (15 psi). Gauges designed to measure pressures above atmospheric indicate ambient pressure as zero. Thus a registered pressure of 1 atmosphere or 15 psi on a gauge represents 2 atmospheres absolute; one of 2 atmospheres or 30 psi is equivalent to 3 atmospheres absolute, etc.

Technical advances of modern engineering have afforded a variety of pressure chambers with almost unlimited degrees of sophistication. Large facilities for H.O. exist at Lutheran General Hospital, Park Ridge, Ill., Duke University, Durham, N. C., Children's Hospital, Boston, Mass., The Mount Sinai Hospital, N. Y. C., and Minneapolis General Hospital Research Foundation, Inc.,

Minneapolis, Minn., in this country; in Europe such exist at the Wilhelmina Gasthuis, Amsterdam and Leiden University in Holland, and at the Royal Infirmary, Glasgow, Scotland. Numerous commercially available units of smaller size are in use or on order in the United States.

Technical developments are in advance of the basic scientific knowledge required for safe and judicious application of H.O. Recognition of the need for a scientific approach in its applications is manifested in the 1963 report of the Ad Hoc Committee on Hyperbaric Oxygenation of the Division of Medical Sciences of the National Academy of Sciences and was evident at the 1964 Conference on H.O. sponsored jointly by the New York Academy of Sciences and the National Academy of Sciences. Whereas the concerted efforts of various scientific disciplines to foster such an approach would favor fruitful development of H.O., imprudent and unscientific applications of it on the part of individual enthusiasts could lead to its abandonment.

H.O. is not an achievement of the past decade; rather, its present status reflects developments and hindrances during hundreds of years. Its developmental history is not only interesting, but also rewarding in the information provided. It begins in the distant past with man's initial exposure to hyperbaric conditions through diving in quest for food, treasures, escape or pleasure. Eventually, his scientific curiosity led to experimentation aimed toward allowing him longer periods of submergence. Breathing of pressurized air by divers submerged within an inverted metal vessel was mentioned by Aristotle (384-322 B.C.). An exhibition of such a fete was held in 1538 at Toledo, Spain. In 1797, Klingert invented a diving gear consisting of a metallic cylinder which encased the body from head to hips and subsequently improved it by the addition of an air supply for breathing. Siebe, in 1819, devised a diving apparatus which incorporated a metal helmet into which air was pumped. Subsequent refinements led to the modern diving suit provided with a constant flow of compressed air breathed at a pressure proportional to depth of submersion.

In 1841, Triger[25] reported the use of the first caisson for submarine mining operations. This initiated the simultaneous ex-

posure of more than one person to hyperbaric conditions within a single apparatus.

Accidents and illnesses associated with increasing exposures of persons to elevated pressures eventually caused a focusing of attention upon the physiologic aspects of hyperbaricity. The first to do so in a detailed scientific study was Paul Bert whose monumental compilation, La Pression Barometrique,[4] is fortunately available in an excellent English translation.[5] Therein are contained observations of phenomena related to the operation of hyperbaric chambers, such as convulsive and pulmonary disorders associated with oxygen toxicity, lethargy and disorientation now attributed to nitrogen narcosis and gas embolism occurring with decompression. Heller and associates[15] compiled a comprehensive treatise on caisson disease in 1900.

The studies of gas solubility and embolism by Haldane were the basis for the establishment of safety rules regulating decompression rates adopted by the British Admiralty in 1907 to minimize decompression sickness. A review of his many researches was published in a monograph[14] on respiration.

The U. S. Navy has fostered extensive physiologic researches in the interest of diving safety. The contributions of Behnke and his associates in their investigations of decompression sickness, oxygen toxicity and nitrogen narcosis will be discussed in subsequent chapters.

Extensive bibliographical references to pertinent information including early therapeutic efforts have been prepared by Hoff and Greenbaum.[17,18] The U. S. Navy Diving Manual[26] is a valuable directive of decompression procedures which is advised in the operation of pressure chambers.

The first suggestion of the clinical application of variations of air pressure is accredited to Henshaw[16] in England who postulated in 1664 the benefits of compression in the treatment of acute diseases and rarification for chronic disorders. For that purpose he designed a chamber called a domicilium for raising and lowering pressure. In 1783, the Haarlem Academy of Science in Holland offered a prize, never claimed, for the design of a pressure chamber for therapeutic use. It was not until 1834 that Junod[19]

described and built the first such chamber to investigate the physiological and therapeutic effects of increased and decreased air pressures. His chamber was not well received because of its limited size and lack of control of pressure variations. Soon thereafter, Tabarie[23,24] investigated the effects of compression and rarification applied to the entire body, and incidentally also to all of the body except the head, thus simulating the effects of modern tank respirators. In his treatment of respiratory diseases within the chamber, he stressed slow changes in pressure. Concurrently, Pravas[21,22] employed compressed air "baths" in his orthopedic clinic at Lyons, instituted therapy for tuberculosis, and eventually established treatments of up to a dozen persons simultaneously in a large chamber. His reports, though not medically convincing, stimulated the development of health spas offering similar treatment. This movement was aided by Bertin's outline[6] of the history and clinical indications for use of pressure chambers.

During the latter half of the 19th century, Europe was dotted with numerous pressure treatment centers including those operated by Milliet at Lyons and Nice, Grindrod in England, von Vivenot in Vienna, Sandahl in Stockholm, von Liebig in Baden-Baden and Hovent in Brussels. The enthusiastic, empirical movement was spurred in 1887 by Arntzenius' publication[2] of *De Pneumatische Therapie* with some 300 references on the subject.

During the last quarter of the eighteenth century in Europe, another type of inhalation therapy was emerging as a result of the discoveries of carbon dioxide, nitrous oxide, carbon monoxide, hydrogen and oxygen. Though initially the interest of pneumatic chemists, these gases quickly attracted the attention of physicians. Such was the case with oxygen which had been discovered independently by Scheele in 1772 and Priestley in 1774. The story is interestingly related by Cartwright[9] of the biological interests of Priestley, Lavoisier and Davy and the development of the famous Pneumatic Institution at Bristol by Thomas Beddoes, a physician, and his associate, James Watt, an engineer. Apparently, with good intentions, excessive credulity, and an irresistible urge to publish inconclusive data, Beddoes administered the above gases for therapeutic purposes. Although accredited for initiating

oxygen therapy, he failed to establish it upon sound scientific principles. The reason for the failure of the Pneumatic Institution is apparent from the report[3] of its operation in 1795.

With the increasing availability of oxygen, its use spread through Europe, including centers possessing hyperbaric chambers. How extensively the gas was employed in hyperbaric therapy is not clear. There is no evidence that partial pressures of oxygen such as those now in vogue were regularly employed prior to the current interest in H.O.

On this continent, possibly because of its remoteness from the above sites of activity, lesser inclinations toward experimental techniques, or lack of conviction of the benefits reported from abroad, few physicians were caught in the early enthusiasm of hyperbaric therapy. Nevertheless, reference to pneumatic chambers in Toronto, Rochester and Buffalo were made by Lee[20] in 1867. Ethridge[13] published on the subject in 1873. Corning[12] employed compressed air in his practice in New York at the turn of the century. The transient operations in the 1920's of a chamber by Cunningham at Kansas City, and the elaborate facility at Cleveland are matters of regrettable record.[1,11]

The inappropriateness of enthusiastic empiricism as an approach to the establishment of a therapeutic regimen is well documented. The dangers and disappointments associated with the misuse of a technique are prone to result in deprivation of its possible benefits. Such has been the previous fate of hyperbaric therapy imprudently applied in the treatment of: amenorrhea, anemia, anorexia, aortic stenosis, aphonia, asthma, atelectasis, bronchiectasis, bronchitis, catarrh, chlorosis, chorea, conjunctivitis, deafness, diabetes, eczema, emphysema, hemoptysis, hysteria, irregular menstruation, kyphosis, laryngeal and tracheal stenosis, laryngitis, leucorrhea, menorrhagia, mitral insufficiency, neuralgia, otorrhea, pleurisy, post-influenzal depression, smallpox, syphilis, tuberculosis, viper bites and whooping cough!

H.O. is currently being investigated in areas where theoretical considerations suggest possible benefits. Included among those are radiotherapy of cancer, temporary vascular occlusion during surgery, vascular insufficiencies from other causes, anaerobic and

other infections, carbon monoxide and barbiturate poisonings, infant resuscitation, shock and hyaline membrane disease.

In succeeding chapters, the theoretical bases for these applications will be provided along with an indication of their progresses. The eventual security of appropriate H.O. among acceptable medical techniques will be dependent upon the predominance of scientific methodology over reckless empiricism and the avoidance of foibles and faddism in experimental applications.

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