1 The History of Hyperbaric Medicine

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This chapter reviews the historical relationship between hyperbaric therapy and diving medicine, recounting the important stages in the development of compressed gas technology and a few of the more interesting early attempts to utilize it for medical purposes. The sections involved are:

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Hyperbaric Therapy and Diving Medicine

As is well known, the origins and development of hyperbaric medicine are closely tied to the history of diving medicine. While the attractions of the deep are easily understood, it was the various unpleasant physical consequences of venturing beneath the surface of the world's oceans that led directly to the many applications of compressed-gas therapy in modern medicine. Although scientifically based applications of hyperbaric technology are a relatively recent development, the use of compressed gas in medicine actually has ancient roots.

The origin of diving is not known, but it was recognized as a distinct occupation as far back as 4500 B. C. However, since humans can only hold their breath for a few minutes, unaided dives are limited to depths of less than about 30 meters. The first use of actual diving equipment to extend the limits of underwater activity is attributed in legend to none other than Alexander the Great, who, in 320 B. C., is said to have been lowered into the Bosphorus Straits in a glass barrel (see Figure 1.1), which purportedly gave him a secret weapon in the siege of Tyre.

Around the year 1500, Leonardo Da Vinci made sketches of a variety of diving appliances, without developing any for practical use. It was not until 1620 that the Dutch inventor Cornelius Drebbel developed the first true diving bell. His device was extremely limited, especially by its simple air supply that delivered air pressurized at only one atmosphere, but it was certainly the forerunner of all submersible vehicles.

In 1691 Edmund Halley, after whom the comet is named, advanced diving bell technology by devising a method of replenishing the air supply using weighted barrels (Smith, 1986). This was followed in the next two centuries by the development of compressed-air diving helmets and suits – which made it possible to remain under water for an hour or more.

Even though the duration of dives had been extended, divers were still limited to the same shallow waters as before. Undersea pioneers had quickly discovered the eardrum-rupturing effects of increasing water pressure. Those attempting to venture even deeper in diving bells also

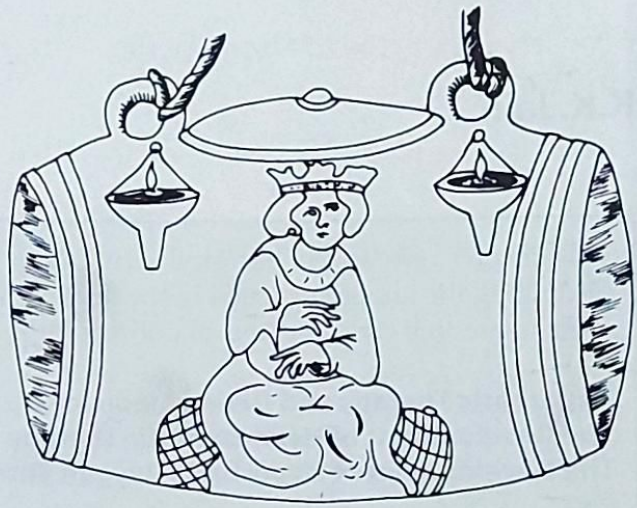

Figure 1.1
Alexander the Great was said to have been lowered into the Bosphorus Straits in a glass barrel. Note that the candles are lighted and if, indeed, Alexander went into this barrel, he was lucky to survive. The illustration is redrawn from a thirteenth century manuscript in the Burgundy Library in Brussels, and is reproduced courtesy of Dr. E. B. Smith (1986).

Table 1.1
Some Important Benchmarks in the History of Diving Medicine in Relation to Hyperbaric Medicine

4500 BC	Earliest records of breathholding dives for mother-of-pearl
400 BC	Xerxes used divers for work on ships and for salvaging sunken goods. Dives were for 2–4 min and to a depth of 20–30 m
320 BC	First diving bell used by Alexander the Great
300 BC	Aristotle described the rupture of the eardrum in divers
1670	Boyle gave the first description of the decompression phenomenon as "bubble in the eye of a snake in vacuum"
1620	Cornelius Drebbel developed a one-atmosphere diving bell, basically the forerunner of all modern submarines
1691	Edmund Halley improved bell technology by devising a method to replenish air supply in the diving bell
1774	Freminet, a French scientist, reached a depth of 50 ft (2.5 ATA) and stayed there for 1 h using a helmet with compressed air pumped through a pipe from the surface
1830	Cochrane patented the concept and technique of using compressed air in tunnels and caissons to balance the pressure of water in soil
1841	Pol an Watelle of France observed that recompression relieved the symptoms of decompression sickness
1869	Publication of *Twenty Thousand Leagues under the Sea*, a science fiction novel by Jules Verne; contains a description of diving gears with air reserves
1871	Paul Bert showed that bubbles in the tissues during decompression consist mainly of nitrogen
1920	Use of gas mixtures for diving (heliox); diving depth extended to 200 m
1935	Behnke showed that nitrogen is the cause of narcosis in humans subjected to compressed air above 4 ATA
1943	Construction of aqua lung by Cousteau; diving at 200 bar possible
1967	Founding of Undersea Medical Society, USA

quickly learned about the best-known medical problem associated with diving: decompression sickness. It was not until the middle of the nineteenth century that the effectiveness of countering decompression sickness with hyperbaric recompression was finally discovered (see Table 1.1). Although recompression in air was utilized first, hyperbaric oxygen (HBO) is now used, and this is the principal connection between diving medicine and the other forms of HBO therapy.

The Development of Hyperbaric Air Therapy

The first documented use of hyperbaric therapy actually precedes the discovery of oxygen. The British physician Henshaw seems to have used compressed air for medical purposes in 1662. The chamber he developed was an airtight room called a "domicilium," in which variable climatic and pressure conditions could be produced, with pressure provided by a large pair of bellows. According to Henshaw, "In times of good health this domicilium is proposed as a good expedient to help digestion, to promote insensible respiration, to facilitate breathing and expectoration, and consequently, of excellent use for the prevention of most afflictions of the lungs." There is, however, no account of any application of Henshaw's proposed treatment, and there were no further developments in the field of hyperbaric therapy for nearly two centuries.

In the nineteenth century there was a rebirth of interest in hyperbaric therapy in France. In 1834 Junod built a hyperbaric chamber to treat pulmonary afflictions using pressures of two to four absolute atmospheres (ATA). In 1837 Pravaz built the largest hyperbaric chamber of that time and treated patients with a variety of ailments. Fontaine developed the first mobile hyperbaric operating theater in 1877 (Figure 1.2), and by this time hyperbaric chambers were available in all major European cities. Interestingly, there was no general rationale for hyperbaric treatments, and prescriptions therefore varied from one physician to another. (In those days no methods were available to estimate the partial pressure of oxygen in blood, which at 2 ATA of air is about double that at sea level. In comparison, if pure oxygen is breathed at 2 ATA, the partial pressure of oxygen in the arterial blood is twelve times higher than normal.)

ÉTUDE CLINIQUE

DE L'EMPLOI ET DES EFFETS

DU

BAIN D'AIR COMPRIMÉ

dans le

TRAITEMENT DES MALADIES DE POITRINE

notamment dans

LE CATARRHE CHRONIQUE, L'ASTHME ET LA PHTHISIE PULMONAIRE

SELON LES PROCÉDÉS

MÉDICO-PNEUMATIQUES OU D'ATMOSPHÉRIE DE M. ÉMILE TABARIÉ

PAR

EUGÈNE BERTIN

Inventeur de l'Établissement médico-pneumatique de Montpellier, Professeur-Agrégé de la Faculté de médecine, Membre titulaire de l'Académie des sciences et lettres et Médecin des Prisons de la même ville, Correspondant de la Société d'hydrologie médicale de Paris, de la Société médicale du canton de Genève, de la Société impériale de médecine de Marseille, de la Société de médecine de Nîmes, etc., etc.

Deuxième Édition, avec une Planche.

PARIS — Adrien DELAHAYE, Libr.-Édit. — Place de l'École-de-Médecine

MONTPELLIER — C. COULET, Libraire-Éditeur — Grand'rue, 5

1868

Figure 1.3
Title page of the 2nd edition (1868) of the book by Bertin on the treatment of diseases by compressed air.

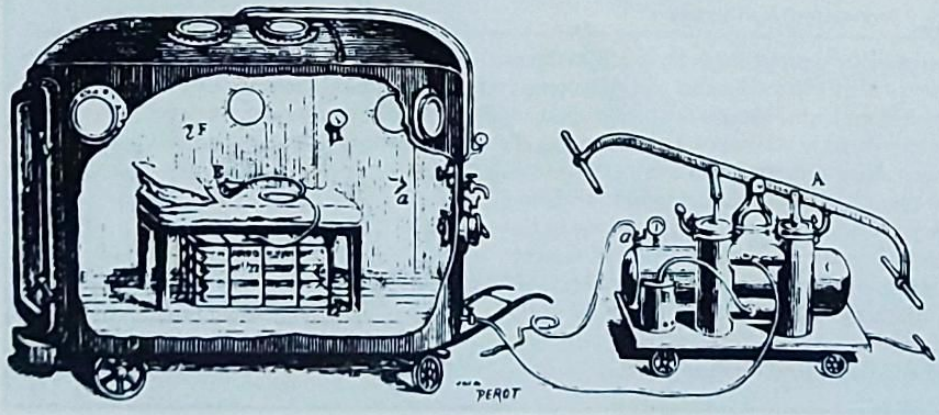

Figure 1.2
Fontaine's mobile operating room of 1877. Note the manual nature of the compressor apparatus and the anesthesia gas container and mask in the chamber. (Photo courtesy of Dr. Baixe, Toulon, France.)

During the second half of the nineteenth century, hyperbaric centers were advertised as being comparable to health spas. Junod referred to his treatment as "*Le Bain d'air comprimé*" (the compressed-air bath). In 1855 Bertin wrote a book on this topic (the title page is shown in Figure 1.3) and constructed his own hyperbaric chamber (Figure 1.4). The literature on hyperbaric medicine up to 1887 was reviewed by Arntzenius and contains a remarkable 300 references.

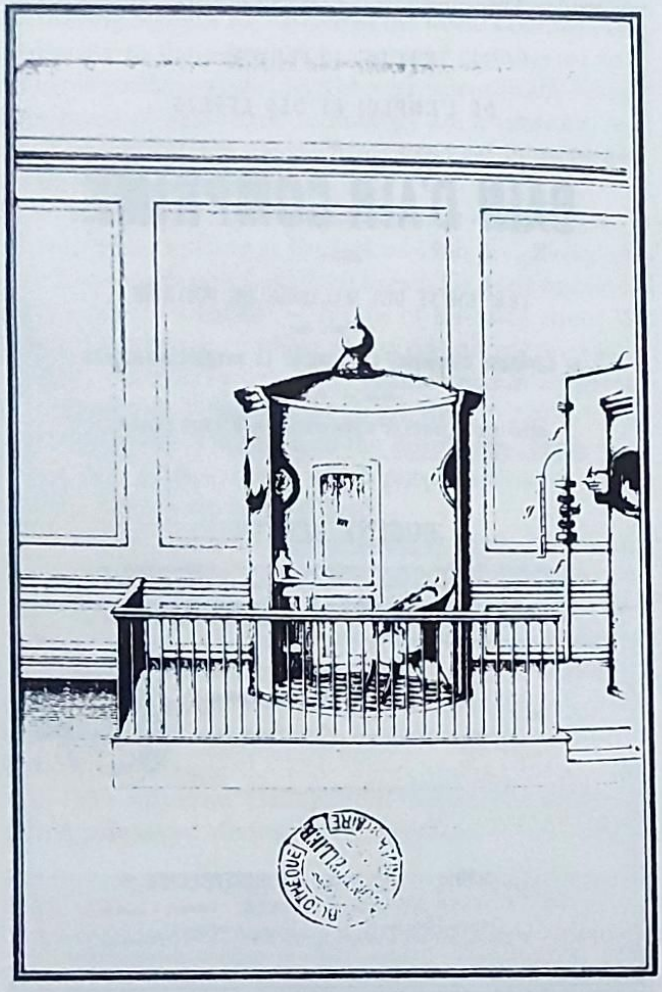

Figure 1.4
Hyperbaric chamber constructed by Bertin in 1874.

The first hyperbaric chamber on the North American continent was constructed in 1860 in Oshawa, Ontario, Canada, just east of Toronto. The first such chamber in the United States was built by Corning a year later in New York to treat nervous disorders. The chamber that received the most publicity, however, and was the most actively used, was that of Cunningham in Kansas City in the 1920s (Sellers, 1965). He first used his chamber to treat the victims of the Spanish influenza epidemic that swept the USA during the closing days of the First World War. Cunningham had observed that mortality from this disease was higher in areas of higher elevation, and he reasoned that a barometric factor was therefore involved. Cunningham claimed to have achieved remarkable improvement in patients who were cyanotic and comatose. In 1923, the first recorded hyperbaric chamber fire occurred at Cunningham's sanatorium. He had installed open gas burners under the tank to keep it warm in winter and someone turned the flame the flame too high so that it scorched the interior insulation. The patients were evacuated safely. However, one night a mechanical failure resulted in a complete loss of compression and all his patients died. This tragedy was a sobering lesson but ultimately did not deter Dr Cunningham. His enthusiasm for hyperbaric air continued, and he started to treat diseases such as syphilis, hypertension, diabetes mellitus, and cancer. His reasoning was based on the assumption that anaerobic infections play a role in the etiology of all such diseases. In 1928, in Cleveland, Cunningham constructed the largest chamber ever built – five stories high and 64 feet in diameter (Figure 1.5). Each floor had 12 bedrooms with all the amenities of a good hotel. At that time it was the only functioning hyperbaric chamber in the world.

As the publicity surrounding his treatments grew, Dr Cunningham was repeatedly requested by the Bureau of Investigations of the American Medical Association (AMA) to document his claims regarding the effectiveness of hyperbaric therapy. Apart from a short article in 1927, however, Cunningham made no efforts to describe or discuss his technique in the medical literature. He was eventually

Table 1.2
Landmarks in the History of Hyperbaric (Compressed) Air Therapy

1662	Henshaw used compressed air for the treatment of a variety of diseases
1834	Junod of France constructed a hyperbaric chamber and used pressures of 2–4 ATA to treat pulmonary disease
1837	Pravaz of France constructed the largest hyperbaric chamber of that time and used it to treat a variety of ailments
1837–1877	Construction of pneumatic centers in various European cities, e.g., Berlin, Amsterdam, Brussels, London, Vienna, Milan
1860	First hyperbaric chamber on the North American continent in Oshawa, Canada
1870	Fontaine of France used the first mobile hyperbaric operating theater
1891	Corning used the first hyperbaric chamber in the USA to treat nervous disorders
1921	Cunningham (USA) used hyperbaric air to treat a variety of ailments
1925	Cunningham tank was the only functional hyperbaric chamber in the world
1928	Cunningham constructs the largest hyperbaric chamber in the world; American Medical Association condemns Cunningham's hyperbaric therapy
1937	The Cunningham chamber is dismantled for scrap metal

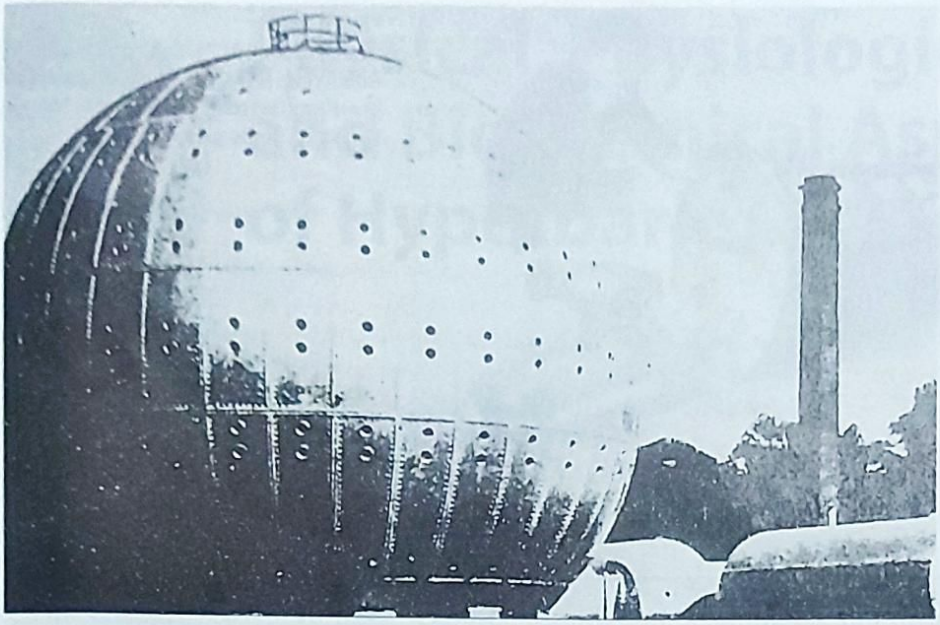

Figure 1.5
Cunningham's giant steel ball hyperbaric chamber built in 1928 in Cleveland, Ohio. It was six stories high and contained 72 rooms. (Photo courtesy of Dr. K.P. Fasecke.)

Table 1.3
Landmarks in the Development of Hyperbaric Oxygen (HBO) Therapy

1775	Discovery of oxygen by Priestley
1789	Toxic effects of oxygen reported by Lavoisier and Seguin, who discouraged use of HBO
1796	Beddoes and Watt wrote the first book on medical applications of oxygen
1878	Bert (father of pressure physiology) placed oxygen toxicity on a scientific basis; recommended normobaric but not hyperbaric oxygen for decompression sickness
1895	Haldane showed that a mouse placed in a jar containing oxygen at 2 ATA failed to develop signs of carbon monoxide intoxication.
1937	Behnke and Shaw first used HBO for treatment of decompression sickness
1938	Ozorio de Almeida and Costa (Brazil) used HBO for treatment of leprosy
1942	End and Long (USA) used HBO for treating experimental carbon monoxide poisoning in animals.
1954	Churchill-Davidson (UK) used HBO to enhance radiosensitivity of tumors
1956	Boerema (The Netherlands) father of modern hyperbaric medicine, performed cardiac surgery in a hyperbaric chamber
1960	Boerema showed life can be maintained in pigs in the absence of blood by using HBO
1960	Sharp and Smith become the first to treat human carbon monoxide poisoning by HBO
1961	Boerema and Brummelkamp used hyperbaric oxygen for treatment of gas gangrene; Smith *et al.* (UK) showed the protective effect of HBO in cerebral ischemia
1962	Illingworth (UK) showed the effectiveness of HBO in arterial occlusion in limbs
1963	First International Congress on Hyperbaric Medicine in Amsterdam
1965	Perrins (UK) showed the effectiveness of HBO in osteomyelitis
1966	Saltzman *et al* (USA) showed the effectiveness of HBO in stroke patients
1970	Boschetty and Cernoch (Czechoslovakia) used HBO for multiple sclerosis
1971	Lamm (FRG) used HBO for treatment of sudden deafness
1973	Thurston showed that HBO reduces mortality in myocardial infarction
1970s	Extensive expansion of hyperbaric facilities in Japan and the USSR
1980s	Development of hyperbaric medicine in China
1983	Formation of the American College of Hyperbaric Medicine (founder/president, late Dr. Neubauer of Florida)
1986	Undersea Medical Society (USA) adds the word hyperbaric to its name and is called UHMS. Reached a membership of 2000 in 60 countries
1987	Jain (Switzerland) demonstrated the relief of spasticity in hemiplegia due to stroke under hyperbaric oxygenation; HBO integrated with physical therapy
1988	Formation of the International Society of Hyperbaric Medicine
2001	The Undersea & Hyperbaric Medical Society established a clinical hyperbaric facility accreditation program in the USA.

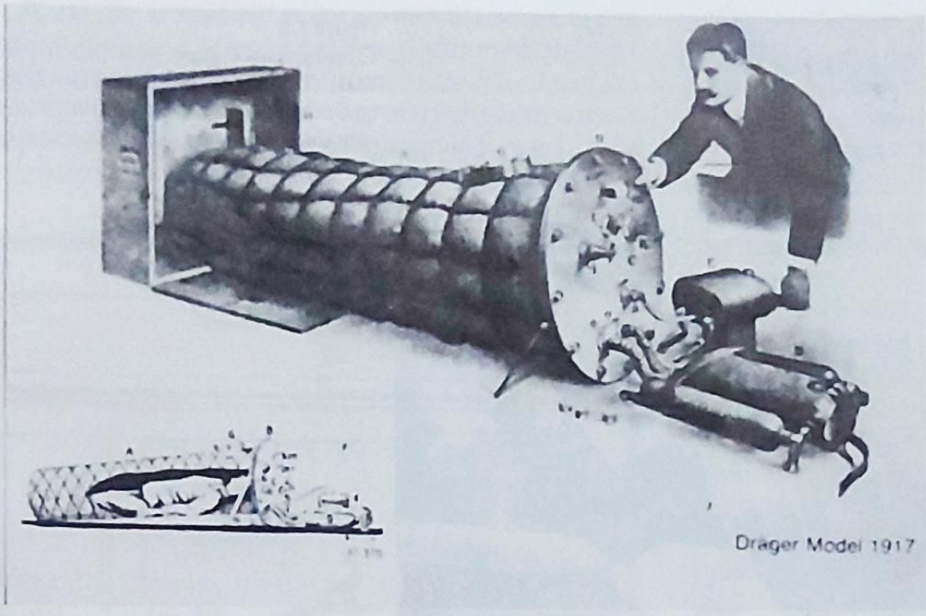

Figure 1.6
Sketch of the 1917 Dräger 2 ATA system for diving accidents, including oxygen breathing system. (Photo courtesy of Dr. Baixe, Toulon, France.)

censured by the AMA in 1928, in a report that stated: "Under the circumstances, it is not to be wondered that the Medical Profession looks askance at the 'tank treatment' and intimates that it seems tinctured much more strongly with economics than with scientific medicine. It is the mark of the scientist that he is ready to make available the evidence on which his claims are based."

Dr Cunningham was given repeated opportunities to present such evidence but never did so. A more detailed account of Cunningham's story and the history of hyperbaric medicine is to be found in Trimble (1974). The Cunningham chamber was dismantled for scrap in 1937, which brought to a temporary end the era of hyperbaric air therapy for medical disorders.

The Development of Hyperbaric Oxygen Therapy

Oxygen was not "discovered" until 1775, when the English scientist Joseph Priestley isolated what he called "dephlogisticated air." A more detailed history of the applications of oxygen since that time can be found in Jain (1989b). Although hyperbaric air had been used as early as 1662, oxygen was not specifically added to early hyperbaric chambers. The toxic effects of concentrated oxygen reported by Lavoisier and Seguin in 1789 were reason enough for hesitation to use it under pressure. Beddoes and Watt, who wrote the first book on oxygen therapy in 1796, completely refrained from mentioning the use of oxygen under pressure. Paul Bert, the father of pressure physiology, discovered the scientific basis of oxygen toxicity in 1878 and recommended normobaric, but not hyperbaric, oxygen for decompression sickness.

The potential benefits of using oxygen under pressure for the treatment of decompression sickness were first realized by Dräger, who in 1917 devised a system for treating diving accidents (Figure 1.6). For some unknown reason, however, Dräger's system never went into production. It was not until 1937 – the very year that Cunningham's "air chamber" hotel was demolished – that Behnke and Shaw actually used hyperbaric oxygen for the treatment of decompression sickness. The age of Hyperbaric Oxygen (HBO) therapy had finally arrived.