An Introduction to Diving and Hyperbaric Medicine - How Does It Work and How Do We Do It?

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INTRODUCTION

Hyperbaric oxygen therapy (HBOT) can be defined as the treatment of disease states by the application of 100% oxygen at pressures above one atmosphere absolute (1 ATA = 101.3 kPa). In practice, we commonly use pressures between 2.0 ATA and 2.8 ATA. Whilst the technology for delivering this treatment has been in development for about 350 years, until the middle of the last century hyperbaric treatment was administered using air rather than oxygen. HBOT is therefore a relatively young modality with most applications dating from the 1960's. The history of HBOT is summarised in point form in Table 1.

Table 1. Some highlights from the history of hyperbaric therapy

Date	Author	Event
Hyperbaric Air		
1662	Henshaw: English physician and clergyman	Described and built his "domicilium" for the treatment of poor digestion, promotion of insensible respiration and to facilitate breathing and expectoration.
1834	Junod: French physician	Built a chamber to treat pulmonary afflictions using 2 - 4 ATA. This was the start of a wave of enthusiasm across Europe.
1877	Fontaine: French surgeon	Built the first mobile hyperbaric operating chamber where nitrous oxide could be used as sole agent for longer operations.
1891	Corning: US physician	Begins treating patients for a variety of nervous disorders.
1918	Orville Cunningham: US physician	Used his chamber to treat victims of the Spanish flu epidemic sweeping the USA. He reasoned that the mortality was higher at altitude (in the mountains) and therefore a barometric factor was involved. The explosive loss of pressure one night led to the death of several patients but did not deter him from expanding his practice to the treatment of syphilis, hypertension, diabetes and cancer among others.
1928	As above	Builds the largest hyperbaric chamber ever constructed. It was 5 stories high, 64 feet in diameter and constituted a hyperbaric hotel. This was also the year Cunningham was censured by the AMA for the failure to provide any scientific descriptions of his treatment methods or validation of his results.
1937	As above	The above led to a decline in the practice of hyperbaric medicine with air fairly rapidly, and the Cunningham chamber was sold for scrap in 1937.

Hyperbaric oxygen		
1775	Joseph Priestly: English chemist	"Discovers" oxygen.
1789	Lavoisier and Seguin: French chemists	First report of oxygen toxicity and use at high pressures was discouraged.
1878	Paul Bert: French physiologist	Scientifically appraised oxygen toxicity and recommended normobaric treatment only. CNS toxicity is still known as the 'Paul Bert Effect'.
1937	Behnke and Shaw: US naval physicians	First use oxygen rather than air for decompression illness.
1938	Ozorio de Almeida and Costa: Brazilian physicians	Use HBO for leprosy.
1954	Churchill-Davidson: British physician	Uses HBO to increase radiosensitivity of tumours.
1956	Ita Boerema: Dutch surgeon	Performs cardiac surgery at pressure in a chamber to allow prolonged cardiac standstill.
1960	George Sharp and George Smith: US physicians	Describe the treatment of carbon monoxide poisoning
1961	Ita Boerema and Brummelkamp: Dutch surgeons	Publish first description of the treatment of gas gangrene
1965	David Perrins: British physician	Publishes data on treatment of chronic osteomyelitis.
1973		Formation of the South Pacific Underwater Medicine Society (SPUMS) – Australia and New Zealand
1986		Undersea and Hyperbaric Medical Society (UHMS) formed with a membership of 2,000 within a short time - USA

In Australia and New Zealand, hyperbaric facilities are most often managed by Anaesthetists – usually on the basis of an understanding of the uptake, distribution and elimination of gases, along with a high level of skill in resuscitation. Hyperbaric practitioners are owners of a single therapy for a wide range of ailments, rather than experts in a field of disease for which there are a variety of therapies available. This situation has lead to the famous accusation that HBOT is 'a therapy in search of diseases'.[1] This is a characterisation with which we still struggle.

HBOT is delivered using a compression vessel and an oxygen delivery system. These vessels may be designed for a single occupant (a monoplace chamber), or multiple occupants (a multiplace chamber). For therapeutic purposes they are identical, but each type of vessel suits particular individuals depending on both physical and psychological factors. The chambers in use at the Prince of Wales Hospital in Sydney are illustrated in Figures 1 and 2 below. The monoplace chamber is filled with oxygen and does not require a specific oxygen delivery system for respiration, while the multiplace chamber is filled with air and oxygen is delivered by mask, hood or anaesthetic circuit as required. The relevant Australian Standards mandate a trained nurse attends patients in a multiplace system at all times.

INDICATIONS FOR HBOT

The assessment of what does and does not constitute an indication for HBOT will vary from country to country and unit to unit based on local experience and where the interest in, and ownership of, the facility lies. One of the more popular benchmarks for many lists of indications is

that produced by the Undersea and Hyperbaric Medical Society. Their list is based on an assessment of the evidence by a dedicated committee and is reviewed on a triennial basis. In Australia and New Zealand, the SIG of the ANZCA publishes an annual list of recommended indications based on the available evidence. The latest of these is reproduced as Table 2.

Figure 1. A multiplace hyperbaric compression vessel. This chamber was built in the mid-1960's for Prince Henry Hospital in Sydney and intended for paediatric cardiac surgery. It is still in use at the Prince of Wales Hospital.

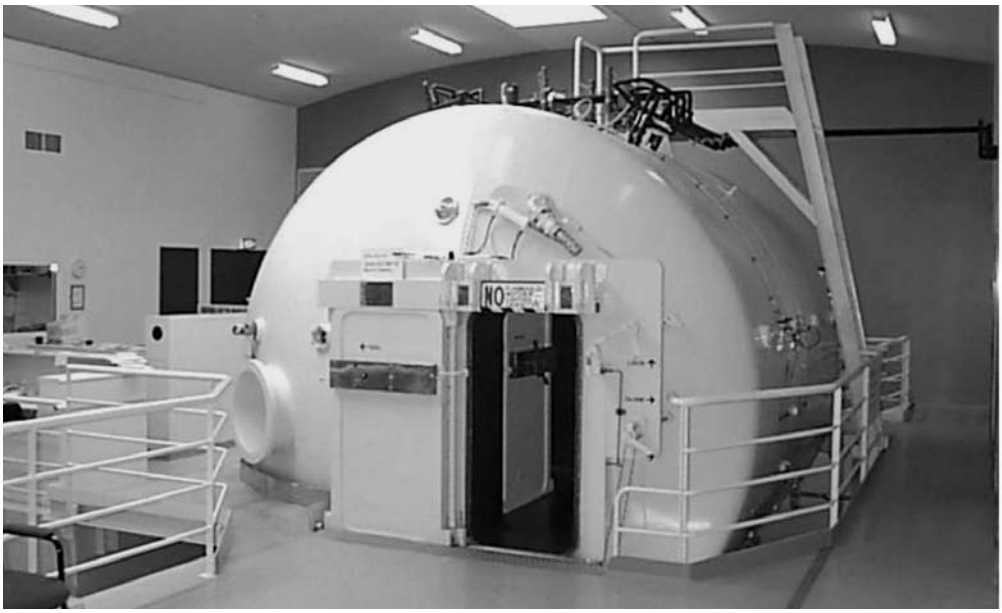


Figure 2. A monoplace chamber in use. The whole vessel is filled with oxygen.

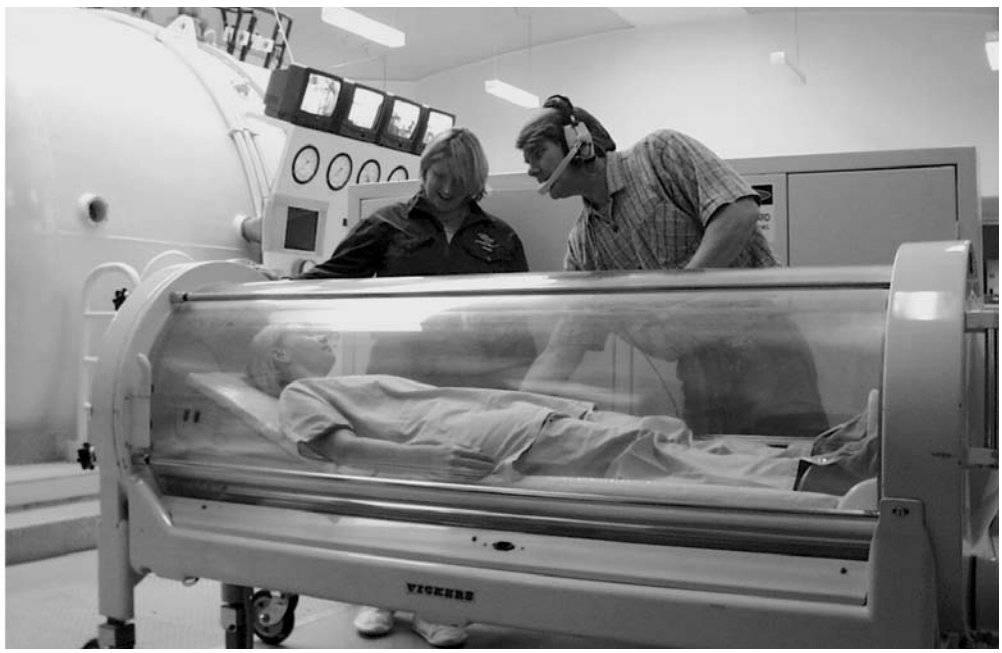


Table 2. The DMH SIG indications for which HBOT may be indicated. This list is reviewed annually in the light of emerging evidence.

BROAD INDICATION	SPECIFIC INDICATION
BUBBLE INJURY	DECOMPRESSION ILLNESS
	ARTERIAL GAS EMBOLUS
	(Diving/Iatrogenic/Misadventure)
ACUTE ISCHAEMIC CONDITIONS	COMPROMISED FLAPS AND GRAFTS
	CRUSH INJURY
	COMPARTMENT SYNDROMES
	POST-OPERATIVE
	REPERFUSION INJURIES
INFECTIVE CONDITIONS	CLOSTRIDIAL MYONECROSIS
	NECROTIZING FASCIITIS/NON-CLOSTRIDIAL MYONECROSIS
	MALIGNANT OTITIS MEDIA
	REFRACTORY MYCOSES
	PNEUMATOSIS CYSTOIDES INTESTINALIS
	REFRACTORY OSTEOMYELITIS
	INTRACRANIAL ABSCESS
RADIATION TISSUE DAMAGE	OSTEORADIONECROSIS
	Established
	Prophylactic
	SOFT TISSUE RADIONECROSIS
	Established
	Prophylactic
PROBLEM WOUNDS	DIABETIC ULCERS/GANGRENE
	VENOUS ULCERS
	DECUBITUS ULCERS
	FROSTBITE
	SURGICAL INCISIONS
	SPIDER BITE
TOXIC GAS POISONING	CARBON MONOXIDE (mod/severe)
	SMOKE INHALATION
	CYANIDE
	HYDROGEN SULPHIDE
OCULAR ISCHAEMIC PATHOLOGY	CYSTOID MACULAR OEDEMA
	RETINAL ARTERY/VEIN OCCLUSION
MISCELLANEOUS	THERMAL BURNS
	EXCEPTIONAL BLOOD LOSS ANAEMIA

These indications are remarkably diverse, and not all are based on a simple 'reversal of hypoxia' phenomenon. It is my intention to illustrate how HBOT might be effective for these conditions, and to briefly review some of the clinical evidence. The interested reader is referred to a comprehensive review of the clinical evidence available on-line. [2, 3]

I will also briefly review the commonly used therapeutic tables. The optimal dose of oxygen per treatment will depend on the mechanism of action and the efficacy of oxygen in each target disease. Ideally, treatment tables would have been developed following appropriate phase I, II and III testing for each indication before introduction to practice. Regrettably, this is far from the case. The situation has been described elegantly by Marroni:

"The clinical application of hyperbaric oxygen therapy (HBOT) although based on sound physiological principles as well as on a logical rationale, has often been characterised by empirical procedures, and the choice of treatment schedules has been more fortuitous than rational".[4]

MECHANISMS OF ACTION

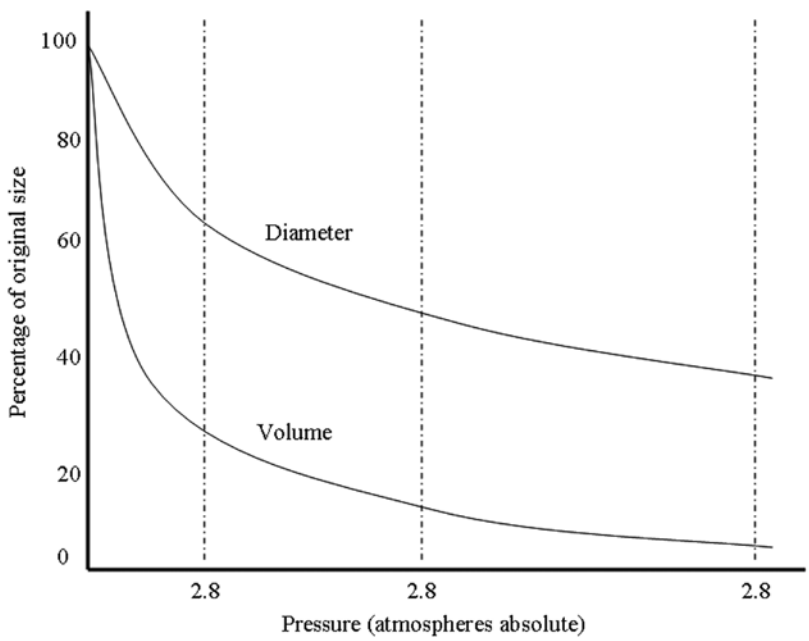
Three primary mechanisms of action may be identified- bubble size reduction and elimination, the achievement of gross hyperoxia in target organs and the enhancement of immune and healing mechanisms through achievement of normoxia in an hypoxic target organ.

1. Bubble Size Reduction

Bubble injury is most often associated with decompression illness (DCI) following breathing of compressed air and subsequent decompression. The situation is highly analogous to the washout of anaesthetic gases following a volatile general anaesthetic, with the added complication of bubble formation secondary to supersaturation of the tissues with nitrogen. Tissue or intra-vascular bubbles may follow compressed air breathing, whilst intra-vascular introduction of air is also seen in association with a variety of medical and surgical procedures, following trauma involving high pressure gas hoses and male to female orogenital sex in late pregnancy.[5, 6] In any of these situations, the physical presence of a bubble may obstruct blood flow and affect tissue perfusion. Intra-arterial gas emboli are particularly problematic in the cerebral circulation.

While bubbles persist, the exposure of the individual to a high-pressure environment will result in reduction in bubble size in accordance with Boyle's Law. The reduction in bubble diameter (when bubble is in the tissues) or more importantly, bubble length (when intra-vascular), may result in improved perfusion and function, reduction in distortion of the local tissue architecture and the regression of symptoms. It is important to understand that, although the *volume* of a spherical bubble will be halved on compression from 1 ATA to 2 ATA, the *diameter* of that bubble is reduced by only a little over 20% (Figure 3). Further compression confers less dramatic decrements in diameter, and this may explain the experimental and clinical finding that there is little added benefit for compression beyond an initial doubling of pressure.[7]

Figure 3. Relationship between pressure, bubble volume and bubble diameter. Taken from[7]. At the usual treatment pressure of 2.8ATA, bubble volume is reduced by 73%, but bubble diameter by only 35%.

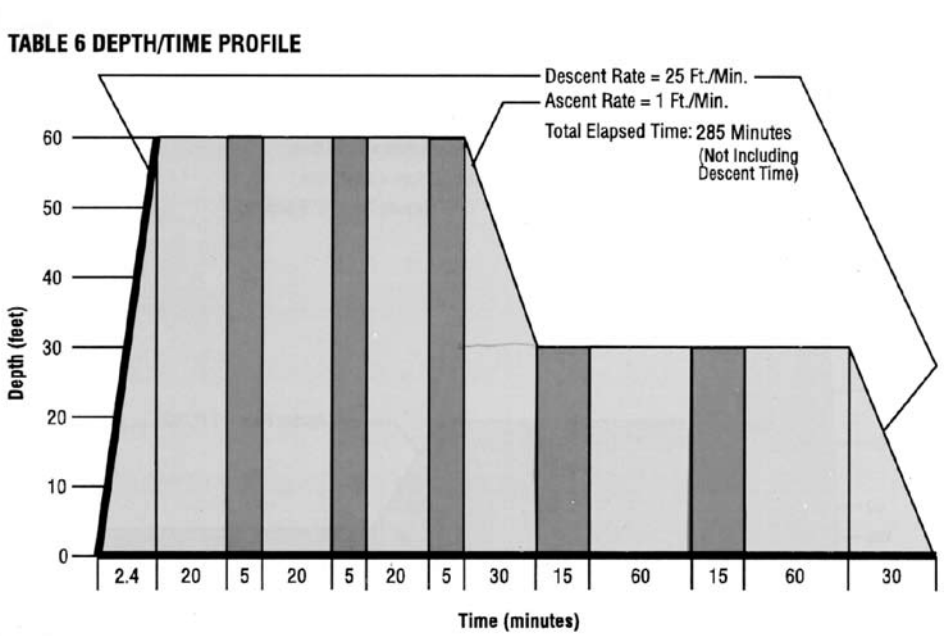


It had been noted since the Hudson River tunnel project in New York in 1909 that recompression of compressed air workers would often relieve the symptoms of 'the bends' that so commonly plagued these workers. [8] In 1924 the US Navy introduced a series of air treatment tables, but these proved to have a 50% failure rate. Nevertheless, refined air recompression was used for many years in the treatment of decompression illness (DCI), either to a pre-determined pressure or by the principle of return to causative depth.

Hyperbaric oxygen administration at lower pressures and for shorter durations has proved highly efficacious because, in addition to the crushing of bubbles according to Boyle's Law, elimination is also achieved by the rapid evolution of nitrogen out of the bubbles down the greatly increased partial pressure gradient that is achieved by nitrogen washout during oxygen breathing. [9] There is some evidence to support the further enhancement of this effect by the addition of relatively insoluble inert gas to the breathing mixture on compression, particularly helium. One randomized clinical trial designed to test the relative efficacy of Heliox treatment tables against oxygen has reported promising trends, but the final results have not been published.[10]

Tables designed for the treatment of DCI consist of a relatively rapid recompression to a specified pressure followed by a slow decompression. Oxygen breathing is used as much as possible at pressures of 2.8 ATA (283.6kPa) or lower (to avoid an unacceptable incidence of CNS oxygen toxicity). While long air tables are still occasionally employed to treat severe DCI where there is failure to respond to oxygen tables, or where oxygen is not available, the most common treatment table by far is designated US Navy Treatment Table 6 (RN Table 62).[9] These are oxygen tables with a maximum pressure of 2.8 ATA, as shown below in Figure 4.

Figure 4. USN TT6 as published for use in the US Navy diving manual. Oxygen and air breathing periods are designated as shown (oxygen starts at initial compression).



The table consists of rapid compression to the equivalent of 60 feet of sea water (60fsw, or 18 metres of sea water, an ambient pressure of 2.8ATA), where the diver breaths oxygen for 20 minutes followed by a 5 minute air break. After three repetitions of oxygen/air, there is a slow ascent to 30 fsw (9 msw) and further cycles as indicated. The exposure may be extended at either depth if the diver is not responding, or in extreme cases, converted during the 60 fsw phase to a longer air table. These tables are also commonly employed for iatrogenic air embolus.

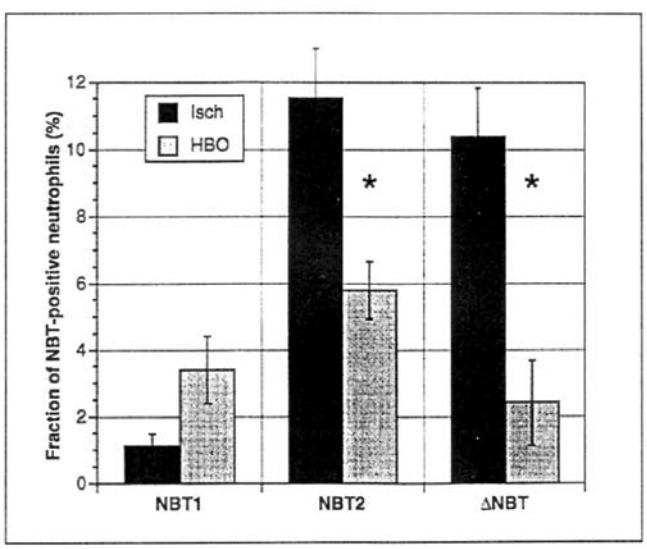
Bubble size reduction may also be of some benefit in compression of tissue gas seen with some anaerobic necrotizing infections, particularly gas gangrene, although this is unlikely to be the major mechanism of action in this setting.

2. Achievement of Gross Hyperoxia

The administration of hyperbaric oxygen results in very high blood partial pressures of oxygen – during a 2 ATA treatment we might expect an arterial oxygen tension of 1,000 to 1,200 mmHg. [11] Such high tensions have profound physiologic and therapeutic consequences. Hyperoxia is most clearly of benefit in those conditions where intravascular injury is prominent - vascular bubble injury, ischaemia/reperfusion injury and those conditions where oxygen competes with toxic gases for important transfer and enzymatic binding sites are all examples. For other conditions where tissue ischaemia is complicated by interstitial oedema, hyperoxic mediated vasoconstriction may contribute to tissue re-oxygenation through the delivery of increased oxygen despite significantly reduced blood flow. This has been studied most recently in the rat brain, where at least one mechanism appears to be the inhibition of nitric oxide production by superoxide anions. [12] One of the exciting possibilities is that such mechanisms are only active in the target region, and may be associated with a beneficial reverse steal phenomenon.

Hyperoxia is also effective in tissue injury via inhibition of the activation and subsequent binding of leucocytes to damaged vascular endothelium. There is strong experimental evidence that this is mediated through an inhibition of β-2 integrin function and subsequent prevention of intracellular adhesion molecule-1 (ICAM-1) activation on the leukocyte surface. The prevention of leukocyte activation ultimately reduces ischaemia-reperfusion injury and subsequent lipid peroxidation.[13, 14] In two animal models of ischaemia-reperfusion, HBOT modified neutrophil activation and prevented the accumulation of activated leucocytes in the lungs, suggesting that HBOT may be helpful in the prevention of adult respiratory distress syndrome (Figure 5),[15-16] while in another a similar prevention of leukocyte infiltration into brain tissue is implied.[17] Using an in-vitro endothelial cell model, Buras has confirmed that ICAM-1 is the likely target molecule through which HBOT acts at the cellular level, and that this effect is mediated through endothelial cell nitric oxide synthetase (Figure 6). [15]

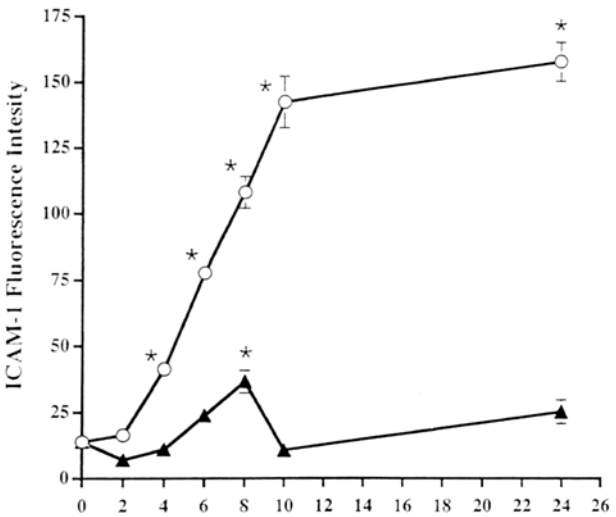
Figure 5. Fraction of activated neutrophils before and after ischaemia-reperfusion. *Significant difference (P<0.05). NBT = Nitroblue tetrazolium test for activation of neutrophils. From[17]



The passage of gas emboli through the arterial circulation causes considerable endothelial damage. The vascular endothelial effects of hyperoxia are probably of great importance in the treatment of this injury through the same mechanisms outlined above, and these act in addition to effects mediated through reductions in bubble size.

Evidence continues to emerge concerning the central role that interactions between hyperoxia and nitric oxide may play in a broad range of applications. Thom has recently published startling evidence that exposure to 2 ATA of oxygen for two hours is sufficient to mobilize stem/progenitor cells from the bone marrow by a nitric oxide dependent mechanism. [19] A course of 20 such treatments on a daily basis increased the population of circulating stem cells eight-fold. These cells are highly attracted to areas of increased vascular growth factor elaboration and may well have implications for chronic wound healing.

Figure 6. ICAM-1 induction following 4 hours of hypoxia and hypoglycaemia. Open circles subsequently exposed to normoxia/normoglycaemia, triangles to a single HBO session at 2.5 ATA for 90 mins. *P<0.05 compared to time zero. From[19]



Hyperoxia is also important in the treatment of toxic gas poisonings. In practice, carbon monoxide is the most common toxic gas encountered in clinical practice. CO binds approximately 240 times as readily with haemoglobin as does oxygen. During normobaric air breathing (PIO_2 approx 160mmHg), very low concentrations of CO in the inspired air can rapidly replace oxygen at a high proportion of haemoglobin binding sites. Delivery of the bound CO to the tissues results in a similar process occurring at a number of intra-cellular enzyme sites. In addition, there is growing evidence that CO, like the mechanical insult associated with the passage of bubbles, causes an injury to the vascular endothelium, leucocyte activation and adherence, production of oxygen free radicals and ultimately lipid peroxidation of neuronal cell walls. [20] If the victim survives the period of acute hypoxia, CO accumulated in the tissues may continue to adversely affect cell function and result in late-onset cell death and profound disability or death in the individual.

The administration of hyperbaric oxygen may improve this situation in a number of ways, although the precise mechanism(s) responsible for most of the benefit remain unclear. High partial pressures of oxygen in the inspired air will drive off CO from binding sites on the haemoglobin molecule through the law of mass action. For this reason, the half-life of HbCO is dramatically reduced under hyperbaric conditions (about 51/2 hours in air at 1 ATA, 71 minutes breathing oxygen at 1 ATA and 29 minutes at 1.6 ATA on 100% oxygen). [21] Similarly, the law of mass action will reduce the time required for removal of CO from intracellular enzyme systems

such as cytochrome C oxidase.[22] While rapid removal of HbCO can be demonstrated in the clinical situation, the relevance is not at all clear given the poor correlation of HbCO level and degree of ultimate neurological impairment.

Another putative mechanism of HBOT in CO poisoning is by the somewhat paradoxical inhibition of lipid peroxidation at hyperbaric doses of oxygen. Some animal work suggests this may be mediated in part by the presence of increased concentrations of hydroperoxyl (HO_2) and hydrogen peroxide (H_2O_2) radicals, and an up-regulation of antioxidant defenses. Others have demonstrated a direct protective effect on leucocytes following HBOT exposure.[23, 24] A great deal of work remains to be done to fully explain the role of oxygen in this area.

The effects of hyperoxia in chronic wound healing are similarly difficult to define with confidence. It appears that modulating the tissue oxygen levels will have complex and sometimes opposing effects. I have already mentioned the positive potential for wound healing by the generation of stem/progenitor cells. On the other hand, in experiments using human skin cell monolayers, dermal equivalents and human skin equivalents, daily HBOT was shown to inhibit fibroblast proliferation and elaboration of collagen, while enhancing keratinocyte differentiation and epidermopoiesis.[25] The net effects are difficult to assess and require good human trials in order to generate clinical recommendations.

In infections caused by anaerobic and facultative organisms, the achievement of a sufficiently high tissue PO_2 may cause increased bacterial vulnerability through a direct bacteriostatic or bacteriocidal effect. For example, oxygen at 3 ATA (304 kPa) is bacteriocidal for *Clostridium perfringens*. Indeed this was the original rationale for treating gas gangrene. Closer inspection of the data however, reveals that 18 hours of oxygen at 3 ATA is required to kill the bacteria. Of greater probable relevance is that the germination of spores is inhibited at 2 ATA for shorter periods. Similarly, HBO is bacteriostatic to *Escheria coli* at 2 ATA and *Mycobacterium tuberculosis* at intermittent exposures at 2.9ATA.[26] Such bacterial effects are probably secondary to a combination of direct toxic effects of oxygen free radicals, synergism with certain antibiotics and enhancement of the host immune system (as described below).

One other intriguing possibility has been suggested by Hills - the osmotic effect of high arterial oxygen tensions.[27] One consequence of soft-tissue injury is ischaemia and hypoxia. This leads to malfunction of capillary membranes and the development of oedema, with subsequent worsening of tissue hypoxia, more leaking of fluid from capillaries and more oedema. Hills maintains this vicious cycle may be broken more at the point of *oedema* than at the more traditionally accepted point of *hypoxia.*

Hills' proposal is that, while *arterial* oxygen tensions are greatly raised during HBOT, the *tissue* level of oxygen is not greatly increased. This leads to an effective steady state gradient of oxygen between arterial blood and the site of oxygen consumption in the tissues - and this gradient will promote fluid reabsorption into the vascular compartment by the osmotic effect of oxygen. Hills calculates the effect of typical arterial oxygen tensions during HBOT as an approximately 8.5% increase in plasma oncotic pressure, although this may be an underestimate. It is the unique nature of oxygen, by which it is consumed in the tissues, that allows the long-term maintenance of an “oxygen pump” effect and no sequestration of the osmotic agent into the tissues over time.

Treatment tables designed for the maximisation of oxygen tensions have traditionally used a treatment pressure of 2.8 ATA (283.6 kPa). As discussed above, this is the maximum oxygen pressure compatible with both a reasonable treatment time and an acceptable incidence of cerebral oxygen toxicity. Typically, such tables employ a treatment pressure of 2.8 ATA for 120 minutes, giving the inside attendant a decompression obligation. At the Prince of Wales Hospital, we achieve this by decompressing the chamber to 3 metres where the inside attendant can breathe 100% O_2 for 32 minutes, while the patient can be transferred out by a second attendant via the lock. After this exposure the inside attendant should not be recompressed for 24 hours.

3. Restoration of Normoxia

All wounds are hypoxic to some degree and this forms an important stimulus to the normal immunological and angiogenic responses that results in wound healing. Some wounds, however, do not heal readily and become a longer-term problem. Hypoxia in these conditions may be

profound and entirely prevent wound healing. In such cases the intermittent application of oxygen at hyperbaric conditions may raise the PO_2 in parts of a wound to levels closer to normal tissues. This enables the normal wound healing mechanisms and stimulates angiogenesis.

Although wound healing is a complex process, a number of key elements can be identified where oxygen may play an important role. We have already discussed leucocyte function in relation to endothelial damage above, and white cells are intimately involved with the clearance of debris and foreign material (including bacteria) from the wound area. Many such functions are exquisitely sensitive to oxygen. For example, the process of phagocytosis involves consumption of oxygen in an "oxidative burst". [28] Although such processes are possible at remarkably low tissue oxygen tensions, improving oxygenation within the physiologic range often dramatically improves the efficiency of such activity. Allen has shown that oxygen tensions between 40 and 80 mmHg are required to maintain activity at 50% of maximum in the NADPH-linked oxygenase responsible for this respiratory burst. To work at 90%, tensions as high as 400mmHg may be required. [29]

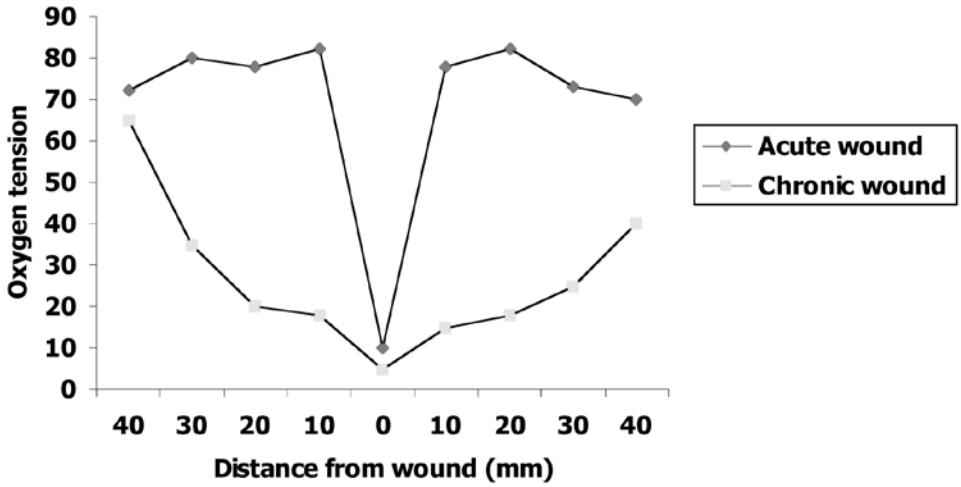
Table 3. Likely mechanisms of action for a range of indications for hyperbaric oxygen

Mechanism of action	Indication
Reduction in bubble size	Decompression Illness
	Arterial Gas Embolism
	Gas Gangrene
Achievement of hyperoxia	Decompression Illness (CAGE)
	Carbon Monoxide Poisoning
	Other toxic Gases
	Anaerobic Infections
	Cerebral Oedema
	Crush injuries
	Ischaemia/reperfusion injury
Restoration of normoxia	Problem Wounds
	Chronic Osteomyelitis
	Osteoradionecrosis
	Soft-tissue Radionecrosis
	Pyoderma Gangrenosum
	Decompression Illness

A further direct effect of raising wound oxygen tension is on the fibroblast. Migration is inhibited at low tensions and the production of collagen through the hydroxylation of proline and lysine is very oxygen sensitive. [30] The enzyme responsible needs 20mmHg of oxygen to reach 50% of maximum activity, and 150mmHg to reach 90%.[31] This effect should be contrasted with the effect of grossly hyperoxic exposures such as those illustrated in Figure 5.

Finally, raising wound PO_2 may also stimulate angiogenesis in a somewhat counter-intuitive way. Hypoxia is the single most powerful stimulus to angiogenesis under normal conditions. However, some evidence exists to suggest that, rather than the absolute value of tissue oxygen, it may be the tension gradient over the healing area that is of prime importance. In many problem wounds there are reasons why the oxygen tension in tissues surrounding the wound will also be low, thus eliminating a point at which tension drops sharply. Examples include radiation tissue damage, diabetes and chronic infective conditions. The situation is illustrated in Figure 7. The application of a high intravascular driving pressure of oxygen can re-establish the steep gradient around the wound and stimulate angiogenesis and repair.

Figure 7. Transcutaneous oxygen tension in acute and chronic wounds.
Note the steep oxygen gradient near the wound edge in an acute wound in normal tissue.

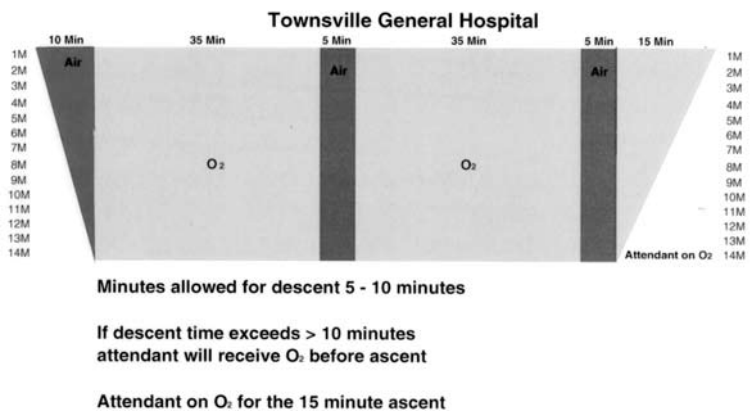


A complementary view is that it is the falling tension following treatment that forms the direct stimulus to enhance new vessel growth. Further, some experimental data exists to suggest that HBOT enhances the expression of angiopoietin-2 and induces angiogenesis through RNA transcriptional stimulation via a nitric oxide stimulating pathway. [32]

As the most common indications for HBOT are chronic hypoxic wounds and radionecrotic lesions, it follows that tables designed to restore approximate normoxia, (or moderate hyperoxia), are those most commonly employed in modern hyperbaric practice. Generally, we apply maximum pressures of 2.4 ATA (14m equivalent depth of seawater or 243.1kPa) for 90 minutes daily. While the details vary from unit to unit, this treatment approach is remarkably uniform in Australia and New Zealand. The schedule in use at the Townsville unit is shown as an example. Most variations relate to air breaks designed to protect the patient from oxygen toxicity, and the oxygen requirement for the attendant in order to produce an acceptable DCI risk (Figure 8).

In other parts of the world and particularly where monoplace chambers are in use, the 'standard' treatment is often 2 ATA (10msw or 202.6kPa) for 2 hours. There is no evidence that either of these approaches is more effective. Nor is there good evidence to suggest which of once or twice daily treatments are more effective.

Figure 8. The Townsville 14m table. Note the two air break periods of 5 minutes each for the patient and the slow ascent with attendant on oxygen.



SUMMARY

HBOT may act through the effect of pressure or through metabolic and chemical effects of oxygen. Hyperoxic mechanisms are mainly credited for intravascular effects or effects in vessel rich tissues without vascular compromise. In wound healing and other hypoxic conditions, restoration of normal tissue oxygen tensions may be the more important and achievable mechanism.

Treatment tables have been developed largely empirically, but do reflect the appropriate dose for the mechanisms discussed above. As with all pharmacological agents, there is a requirement for demonstrating the appropriate dosing schedule to maximize efficacy while minimizing toxicity. The appropriate balance between these conflicting goals will depend on a careful risk/benefit analysis for each individual indication and patient. Ultimately, we may develop individual treatment tables based on real-time tissue oximetry where oxygen dose is manipulated to achieve a specific target tissue PO_2. These are exciting times in this field and we look with anticipation toward the future.

One of the principle criticisms leveled at the practice of hyperbaric oxygen therapy is the lack of a proven mechanism of action. This remains a valid criticism for many of the common indications. Much work needs to be done to show which, if any, of the many putative mechanisms are operating in a given pathological situation.

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