In-Water Oxygen Recompression: A Potential Field Treatment Option For Technical Divers

by Carl Edmonds

The failure of decompression illness to respond to recompression chamber therapy is often related directly to the delay in treatment (see *"Get Me To The Chamber On Time,"* staff. *aquaCorps Journal* N1, 1990). Sometimes chambers are simply not readily available. For these reasons, immediate in-water air recompression has been used in Hawaii, with good results, and also among the professional shell divers of Australia, at least until the underwater oxygen became available: Interesting enough, most diving medical text books do not even mention in-water therapy as an option.

When using in-water air recompression therapy, pressure is exerted by water instead of in a recompression chamber, while air is usually supplied from compressors sited on the diving boat. Although this treatment is frequently ridiculed by those in the cloistered academic environments, especially those committed to elaborate recompression facilities, it has frequently been the only therapy available to severely injured divers, has had many successes, and is recognized by many experienced and practical divers to often be of life saving value. This has certainly been the case in remote localities such as the pearl fishing areas of Northern Australia, where divers spend long times underwater using standard diving equipment. In-water air treatment continued to be used, in the absence of available recompression chambers.

Despite the value of in-water air recompression therapy, there are many problems associated with it that are well recognized by both divers and medical advisers. First, the majority of amateurs or semi-professional divers do not carry the compressed air supplies or compressor facilities necessary for the extra decompression. Most have only scuba cylinders, or simple portable compressors that will not reliably supply divers (the patient and his attendant) for the depths and durations required.

What's more is that environmental conditions are often not conducive to in-water air treatment. The depths required for these treatments (often as deep as 50 msw/165 fsw) can usually only be achieved by returning to the open ocean, where the advent of night, inclement weather, rising seas, tiredness and exhaustion, and boat safety requirements, make the choice of in-water treatment a very serious decision. In addition, because of the considerable depths and time involved, hypothermia as a result of wet suit compression becomes likely. Seasickness in the injured diver and the diving attendants and the boat tenders, is also a significant problem. Nitrogen narcosis produces added difficulties in the diver and the treatment. Because of these difficult circumstances, treatment must often be aborted, resulting in DCI in the attendants, and aggravating it in the diver.

In-water air treatment of DCI is not to be undertaken lightly, however, in the absence of a recompression chamber or other options, it may be the only treatment available to prevent death or severe disability. Fortunately, a newer method has been developed that addresses many of the problems associated with air treatments.

Oxygen Therapy

The value of substituting oxygen for air, in recompression chamber treatment has been well established. The pioneering work of Yarborough and Behnke (1939) eventuated in the oxygen tables described by Goodman and Workman (1965). They received widespread acceptance, with revisions and modifications they are now incorporated in oxygen treatment tables of most Navies.

The advantages of oxygen over air tables include; increasing nitrogen elimination gradients, avoiding extra nitrogen loads, increasing oxygenation to tissues, decreasing the depths required for the exposure time and improving the overall therapeutic efficiency. The same arguments are applicable when one compares in-water air and oxygen treatment.

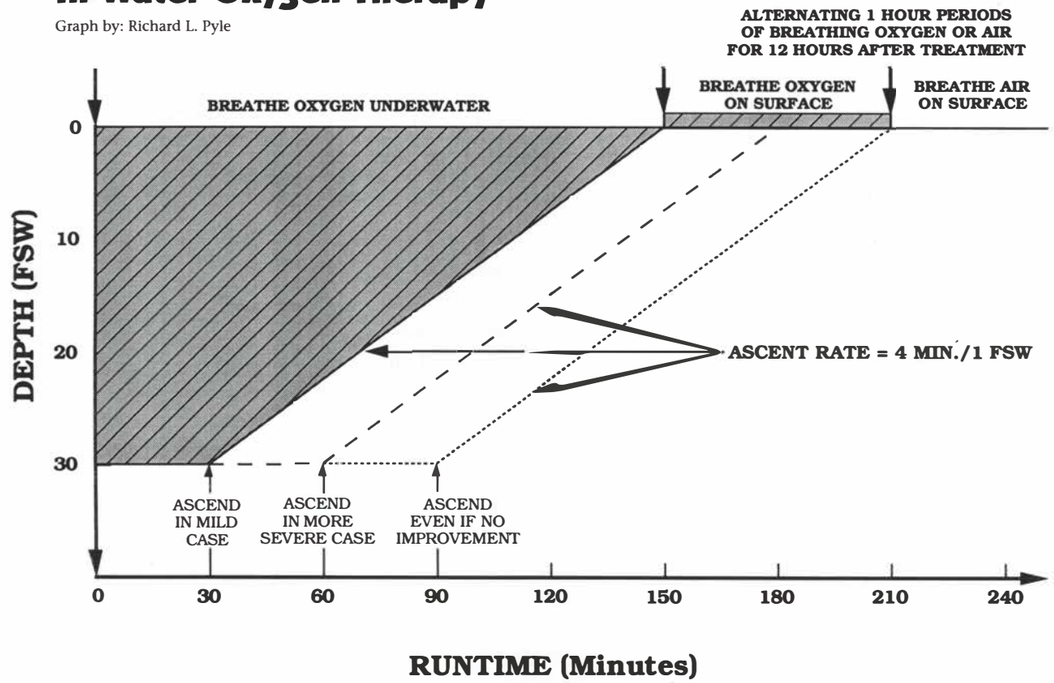
Australian In-water Oxygen Therapy

In response to an urgent need for managing cases in remote locations, both time and distance from hyperbaric facilities, oxygen therapy was first applied to the in-water treatment of decompression illness in Australia, in 1970. Because of the success of this treatment and its ready availability, it became known and practiced, even when experts were not available to supervise it.

The physiological principles on which this treatment is based are well known and not contentious, although the indications for treatment have caused some confusion. Like conventional oxygen therapy tables, it was first applied mainly for the minor cases of DCS, but was subsequently found

In-Water Oxygen Therapy

Graph by: Richard L. Pyle



of considerable value in serious cases. The techniques and equipment for Australian in-water oxygen therapy were designed to increase safety, ease and ready availability, even in medically unsophisticated countries (see box). It is now in widespread use in the Pacific Islands and the northern parts of Australia. It spread to the colder southern waters of Australia, where it is now used by abalone divers who sometimes dive in areas difficult to service by conventional transport. It has also been included in certain diving manuals (Table 81 & 82 in the Royal Australian Navy Diving Manual and has been modified by allowing the use of oxygen rebreathing equipment, in the current US Navy Diving Manual. The French have had a very similar table (Comex12) which was immediately applicable to underwater use, and some Italian groups claimed to have employed the full US Navy oxygen therapy tables underwater - although how they managed this is not clear.

The original Australian in-water oxygen procedures and tables seem simpler and less likely to cause problems for the general diver population than these various alternatives, however, other procedures have evolved. Hawaiian commercial divers have included a **deep "air" spike** prior to the underwater oxygen treatment, in an attempt to either force bubbles back into solution or to allow bubbles trapped in arteries to transfer to the venous system.The relative value of this additional deep air dip is subject to some controversy and discussion, and its value remains to be clarified (*Note that the deep "air" spike to 50 msw/165 fsw used in the USN 6a recompression table appears to be increasingly falling "out of favor" in U.S. treatment circles due to problems of additional nitrogen loading and other complications. Many leading edge facilities are now using enriched air nitrox, and or heliox, in place of air for these treatments—ed.)*

In-water Oxygen Treatment Procedures

Australian In-Water Oxygen Therapy (Runtime in minutes)

Depth msw	Mild	Severe	Severe w' Extension
9	30	60	90
8	42	72	102
7	54	84	114
6	66	96	126
5	78	108	138
4	90	120	150
3	102	132	162
2	114	144	174
1	126	156	186
Total Time	2hrs. 6 min.	2 hrs. 36 min.	3 hrs. 6 min.

Oxygen should be supplied at maximum depth of 9 msw (30 fsw), from a surface supply system. The ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if significant improvement has occurred. These times may be extended for another 30 minutes, if there has been no improvement. The ascent is at the rate of 12 minutes per metre (4 minutes/foot). ***A diver attendant should always be present, and the ascent controlled by the surface tenders.*** The duration of the tables range from 2 hours 36 minutes or 3 hours 6 minutes depending on the treatment options used.

After surfacing the patient should be given periods of oxygen breathing, interspersed with air breathing, usually on a one hour on, one hour off, basis, with respiratory volume measurements and chest X-ray examination if possible. The treatment can be repeated twice daily, if needed.

The equipment required for this treatment is similar to that used in a surface supplied oxygen decompression system with some important differences. In the case of an in-water treatment, a G size cylinder (220 cubic feet or 7000 litres) of medical oxygen is probably adequate though specific requirements can easily be calculated. This is usually available from local gas supply companies or hospitals, although in some cases industrial oxygen has been used. ***For a diver at rest, breathing this volume of oxygen at a depth varying between 9 metres (30 feet) and the surface is usually insufficient to produce either neurological (CNS) or respiratory oxygen toxicity*** Note that all equipment used with pure oxygen must be rated for oxygen service. Also, whenever oxygen is given, the cylinder should be turned on slowly and the flow commenced, before it is given to patients or divers.

A 2-stage regulator, set at 550 kPa (80 psi) is fitted with a safety valve, and connects with 12 metres (40 feet) of supply hose. This allows for 9 metres depth, 2 metres from the surface of the water to the cylinder, and 1 metre around the diver. A non-return valve is attached between the supply line and the full face mask. ***The full face mask is critical as it enables the system to be used with a semi-conscious or unwell patient. It reduces the risk of aspiration of sea water, allows the patient to speak to his attendants, and also permits vomiting to occur without obstructing the respiratory gas supply.***

The supply line is marked in distances of 1 metre from the surface to the diver, and is tucked under the weight belt, between the diver's legs, or is attached to a harness. The diver must be weighted to prevent drifting upwards in an arc by the current.

A Field Treatment Option For Technical Divers

It was originally hoped that the underwater oxygen treatment would be sufficient for the management of minor cases of DCI, and to prevent deterioration of the more severe cases while suitable transport was being arranged. When the regime is applied early, even in the severe cases the transport is often not required. It is a common observation that improvement continues throughout the ascent, at 12 minutes per metre. Presumably the resolution of the bubble is more rapid at this ascent rate than its expansion, due to Boyle's Law.

Certain other advantages are obvious. During the hours of continuous hyperbaric oxygenation, tissues become effectively de-nitrogenated. Bubbles are initially reduced in volume, due to the hyperbaric exposure and Boyle's Law, and the resolution is speeded up by increasing the nitrogen gradient from the bubble. Attendant divers are not subjected to the risk of DCI or nitrogen narcosis, and ***the affected diver is not going to be made worse by premature termination of the treatment if this is required*** *(for example, in order to transport the diver—ed.).* In addition, hypothermia is much less likely to develop, because of the greater efficiency of the wet suits at these minor depths (*Note that the majority of technical divers utilize dry suits even in relatively warm water, so hypothermia is unlikely to be a major issue in most cases. See discussion below—ed.).*

The site chosen can often be in a shallow protected area, reducing the influence of weather on the patient, the diving attendants and the boat tenders. Communications between the diver and the attendants are not difficult, and the situation is not as stressful as the deeper, longer, in-water air treatments, or even as worrying as in some recompression chambers.

When hyperbaric chambers are used in remote localities, often with inadequate equipment and insufficiently trained personnel, there is an appreciable danger form both fire and explosion. There is the added difficulty in dealing with inexperienced medical personnel not ensuring an adequate face seal for the mask. These problems are not encountered in in-water treatment.

In spite of these advantages, in-water oxygen recompression is not applicable to all cases, especially when the patient is unable or unwilling to return to the underwater environment. It is also of very little value in the cases where gross decompression staging has been omitted, or where the disseminated intravascular coagulation syndrome has developed. The author would be reluctant to administer this regime where the patient has either epileptic convulsions or clouding of consciousness. Reference to the case reports reveals that others are less conservative.

One of the common myths in Australia, is that in-water treatment is applicable to the semi-tropical and tropical areas, where it was first used, but not to the southern parts of the continent, where water temperatures may be as low as 5° C (41° F). There are certain inconsistencies with this statement. First, if the diver developed DCI while diving in these waters, then he or she is most likely to already have an effective thermal protection suit available. Also, the duration underwater for the oxygen treatment is not excessive, and is conducted at a depth at which even wet suits provide effective insulation. If the diver is wearing a dry suit, the argument is even less applicable. The most effective argument is that in-water oxygen recompression is used, often very successfully, in these very areas.

Some claim that the in-water oxygen treatment is useful only when there are no transport facilities available. Initially this was also our own teaching, but with the logic that comes with hindsight, ***a three hour gap is all that is needed between the instituting of in-water oxygen therapy and the arrival of transport, to be able to effectively employ this procedure.*** It is probably just as important to treat the serious cases early, even though full recovery is unlikely, than to do nothing and watch the symptoms progress during those hours. Note that transport should be sought while the in-water treatment is being utilized,especially in serious cases.

There has also been a concern that if this technique is available for treatment of DCI, other divers may misuse it to decompress on oxygen underwater and perhaps run into subsequent problems. This is more an argument in favour of educating divers, than depriving them of potentially valuable treatment facilities. *(Note that in-water oxygen decompression has become a "community standard" among technical divers in the U.S. and other parts of the world, though it is not an accepted procedure for recreational divers who are not trained in decompression diving.—ed.).* With the same rationale, one could use this argument to totally prohibit all safety equipment, including recompression chamber, and thereby hope to circumvent all diving related problems.

It has also been argued that this treatment is unlikely to be of any value for those patients suffering from air embolism. Such may well be the case. The treatment was never proposed for this, and nor was it ever suggested that the in-water oxygen treatment should be used in preference to recompression facilities where they exist and are easily accessible to the diver. It is, however, possible that the treatment may be of value for cases of mediastinal emphysema, and perhaps even a small pneumothorax.

In conclusion, in-water oxygen recompression is an application and modification of current treatment regimes. It is not meant to replace the formal treatment techniques of recompression therapy in chambers. It is an emergency procedure, able to be applied with equipment usually found in remote localities and is designed to reduce the many hazards associated with the conventional in-water air treatments. The customary supportive and pharmacological adjuncts to the treatment of recompression sickness are in no way avoided, and the superiority of experienced personnel and comprehensive hyperbaric facilities is not being challenged. In-water oxygen treatment is considered as a first aid regime, not superior to portable recompression chambers, but sometimes surprisingly effective and rarely, if ever, detrimental.

Dr. Carl Edmonds is regarded as the leading authority on in-water treatment of decompression illness, and has made major contributions to diving medicine in a variety of capacities including; Director of the Diving Medical Centre, Sydney, Australia, consultant in underwater medicine to the Royal Australian Navy, past president, South Pacific Underwater Medicine Society, Officer in charge, Royal Australian Navy School of Underwater Medicine. Dr. Edmonds can be contacted at: North Shore Medical Centre, 66 Pacific Hwy., St. Leonards 2065, Australia.

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SUMMARY

AUSTRALIAN IN-WATER OXYGEN THERAPY

This technique may be useful in treating cases of decompression illness in localities remote from recompression facilities. It may also be of use while suitable transport to such a centre is being arranged.
In planning, it should be realized that the therapy may take up to 3 hours. The risks of cold, immersion and other environmental factors should be balanced against the beneficial effects. The diver must be accompanied by an attendant.

Equipment

The following equipment is essential before attempting this form of treatment:

1. Full face mask with demand valve and surface supply system or helmet with free flow.
2. Adequate supply of 100% oxygen for patient, and air for attendant, typically about **200** cf per treatment.
3. Shot with at least 10 metres of rope (a seat or harness may be rigged to the shot).
4. Some form of communication system between patient, attendant and surface, preferably voice communications.

Method

1. The patient is lowered on the shot rope to 9 metres (30 fsw), breathing 100% oxygen.
2. Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if improvement has occurred. These times may be extended to 60 minutes and 90 minutes respectively if there is no improvement.
3. Ascent is at the rate of 1 metre every 12 minutes. Staging may be applied where applicable.
4. If symptoms recur remain at depth a further 30 minutes before continuing ascent.
5. If oxygen supply is exhausted, return to the surface, rather than breathe air.
6. After surfacing the patient should be given one hour on oxygen, one hour off, for a further 12 hours.

In-water Recompression: The Hawaiian Experience

by Richard L. Pyle

A little over ten years ago, Frank P. Farm, Edwin M. Hayashi, and Edward L. Beckman, from the Hyperbaric Treatment Center at the University of Hawaii School of Medicine conducted a survey of Hawaiian diving fisherman. The purpose of the survey, which was part of a Sea Grant Research project, was to chronicle the diving practices of Hawaii's fisherman, and to investigate their usage of in-water recompression therapy methods for the treatment of decompression illness (DCI). These fisherman, who regularly made five to eight dives per day, had collectively made over a *quarter of a million* dives at the time of the survey. As diving fisherman, their work entailed multiple daily exposures to 140-350 fsw (43-107 msw), followed by a shallow dive at the end of the day. With these profiles in mind, it should come as no surprise that every one of them had suffered DCI at least once in their careers. In fact, most of them had experienced DCI many times; so many that it was considered part of the job— an occupational hazard. To deal with this hazard, these diving professionals had, over the years, developed informal methods of in-water recompression therapy.

The survey revealed that these divers had utilized in-water therapy to treat DCI 527 times, and that the treatment completely eliminated DCI symptoms in 462 (88%) of the cases. In 51 of the remaining 65 cases, the divers had improved to the point where they opted not to seek further treatment and fully recovered in a day or two. The severity of the DCI symptoms treated with in-water methods ranged from mild shoulder pain to paralysis and other neurological dysfunction. The exact treatment methodology varied from diver to diver and there was no set standard. The divers included in the survey had made an *average* of 11,000 career dives (one had made over 23,000 dives), and had developed their diving regimes and in-water treatment methods by trial and error.

The somewhat remarkable results of the survey prompted the researchers to further investigate the effectiveness of in-water recompression therapy for use as an immediate, emergency treatment for DCI. Citing studies of bubble dissolution, growth dynamics and physiology, they attributed the high success rate of the in-water therapy to *immediate* recompression of the afflicted diver. They pointed out that the effectiveness of recompression therapy is greatly enhanced if recompression occurs *within five minutes* of the onset of symptoms.

The results of the survey were compiled in a report published by Sea Grant in 1986 (University of Hawaii Sea Grant Technical Paper UNIHI-SEAGRANT-TT-86-01). Melding the wisdom accumulated from the immense diving experience of the surveyed divers, and the results obtained from scientific studies on the physics and physiology of DCI and recompression therapy, Farm, Hayashi and Beckman formulated a list of conclusions and recommendations for Hawaii's commercial fisherman including a **strong recommendation that oxygen be incorporated into in-water recompression regimes** following the *"Australian Method"* developed by Dr. Carl Edmonds (see preceding article), or a modified version that was termed the *"Hawaiian Method" (Note that the Hawaiian Method includes a "deep dip on air" to 165 fsw (50 msw) and, in the opinion of many authorities, is <u>not</u> recommended for technical divers, due to the logistics involved, and the fact that the additional nitrogen gas loading may outweigh the benefits of the additional pressurization—ed.)* They also point out that **many factors should be considered before opting for in-water treatment, and it should be considered *only* as an emergency treatment. Subsequent treatment at a hyperbaric facility should be sought in *all* cases, regardless of the outcome of the in-water therapy.**

As a result of the work done in Hawaii, there appears to be an interesting contrast between the attitudes of Hawaiian divers and those elsewhere. Whereas the practice of in-water recompression is either "unheard of" or strongly discouraged in many (most) parts of the world, it is considered a part of diving among Hawaii's diving fisherman and others, and there seems to be little controversy on the subject. Certainly not all divers are aware of it or consider it useful, but few dispute that it is a viable field option. Most of those who are aware of in-water therapy are also aware of the dangers associated with it. Even so, among many groups, there is seldom much deliberation at the onset of DCI symptoms; conditions are assessed, and more often than not, in-water recompression is practiced, often with good results.

It's not that proper treatment is unavailable; Hawaii is home to an excellent hyperbaric facility which is only hours away from just about anywhere in the state. Hard-core Hawaiian divers simply have a different mindset with regards to the practice of in-water recompression. They view it as a viable procedure which has saved many lives, perhaps even their own.

Richard Pyle, aquaCorps field editor, is an ichthyologist and fish collector working with the Bishop Museum, Honolulu, and is currently completing his graduate studies at the Univ. of Hawaii. He can be contacted at: PO Box 19000A, Honolulu, Hawaii 96817. Fax: 808-841-8968.

incident reports

Double Fatality on the "U—Who"

by Dennis J. Willis

On October 12, 1992 two highly experienced cave divers, Chris Rouse and Chris Rouse, Jr., died exploring a U-boat wreck known as the "U-Who" offshore New Jersey. Both were trained in deep diving on air and mixed gases. This accident has had a major impact on the technical diving community. A formal report is being prepared, but aquaCorps felt it important that a preliminary report be issued at this time.

The Rouses were diving with double 104's filled with air for their travel and bottom mix. Each diver also carried an 80 cu ft aluminum tank of 60% oxygen-enriched air intermediate decompression mix, and a 72 cu ft steel tank of 100% oxygen.

After clipping off 3 of the 4 stage bottles (probably one EAN and two oxygen) near the anchor line, they proceeded to their point of penetration where a tie off was made and the 4th stage bottle (of EAN) was clipped. Shortly after entering the wreck Chris Jr. was trapped by falling debris; loosened silt reduced the visibility to nearly zero. Chris Sr. entered or was already just inside the wreck and began to dig out Chris Jr., further reducing the visibility. After Chris Jr. was freed the two divers were unable to follow their line out; according to statements by Chris Jr., and examination of their equipment, they evidently began exploring with line for a new exit. During their exit

continues on page 52

Big Bend

by Bernie Chowdhury

Editor's note: *Due to operational problems, the author omitted staged decompression after a 53-minute dive to 150 fsw and suffered acute neurological DCI. A moderately experienced deep diver, he attributes the accident to diving while ill on medication, and to fatigue, which predisposed him to nitrogen narcosis and the concomitant disorientation. As a result, he did not adhere to a precise dive plan and opted to make a direct ascent to the surface when he could not locate his stage bottle or the anchorline.*

As I lay limp and powerless on the *Seeker*'s gearing-up platform, I took in the efforts of the crew and passengers to save my life. Both of my Aladin Pro dive computers were screaming in protest at my having missed more than 99 minutes of decompression. My first stage stop was scheduled for 50 fsw.

The pain was excruciating. I felt like the guy in the movie *Alien*—you know, when the Alien pops out of his stomach during dinner. It felt like my insides were being rearranged. As time passed, my thoughts centered increasingly on the arrival of the Coast Guard rescue chopper and getting to a recompression chamber. I was spared the noise of computers beeping and the captain bellowing as I went completely deaf. I drifted in and out of consciousness and floated to a numb and painless world.

"Routine" dive

The dive had gone smoothly at first. I dropped an oxygen stage bottle at the anchor, at the wreck's stern. My buddy, Ed, and I separated to

continues on page 52

Confessions of a Mortal Diver: Learning the Hard Way

by Richard L. Pyle

Editor's note: *In July 1986, after repetitive air dives to 250 fsw and 140 fsw off Palau, the author suffered acute neurological DCI symptoms. He was treated in a chamber on Palau after several hours of unsuccessful in-water air recompression, then transferred to a hyperbaric facility on Guam. His condition improved slightly after two treatments there, after which he was taken to the chamber in Hawaii.*

Thus began the long series of treatments at Honolulu's Hyperbaric Treatment Facility. The first few treatments were 12 hours in duration, but most of the rest were standard eight-hour "Hyperbaric Oxygen" (HBO) treatments. These consisted of an initial "spike" to a simulated 220 fsw, a slow ascent to 60 fsw breathing a special enriched-air nitrox mixture, four 20-minute periods of breathing pure oxygen (with five-minute "air breaks" in between) at 60 fsw, a long haul on pure oxygen at 30 fsw, then a very slow ascent to the surface. I was given one such treatment per day, then taken to a nearby hospital to spend the night.

Through intensive physical therapy, my legs increased in strength. I regained control of my bladder, eliminating the need for a catheter. I began walking up and down stairs for additional exercise. I had many long discussions with Dr. Robert Overlock regarding the theory and practice of recompression treatment and the physiology of bends. He explained that my injury was analogous to a shotgun wound in my spinal cord and made certain that I understood that many of my nerve cells had died forever. My recovery was not a result of new nerve growth, but rather a result of my brain learning new nerve pathways to send signals to the rest of my body. He explained how I was now much more susceptible to DCI, that a subsequent

continues on page 54