In-Water Recompression

other stuff

In-water Recompression as an Emergency Field Treatment of Decompression Illness

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Abstract

In-Water Recompression (IWR) is defined as the practice of treating divers suffering from Decompression Sickness (DCS) by recompression underwater after the onset of DCS symptoms. The practice of IWR has been strongly discouraged by many authors, recompression chamber operators, and diving physicians. Much of the opposition to IWR is founded in the theoretical risks associated with placing a person suffering from DCS into the uncontrolled underwater environment. Evidence from available reports of attempted IWR indicates an overwhelming majority of cases in which the condition of DCS victims improved after attempted IWR. At least three formal methods of IWR have been published. All of them prescribe breathing 100% oxygen for prolonged periods of time at a depth of 30 feet (9meters), supplied via a full face mask. Many factors must be considered when determining whether IWR should be implemented in response to the onset of DCS. The efficacy of IWR and the ideal methodology employed cannot be fully determined without more careful analysis of case histories.

Introduction

There are many controversial topics within the emerging field of "technical" diving. This is not surprising, considering that technical diving activities are often high-risk in nature and extend beyond widely accepted "recreational" diving guidelines. Furthermore, many aspects of technical diving involve systems and procedures which have not yet been entirely validated by controlled experimentation or by extensive quantitative data. Seldom disputed, however, is the fact that many technical divers are conducting dives to depths well in excess of 130 feet for bottom times which result in extensive decompression obligations, and that these more extreme dive profiles result in an increased potential for suffering from Decompression Sickness (DCS).

Although technical diving involves sophisticated equipment and procedures designed to reduce the risk of sustaining DCS from these more extreme exposures, the risk nevertheless remains significant. Along with this increased potential for DCS comes an increased need for many "technical" divers to be aware of, and be prepared for, the appropriate implementation of emergency procedures in response to DCS. In the words of Michael Menduno (1993), "The solution for the technical community is to expect and plan for DCS and be prepared to deal with it".

There is almost universal agreement on the practice of administering oxygen to divers exhibiting symptoms of DCS. This practice is strongly supported both by theoretical models of dissolved-gas physiology, and by empirical evidence from actual DCS cases. The answer to the question of how best to treat the afflicted diver beyond the administration of oxygen, however, is not as widely agreed upon. Perhaps the most controversial topic in this area is that of In-Water Recompression (IWR); the practice of treating a diver suffering from DCS by placing them back underwater after the onset of DCS symptoms, using the pressure exerted by water at depth as a means of recompression.

At one extreme of this controversy is conventional conviction: divers showing signs of DCS should never, under any circumstances, be placed back in the water. As pointed out by Gilliam and Von Maire (1992, p. 231), "Ask any hyperbaric expert or chamber supervisor their feelings on in-the-water recompression and you will get an almost universal recommendation against such a practice." Most diving instruction manuals condemn IWR, and the Divers Alert Network (DAN) Underwater Diving Accident &

Oxygen First Aid Manual states in italicized print that "In-water recompression should never be attempted" (Divers Alert Network, 1992, p. 7).

On the other hand, IWR for treatment of DCS is a reality in many fields of diving professionals. Abalone divers in Australia (Edmonds, et al., 1991; Edmonds, 1993) and diving fishermen in Hawaii (Farm et al., 1986; Hayashi, 1989; Pyle, 1993) have relied on IWR for the treatment of DCS on repeated occasions. Many of these individuals walking around today might be dead or confined to a wheelchair had they not re-entered the water immediately after noticing symptoms of DCS.

At the root of the controversy surrounding this topic is a clash between theory and practice.

IWR in Theory

There are many important reasons why the practice of IWR has been so adamantly discouraged. The idea of placing a person who is suffering from a potentially debilitating disorder into the harsh and uncontrollable underwater environment appears to border on lunacy. Hazards on many levels are increased with immersion, and the possibility of worsening the afflicted diver's condition is substantial.

The most often cited risk of attempted IWR is the danger of adding more nitrogen to already saturated tissues. Using air or Enriched Air Nitrox (EAN) as a breathing gas during attempted IWR may lead to an increased loading of dissolved nitrogen, causing a bad situation to become worse. Furthermore, the elevated inspired partial pressure of nitrogen while breathing such mixtures at depth leads to a reduced nitrogen gradient across alveolar membranes, slowing the rate at which dissolved nitrogen is eliminated from the blood (relative to breathing the same gas at the surface).

The underwater environment is not very conducive to the treatment of a diver suffering from DCS. Perhaps the most obvious concern is the risk of drowning. Depending on the severity of the DCS symptoms, the afflicted diver may not be able to keep a regulator securely in his or her mouth. Even if the diver is functioning nearly perfectly, the risk of drowning while underwater far exceeds the risk of drowning while resting in a boat. Another complicating factor is that communications are extremely limited underwater. Therefore, monitoring and evaluating the condition of the afflicted diver (while they are performing IWR) can be very difficult.

In almost all cases, attempts at IWR will occur in water which is colder than body temperature. Successful IWR may require several hours of down-time, and even in tropical waters with full thermal diving suits, hypothermia is a major cause for concern. Exposure to cold also results in the constriction of peripheral circulatory vessels and decreased perfusion, reducing the efficiency of nitrogen elimination (Balldin, 1973; Vann, 1982). In addition to cold, other underwater environmental factors can decrease the efficacy of IWR. Strong currents often result in excessive exertion, which may exacerbate the DCS problems. (Although exercise can increase the efficiency of decompression by increasing circulation rates and/or warming the diver [Vann, 1982], it may also enhance the formation and growth of bubbles in a near- or post-DCS situation.) Depending on the geographic location, the possibility of complications resulting from certain kinds of marine life (such as jellyfish or sharks), cannot be ignored.

Published methods of IWR prescribe breathing 100% oxygen at a depth of 30 feet (9 meters) for extended periods of time. Such high oxygen partial pressures can lead to convulsions from acute oxygen toxicity, which can easily result in drowning.

Another often overlooked disadvantage of immersion of a diver with neurological DCS symptoms is that detection of those symptoms by the diver may be hampered: the "weightless" nature of being underwater can make it difficult to assess the extent of impaired motor function, and direct contact of water on skin may affect the diver's ability to detect areas of numbness. Thus, an immersed diver may not be able to determine with certainty whether or not symptoms have disappeared, are improving, are remaining constant, or are getting worse.

The factors described above are all very serious, very real concerns about the practice of IWR. There are really only two main theoretical advantages to IWR. First and foremost, it allows for immediate recompression (reduction in size) of intravascular or other endogenous bubbles, when transport to recompression chamber facilities is delayed or when such facilities are simply unavailable. Bubbles formed as a result of DCS continue to grow for hours after their initial formation, and the risk of permanent damage to tissues increases both with bubble size and the duration of bubble-induced tissue hypoxia. Furthermore, Kunkle and Beckman (1983) illustrate that the time required for bubble resolution at a given overpressure increases logarithmically with the size of the bubble. Farm, et al. (1986, p. 8) suggest that "Immediate recompression within less than 5 minutes (i.e. when the bubbles are less than 100 micrometers in diameter) is...essential if rapid bubble dissolution is to be achieved" (italics added). If bubble size can be immediately reduced through recompression, blood circulation may be restored and permanent tissue damage may be avoided, and the time required for bubble dissolution is substantially shortened. Kunkle and Beckman, in discussing the treatment of central nervous system (CNS) DCS, write:

"Because irreversible injury to nerve tissue can occur within 10 min of the initial hypoxic insult, the necessity for immediate and aggressive treatment is obvious. Unfortunately, the time required to transport a victim to a recompression facility may be from 1 to 10 hours [Kizer, 1980]. The possibility of administering immediate recompression therapy at the accident site by returning the victim to the water must therefore be seriously considered." (p. 190)

The second advantage applies only when 100% oxygen is breathed during IWR. The increased ambient pressure allows the victim to inspire elevated partial pressures of oxygen (above those which can be achieved at the surface). This has the therapeutic effect of saturating the blood and tissues with dissolved oxygen, enhancing oxygenation of hypoxic tissues around areas of restricted blood flow.

There is also some evidence that immersion in and of itself might enhance the rate at which nitrogen is eliminated (Balldin and Lundgren, 1972); however, these effects are likely more than offset by the reduced elimination resulting from cold during most IWR attempts.

IWR in Practice

Three different methods of IWR have been published. Edmonds et al., in their first edition of Diving and Subaquatic Medicine (1976), outlined a method of IWR using surface-supplied oxygen delivered via a full face mask to the diver at a depth of 9 meters (30 feet). According to this method, the prescribed time an treated diver spends at 9 meters varies from 30-90 min depending on the severity of the symptoms, and the ascent rate is set at a steady 1 meter per 12 min (~1 ft/4 min). This method of IWR was expanded and elaborated upon in the 2nd Edition (1981), and again in the 3rd Edition (1991); and has come to be known as the "Australian Method". It has also been outlined in other publications (Knight, 1984; 1987; Gilliam and von Maier, 1992; Gilliam, 1993; Edmonds, 1993), and is presented in Appendix A of this article. [NOTE: Appendices are not included on this web page].

The U.S. Navy Diving Manual (Volume 1, revision 1, 1985) briefly outlines a method of IWR to be used in an emergency situation when 100% oxygen rebreathers are available. Gilliam (1993, p. 208) proposed that this method could "easily be adapted to full facemask diving systems or surface supplied oxygen". It involves breathing 100% oxygen at a depth of 30 feet (9 meters) for 60 min in so-called "Type I" (pain only) cases or 90 min in "Type

II" (neurological symptoms) cases, followed by an additional 60 min of oxygen each at 20 feet (6 meters) and 10 feet (3 meters). This method is outlined in Gilliam (1993), and in Appendix B of this article. [NOTE: Appendices are not included on this web page].

The third method, described in Farm et al. (1986), is a modification of the Australian Method which incorporates a 10-minute descent while breathing air to a depth 30 feet (9 meters) greater than the depth at which symptoms disappear, not to exceed a maximum depth of 165 feet (50 meters). Following this brief "air-spike", the diver then ascends at a decreasing rate of ascent back to 30 feet (9 meters), where 100% oxygen is breathed for a minimum of 1 hour and thereafter until either symptoms disappear, emergency transport arrives, or the oxygen supply is exhausted. This method of IWR, developed in response to the experiences of diving fishermen in Hawaii, has come to be known as the "Hawaiian Method". This method is described in Appendix C of this article. [NOTE: Appendices are not included on this web page].

All three of these methods share the requirement of large quantities of oxygen delivered to the diver via a full face mask at 30 feet (9 meters) for extended periods, a tender diver present to monitor the condition of the treated diver, and a heavily weighted drop-line to serve as a reference for depth. Also, some form of communication (either electronic or pencil and slate) must be maintained between the treated diver, the tending diver, and the surface support crew.

Information on at least 535 cases of attempted IWR has been reported in publications. Summary data from the majority of these attempts are included in Farm et al. (1986), who present the results of their survey of diving fishermen in Hawaii. Of the 527 cases of attempted IWR reported during the survey, 462 (87.7%) involved complete resolution of symptoms. In 51 cases (9.7%), the diver had improved to the point where residual symptoms were mild enough that no further treatment was sought, and symptoms disappeared entirely within a day or two. In only 14 cases (2.7%) did symptoms persist enough after IWR that the diver sought treatment at a recompression facility. None of the divers reported that their symptoms had worsened after IWR. It is also interesting (and somewhat disturbing) to note that none of the divers included in this survey were aware of published methods of IWR (i.e. all were "winging it" - inventing the procedure for themselves as they went along), and all had used only air as a breathing gas.

Edmonds et al. (1981) document two cases of successful IWR in which divers suffering from DCS in remote locations followed the Australian Method of IWR with apparently tremendous success (both are presented below as Case #8 and #9). Overlock (1989) described six cases of DCS involving divers using decompression computers. Of these, four involved attempted IWR, three of which were apparently successful (the results from the fourth case are unclear). Two of these cases are described as Case #1 and Case #4 below. Hayashi (1989) reported two cases of attempted IWR, one of which involved the use of 100% oxygen, and the other, involving air as a breathing gas, was also described in Farm et al. (1986) and is described below as Case #2.

At present, we are aware of about twenty additional cases of attempted IWR which have not previously been reported in literature. Of these, two resulted in the death of the attempting divers (both divers were together at the time - see Case #3 below), and one resulted in an apparent aggravation of the conditions (i.e. turning a sore shoulder into permanent quadriplegia - see Case #10 below). Another case, for which we do not have details, involved a diver who apparently worsened his condition with IWR, but eventually recovered after proper treatment in a recompression chamber facility. In six other cases, the condition of the diver had remained constant or improved after attempted IWR, and further treatment in a recompression chamber was sought by most of them. In all of the remaining cases, the diver was asymptomatic after IWR, they sought no further treatment, and their symptoms did not return. Without doubt, many more attempts at IWR have occurred but have not been reported. Edmonds, et al. (1981, p. 175), in discussing the practice of the Australian Method of IWR, note that "Because of the nature of this treatment being applied in remote localities, many cases are not well documented. Twenty five cases were well supervised before this technique increased suddenly in popularity, perhaps due to the success it had achieved, and perhaps due the marketing of the [proper] equipment..." Several professional divers have privately confided to one of us (RLP) that they have used IWR to treat themselves and companions on multiple occasions, and all have reported great success in their efforts. Some continue to teach the practice to their more advanced students (although the practice was once taught on a more regular basis, it has since fallen out of widely accepted instruction protocol).

Evaluation of Case Histories

In determining the relative value of IWR as a response to DCS, it is perhaps most useful to carefully examine case histories involving attempted IWR. DCS is, by nature, a very complex, dynamic, and unpredictable disorder, and evaluation of the role of IWR as a treatment in reported cases is often difficult. Assessing the success or failure of an attempt at IWR is obscured by the fact that a positive or negative change in the victim's condition may have little or nothing to do with the IWR treatment itself. Furthermore, even the determination of whether or not a DCS victim's condition was better or worse after attempted IWR is not always clear. For example, consider the following case, first reported by Overlock (1989):

Case #1. Fiji.
Five minutes after surfacing from the fourth dive to moderate depth (75-120 feet) over a 24 hr period, a diver developed progressive arm and back weakness and pain. She returned to 60 feet for 3 min, then ascended (decompressed) over a 50-minute period (with stops at 30, 20, and 10 feet), breathing air. Tingling and pain resolved during the first 10 min of IWR. Three hours after completing IWR, she developed numbness in the right leg and foot, and reported "shocks" running down both legs, whereupon she was taken to a recompression chamber. After 3 successive U.S. Navy "Table 6" treatments, she still felt weakness and some decreased sensation. The effect of IWR on the recovery of this diver is unclear. Although the pain and weakness were resolved during IWR, more serious symptoms developed hours afterward. Perhaps numbness would never have developed had the diver been taken directly to a recompression chamber instead of re-entering the water, in which case she may have responded to treatment without residuals. On the other hand, had she not returned to the water, the initial symptoms may have progressed into paralysis during her evacuation to the chamber, and she might have ultimately suffered far more serious and debilitating residuals. Cases such as this do not contribute much insight into the efficacy of IWR. Other cases, however, provide stronger evidence suggesting that IWR has been of benefit. Consider the following case documented in Farm et al. (1986) and Hayashi (1989):

Case #2. Hawaii.
"Four fisherman divers were working in pairs at a site about 165 to 180 feet deep. Each pair alternated diving and made two dives at the site. Both divers of the second pair rapidly developed signs and symptoms of severe CNS decompression sickness upon surfacing from their second dive. The boat pilot and the other diver decided to take both victims to the U.S. Navy recompression chamber and headed for the dock some 30 minutes away [the recompression chamber was an additional hour away from the dock]. During transport, one victim refused to go and elected to undergo in-water recompression, breathing air. He took two full scuba tanks, told the boat driver to come back and pick him up after transporting the other bends victim to the chamber, and rolled over the side of the boat down to a depth of 30 to 40 feet. The boat crew returned after 2 hours to pick him up. He was asymptomatic and apparently cured of the disease. The other diver died of severe decompression sickness in the Med-Evac helicopter en route to the recompression chamber." (Hayashi, 1989, p. 157) This is just one example of many which provide compelling evidence that IWR can, in some circumstances, result in dramatic relief of serious DCS symptoms. Ironically, had this incident occurred in an area where a recompression chamber was not an option, both divers would probably have opted for IWR, and the less fortunate victim might possibly have survived the ordeal. On the other hand, attempts at IWR under inappropriate circumstances can lead to tragedy, as is clearly

evident from the following case:

Case #3. Sussex, England.
Twelve experienced divers conducted an 18-minute dive on a wreck in about 215 feet. They surfaced following 38 minutes of air decompression, at which time two of the divers reported "incomplete decompression". These two divers obtained additional supplies of air and returned to the water in an apparent effort to treat DCS symptoms. They never returned to the boat, and their bodies were recovered two weeks later. The reason for their deaths remains a mystery. It is possible that they were suffering from neurological DCS symptoms, and drowned as a result of these symptoms. The tragedy of this case lies in the fact that they most likely would have survived had they not re-entered the water. The boat was equipped with 100% oxygen (surface-breathing) equipment, and the incident occurred in an area where emergency air-transport could have delivered the divers to a recompression chamber less than an hour after surfacing. The water temperature in this case was about 61-63° F (16-17° C), and the surface conditions were relatively rough (3-5 ft seas). Whether or not these divers perished as a direct result of DCS symptoms, they would, in all likelihood, have survived the incident had they not returned to the water. The main potential benefit of IWR lies in the ability to recompress the DCS victim immediately after the onset of DCS symptoms, before intravascular bubbles have a chance to grow or cause serious permanent damage. The apparent success of many reported attempts of IWR may be attributed to the immediacy of the recompression. In one case, reported by Overlock (1989), IWR began before the diver even reached the surface:

Case #4. Hawaii.
After ascending from his second 10-minute dive to 190 feet, a diver followed the decompression `ceilings' suggested by his dive computer. As he was nearing the end of his computer's suggested decompression schedule, he suddenly noticed weakness and incoordination in both arms, and numbness in his right leg. He immediately descended to a depth of 80 feet where, after 3 min, the symptoms disappeared. After a total of 8 min at 80 feet, he slowly ascended over a period of 50 min to 15 feet (his companion supplied him with fresh air tanks). He remained at this depth until his decompression computer had "cleared". He felt tired after surfacing, but was otherwise asymptomatic. In many other cases, IWR was commenced within a few minutes after surfacing, usually resulting in the elimination or substantial reduction of symptoms. In cases where DCS results from gross omission of required decompression, divers may anticipate the probable consequences, and often return immediately to depth as soon as possible in an effort to complete the required decompression. Two such cases are presented here:

Case #5. Hawaii.
While conducting a solo dive at a depth of 195 feet, a diver became entangled in lines and mesh bags. In his struggles to free himself, he extended his time at depth well beyond the intended 10 minutes, and squandered much of the air he had expected to use for decompression. Upon freeing himself, he immediately began his ascent, but was mortified to discover that the boat anchor had broken loose and was gone. Swimming down-current, he fortuitously saw the anchor dragging across the bottom, and quickly caught up with the anchor line at a depth of 60 feet. At this time, his decompression computer indicated a `ceiling' of 70 feet, and his pressure gauge showed that his scuba tank was nearly empty. He slowly ascended to the surface and quickly explained his predicament to his companion in the boat. While waiting for his companion to rig a regulator to a fresh tank of air, he began feeling symptoms of severe dizziness and had problems with his vision. Grasping the second tank under his arm, he allowed himself to sink back down, nearly losing consciousness. Upon reaching a depth of 80 feet, his clouded consciousness fully resolved, and he remained 10-15 ft below his computer's recommended `ceiling' during subsequent decompression. Although he eventually exited the water before his computer had "cleared", he did not experience any additional symptoms.

Case #6. Central Pacific.
A diver had partially completed his decompression following 15 minutes at 200 feet, when he suddenly became aware of the presence of a very large and somewhat "inquisitive"

Tiger Shark. Initially, the diver maintained his composure, fearing DCS more than the threat of attack. When the shark rose above, passing between the diver and the boat, the diver reconsidered the situation and opted to abort decompression. After a rapid ascent from about 40 feet, the diver hauled himself over the bow of the 17-foot Boston Whaler (without removing his gear). Anticipating the onset of DCS, he instructed his startled companion to quickly haul up the anchor and drive the boat rapidly towards shallower water. By the time they re-anchored, the diver was experiencing increasing pain in his left shoulder. He re-entered the water and completed his decompression, emerging asymptomatic. There are many other cases in which divers must interrupt their decompression temporarily, then resume decompression within a few minutes without ever experiencing symptoms of DCS. Generally, these cases of asymptomatic `interrupted decompression' are not considered as IWR. However, one such incident which recently occurred in Australia is worth mentioning:

Case #7. Australia.
After spending 18 minutes at a depth of 220 feet, a diver experienced a serious malfunction of her Buoyancy Compensator inflation device which resulted in the rapid loss of her air supply and a sudden increase in her buoyancy. Additionally, she became momentarily entangled in a guide line, further delaying ascent, and was freed from the line with the assistance of her diving companion. As they ascended, they were met by a second team of divers just beginning their descent. Although one of the members of the second team was able to provide her with air to breathe, he was unable to deflate her over-expanded B.C., and both ascended rapidly to the surface. Within 4 minutes, she returned to a depth of 20 feet where she breathed 100% oxygen for 30 min. She then ascended to 10 feet where she completed an additional 30 min of breathing oxygen. Upon surfacing, she was taken to a nearby recompression chamber facility, breathing oxygen during the 30 min required for transport. Arriving at the facility, she noticed no obvious symptoms of DCS, but was diagnosed with mild "Type II" DCS and treated several times in the chamber. She suffered no apparent residual effects. Although no DCS symptoms developed prior to recompression, serious symptoms undoubtedly would have ensued had recompression not been immediate, given the extent of the exposure and the explosive rate of ascent. It is interesting that a modified version of the Australian Method of IWR was employed, rather than the diver descending to greater depth on air to complete the omitted decompression. Recompression depth was limited to a maximum of 20 feet due to concerns of oxygen toxicity at greater depths. The victim was monitored continuously while breathing oxygen underwater by at least two tending divers. It should be noted that successful attempts at IWR are not limited to cases which take advantage of the ability to immediately recompress the victim. Edmonds et al. (1981) report on a case where IWR yielded favorable results many hours after the initial onset of DCS:

Case #8. Northern Australia.
After a second dive to 100 feet, a diver omitted decompression due to the presence of an intimidating Tiger Shark. Within minutes of surfacing, he "developed paraesthesia, back pain, progressively increasing incoordination, and paresis of the lower limbs". After two unsuccessful attempts at air IWR, arrangements were made to transport the victim to a hospital 100 miles away. He arrived at the hospital 36 hours after the onset of symptoms, and due to adverse weather conditions, he could not be transported to the nearest recompression chamber (2,000 miles away), for an additional 12 hours. By this time, the victim was "unable to walk, having evidence of both cerebral and spinal involvement", manifested by many severe neurological ailments. The diver was returned to the water to a depth of 8 meters, where he breathed 100% oxygen for 2 hours, then decompressed according to the Australian Method of IWR. Except for small areas of hypoaesthesia on both legs, all other symptoms had remised at the end of the IWR treatment. This case suggests that in-water oxygen treatment in depths as little as 8 meters can have positive effects on DCS symptoms even after much time has elapsed. It also underscores another aspect of IWR; the fact that it may be the only treatment available in remote areas where recompression chamber facilities are many thousands of miles and several days away. For example, Edmonds et al. (1981) report on another case which occurred in the Solomon Islands. At the time, the nearest recompression chamber was 3,500 km away and prompt

air transport was unavailable:

Case #9. Solomon Islands.
Fifteen minutes after a 20-min dive to 120 feet, and 8 min of decompression, a diver developed severe neurological DCS symptoms, including "respiratory distress, then numbness and paraesthesia, very severe headaches, involuntary extensor spasms, clouding of consciousness, muscular pains and weakness, pains in both knees and abdominal cramps". No significant improvement occurred after 3 hours of surface-breathing oxygen. She was returned to the water where she followed the "Australian Method" of IWR (breathing 100% oxygen at 9 meters [30 feet]). Her condition was much improved after the first 15 minutes, and after an hour she was asymptomatic, with no recurring symptoms. Although most of the reported attempts at IWR have utilized only air as a breathing gas, this practice has been strongly discouraged due to the risks of additional nitrogen loading. The concern that air-only IWR may transform an already bad situation into tragedy seems clearly validated by the following case:

Case #10. Caribbean.
A young diver experienced pain-only symptoms of DCS after an unknown dive profile. He made three successive attempts at IWR (presumably breathing air), each time worsening his condition. After the third attempt, his condition had degenerated into quadriplegia. Because of transport delays, he did not arrive at a recompression chamber until about three days after the incident. Saturation treatment yielded no improvement in his condition, and he remained permanently paralyzed. Whereas the above case illustrates an unsuccessful attempt to treat relatively mild symptoms of DCS with air-only IWR, the following case, reported by Farm et al. (1986), represents an apparently successful attempt at treating very severe symptoms with similar techniques:

Case #11. Hawaii.
Shortly after a third dive to 120-160 feet, a diver developed "uncontrollable movements of the muscles of his legs". Within a few minutes, his condition deteriorated to the point where he was paralyzed; numb from the nipple-line down and unable to move his lower extremities. He was able to hold a regulator in his mouth, so a full scuba tank was strapped to his back and he was rolled into the water to a waiting tender diver. The tender verified that the victim was able to breathe, and proceeded to drag him down to 35-40 feet. When the symptoms did not regress, the victim was pulled deeper by the tender. At 50 feet, he regained control of his legs and indicated that he was feeling much better. He was later supplied with an additional scuba tank, ascended to 25 feet for a period of time, and then finished his second tank at 15 feet. Except for feeling "a little tired" that evening, he regained full strength in his arms and legs and remained asymptomatic. Another, previously unpublished case, involved a DCS victim whose symptoms were so severe that IWR was not attempted for fear that he would drown:

Case #12. Central Pacific.
Four aquarium fish collectors ascended rapidly from their second 200 feet dive of the day, aborting essentially all decompression. All immediately began experiencing nausea and varying degrees of neurological DCS symptoms. Three of the divers returned to a depth of about 50 feet, but the fourth opted instead to stay in the boat. When the three completed their abridged attempt at IWR (after which all three felt noticeably improved), they headed for shore. Help was summoned, and additional scuba tanks and 100% oxygen were obtained and loaded into the boat. By this time, one of the divers felt only pain in his shoulders, and the other three were experiencing varying degrees of neurological DCS symptoms. The worst of these was diver who did not attempt IWR immediately after the initial onset of symptoms: he was unable to move his arms or legs and was having difficulty breathing. The other three attempted to assist him back in the water, but they eventually gave up, fearing that he might drown (due to his inability to hold the regulator in his mouth). The other three continued IWR, breathing both air and 100% oxygen at 30-40 feet, until nightfall forced them out of the water. That night, all four took turns breathed 100% oxygen on the surface while waiting for the emergency evacuation plane to arrive. The following day, the three who had attempted IWR were flown to Honolulu, where they

experienced varying degrees of recovery after treatment in a recompression chamber. The one who did not attempt IWR died before the plane arrived. All of the cases described thus far have involved either 100% oxygen or air (or both) as breathing gasses during IWR. In at least one reported case, EAN was used as a breathing gas for the IWR treatment:

Case #13. Northeastern United States.
After spending 25 minutes at a maximum depth of 147 feet, a diver ascended following decompression stops required by his tables. He began feeling a tingling sensation and sharp pain in his right elbow as he arrived at his 30 feet decompression stop. He completed an additional 30 min at 10 feet beyond what was called-for by his tables, and then surfaced. His symptoms subsided somewhat after an hour of breathing 100% oxygen on the boat, but persisted enough to prompt the diver to attempt IWR. He returned to the water with an additional cylinder containing EAN-50 (50% oxygen, 50% nitrogen) and descended to 100 feet for a period of 10 minutes. He ascended to 20 feet over a 10-minute period, and remained there for 68 min. He spent an additional 5 min at 10 feet, then surfaced asymptomatic, with no recurrence of symptoms. This case illustrates another fundamental risk associated with IWR; that of acute CNS oxygen toxicity. During the deepest portion of above IWR profile, the diver was breathing an oxygen partial pressure of 2.02, considerably greater than what is considered safe. The diver was aware of the potential for acute CNS oxygen toxicity and had an additional cylinder of air with him, just in case. Furthermore, he was exposed to this excessive oxygen partial pressure for only 10 minutes.

Discussion

As stated earlier, the source of controversy surrounding the topic of in-water recompression is essentially the conflict between what is predicted by theory, and what appears to be demonstrated by practice. In reviewing the issue of IWR, several questions require attention. First and foremost, should IWR ever be attempted under any circumstances? If the answer is "yes", then under what circumstances should it be performed? Also, if the decision to perform IWR has been made, which method should be followed?

The Efficacy of IWR

From the cases described above, it should be evident that IWR has almost certainly been of benefit to some DCS victims in certain circumstances. If the selection of cases seems biased towards "successful" attempts at IWR, it is only a reflection of the numbers of actual cases on record. Whereas only one additional attempt at IWR (besides Case #3 and #10) clearly led to deterioration of the condition of a DCS victim, there are literally hundreds of additional cases where IWR was almost certainly of (sometimes great) benefit.

Opponents to the practice of IWR are usually quick to point out that DCS symptoms are often relieved, sometimes substantially, when the victim breathes 100% oxygen at the surface (the presently accepted and recommended response to DCS). Indeed, if symptoms do resolve with surface-oxygen, and recompression treatment facilities are relatively close at hand (via emergency transport), then the additional risks incurred with re-immersion seem unwarranted. The two deceased divers discussed in Case #3 would have, in all likelihood, survived their ordeal if oxygen was administered on the boat and transport to the nearby recompression chamber was effected. However, in cases where chamber facilities are not available, or when symptoms persist in spite of surface-oxygen (such as in Case #9 and #13), then recompression is clearly necessary, and IWR perhaps should be attempted.

Determining Circumstances Appropriate for IWR

It should also be clear that identifying those circumstances under which IWR should be implemented is an exceedingly difficult task. A wide variety of variables must be taken into account, and many factors must be carefully considered. Although the decision to perform IWR should be made quickly, it should not be made in haste.

Hunt (1993) pointed out that DCS often carries with it a certain stigma. Under some circumstances, a diver suffering from the onset of DCS symptoms may be reluctant to reveal their condition to companions. Consequently, such an individual might attempt IWR so as to "fix" themselves without anyone else becoming aware of the problem. For obvious reasons, this alone is not a reasonable justification for considering IWR, and is especially dangerous because it likely results in the diver attempting IWR without the safety of an observing attendant or tender. Similarly, IWR should never be thought of as a substitute for proper treatment in a recompression chamber. IWR is not a "poor man's" treatment, and the decision to implement it should not be motivated by financial concerns. Regardless of the outcome of an IWR attempt, medical evaluation by a trained hyperbaric specialist should always be sought as soon afterward as possible.

The major factor in determining whether IWR should be implemented is the distance and time to the nearest recompression facility. In a study of more than 900 cases of DCS in U.S. Navy divers, Rivera (1963) found that 91.4% of the cases treated within fifteen minutes were successful, whereas the success rate when treatment was delayed 12-24 hours was 85.7%. A similar study on DCS cases among sport (recreational) divers showed similar results. Of 394 examined cases, 56% of divers with mild DCS symptoms achieved complete relief when treated within 6 hours, whereas only 30% were completely relieved when treatment was delayed 24 hours or more. The same study found that 39% of divers with severe symptoms were relieved when treated within 6 hours, whereas only 26% were relieved when treatment was delayed 24 hours or more (Divers Alert Network, 1988). In reviewing these numbers, Moon (1989) stressed that delay of treatment for DCS should be minimized, but also noted that response to delayed treatment is not entirely unacceptable. Knight (1987) recommends that IWR should be considered when the nearest recompression facility is more than 6 hours away. Such generalizations are difficult to make, however, as indicated by the fact that the ill-fated diver in Case #2 was less than 2 hours away from a recompression chamber.

One of the most important variables affecting the decision to attempt IWR is the mental and physical state of the diver. Certainly divers who are, for whatever reason, uncomfortable or reluctant to return to the water for IWR should not be coerced or forced to do so. The extent and severity of the DCS symptoms are also important factors. Whether or not mild DCS symptoms (i.e. pain-only) should be treated is not certain. One perspective is that such symptoms are not likely to leave the diver permanently disabled, and thus the risks associated with attempted IWR would not be worth taking. Furthermore, individuals with such symptoms are prime candidates for "making a bad situation worse" (as was demonstrated in Case #10). Conversely, the risks of submerging severely incapacitated divers might override the potential benefits of IWR when serious neurological manifestations are evident. Edmonds (1993) recommends against the practice of IWR in situations "where the patient has either epileptic convulsions or clouding of consciousness. "The death of the two divers in Case #3 might have resulted from drowning due to loss of consciousness from severe neurological symptoms. However, some evidence indicates that IWR may be of value even under these circumstances. Although the divers treated in some cases (e.g. #2, #5, and #11) might have gone unconscious underwater and drowned, the consequences of no immediate recompression may have been equally grave. Also, the diver who perished in Case #12 may have survived had he performed IWR along with his companions. The immediacy of recompression may be particularly advantageous if DCS symptoms develop soon after surfacing from a deep dive, and when these symptoms are neurological and "progressive" (sensu Francis, et al., 1993). Under such circumstances, the condition of the DCS victim can rapidly degenerate, and permanent damage may ensue in the absence of immediate recompression. However, it is also particularly critical in these circumstances to monitor the condition of the treated diver with a tender close by.

As mentioned earlier, environmental factors such as water temperature, surface conditions, hazardous marine life, and strong currents might significantly influence the feasibility of IWR. Many technical dives are conducted in relatively cold water (such as Europe, the northeastern and western coasts of the continental United States, southern Australia, and many freshwater systems), and the risk of hypothermia and decreased nitrogen elimination rates create additional complications for attempted IWR in these environments. Edmonds et al. (1981) and Edmonds (1993) have pointed out that reduced water temperature is not necessarily as great a concern as many opponents of IWR have suggested. The reasoning is that divers in these environments are usually well-equipped with thermal protection such as dry-suits, which have come into wide-spread use among technical divers. If the divers have adequate thermal protection to conduct the initial dive, then they are likely prepared to tolerate additional in-water exposure during IWR. However, Sullivan and Vrana (1992) reported on two cases of simulated IWR off Antarctica in - 1.4°C water, and concluded that "[IWR] cannot be considered sufficiently reliable in [extremely] cold waters..." protection.

Sharks and other hazardous marine life can tremendously complicate IWR efforts. In Case #5, a large Tiger Shark did appear during IWR, but did not influence the diver's ascent profile. Divers omitted required decompression in Case #6 and #8 due to the presence of large Tiger Sharks, thus leading to subsequent attempts at IWR. The risks of this threat are generally minuscule, however these cases illustrate that such problems can occur.

In addition to the factors discussed above, the availability of large quantities of 100% oxygen and the equipment needed to deliver it safely to a diver 30 feet (9 meters) underwater are also very important factors when considering an attempt at IWR. These factors are discussed in greater detail in the following section.

Methodology of IWR

Once the decision to perform IWR has been made, the next question to consider concerns methodology. The fundamental difference between the Australian Method and the Hawaiian Method of IWR is that the latter incorporates a deeper "air-spike" as an initial step in the treatment. The two methods are analogous in form, respectively, to the U.S. Navy's "Table 6" and "Table 6A" (however, the depths at which 100% oxygen is breathed is shallower, and the durations shorter for the IWR methods than for the chamber schedules).

The primary purpose for the deeper "air-spike" of the Hawaiian Method is essentially to exert a greater pressure on the diver so that the DCS bubbles are further reduced in size. In addition to restoring circulation, the extra "overpressure" may facilitate bubble resolution (Kunkle and Beckman, 1983; Farm et al., 1986). Air is used instead of oxygen because of the risk of acute CNS oxygen toxicity which results from breathing oxygen at such depths. Along with the benefits of increased bubble compression, however, come the risks of additional nitrogen absorption during this "spike".

To address the therapeutic advantages of the "spike", it is important to examine the physical effects of pressure on bubble size. Although by Boyle's Law alone there is a substantial "diminishing of returns" in terms of bubble size reduction as one descends deeper, gas phase bubbles are subject to other forces that may affect their size. Although a discussion of bubble physics is beyond the scope of this article, suffice it to say that bubble radii are reduced proportionally more with increasing depth than what would be predicted by Boyle's Law alone. Perhaps more importantly, the pressure of the gas within the bubble increases proportionally more, which leads to increased rates of bubble dissolution. However, the added risks of nitrogen loading and nitrogen narcosis increase with depth, adding potentially substantial greater risk to performing the deep spike. A depth of 165 feet was chosen by the USN (Table 6A) and Farm et al. (1986; the Hawaiian Method) as the maximum at which benefit from recompression was significant. Descent to a depth of 30 feet, the maximum depth prescribed by the Australian Method, yields a nearly 50% reduction in bubble volume, and approximately 20% decrease in bubble diameter. Descent to 165 feet further reduces the bubble volume by an additional 33%, and the diameter by an additional 25%. Thus, in the case of bubble volume, more benefit results in the first 30 feet of recompression than is gained in the next 135 feet, whereas the reduction in bubble diameter is slightly greater during the subsequent 135 feet depth than the initial 30 feet. Whether or not bubble diameter or bubble volume is more critical to the manifestation of DCS symptoms is uncertain.

The fundamental question is whether or not the additional recompression confers physiological advantages sufficiently in excess of the disadvantages associated with breathing air at depth (in an IWR situation). Obviously, this depends on the immediate diving history of the afflicted diver, and the particular circumstances involved. The practice of subjecting DCS victims to a 165 feet "spike" during chamber treatments has recently begun to "fall out of favor" among hyperbaric medical specialists. Hamilton (1993) points out that "the 6-atm recompression with air or enriched air of Table 6A is likely to be discontinued as evidence accumulates that it offers no real benefit over the 100% oxygen [treatment] of Table 6". This philosophy may also be applied to IWR treatment procedures. The possibility of substituting EAN or high-oxygen Heliox during the "spike" must also be examined. Modern technical diving operations often involve EAN for some portion of the dive, and thus EAN may be available in some DCS situations. EAN contains a percentage of oxygen which is greater than 21%, and thus may offer therapeutic advantages over air. The presence of nitrogen as a diluent in EAN allows a diver attempting IWR to recompress at a greater depth than permitted by 100% oxygen (for reasons associated with acute CNS oxygen toxicity). In at least one case (#13), EAN was used during IWR, with apparently successful results. James (1993) outlines the benefits associated with using 50/50 Heliox (50% helium, 50% oxygen) for recompression therapy. Since helium mixtures commonly incorporated into technical diving operations do not contain such high proportions of oxygen, a supply of high-oxygen Heliox would have to be maintained at the dive site specifically for the purpose of IWR. Unless closed-circuit rebreathers are available at the site, the option of using Heliox for IWR is probably unfeasible.

There are a number of safety advantages to the Australian Method over the Hawaiian Method. Since the only breathing gas of the Australian Method is oxygen, there is no risk of additional loading of nitrogen or other inert gases. Thus, if the treatment must be terminated prematurely (e.g. in response to the onset of nightfall; see Case #12), there is no risk of aggravating the DCS symptoms. Furthermore, the Australian Method may be conducted in shallow, protected areas such as lagoons or boat harbors, where sea surface and current conditions are less likely to be adverse.

We are unable at this time to entirely condemn the Hawaiian Method of IWR, for it may confer important advantages under certain circumstances. Edmonds (1993) suggests that the Australian Method of IWR is "of very little value in the cases where gross decompression staging has been omitted", presumably because such situations may require recompression to depths in excess of 30 feet (9 meters) (although see Case #7 and #8). Under such circumstances (e.g. `interrupted decompression' situations), the "spike" might be advantageous. Nevertheless, we are compelled to strongly discourage technical divers from incorporating an "air-spike" into IWR attempts, at least until additional verification of its efficacy can be established through empirical and theoretical lines of evidence.

The USN method of IWR differs from the Australian Method primarily in the recommended ascent pattern. Whereas the Australian Method advocates a slow steady (1 meter/12 min.) ascent rate, the USN Method divides the ascent into two discrete stages at 20 and 10 feet. Although at first this difference may seem trivial, it might, in fact, have important physiological ramifications. Edmonds (1993) reports that "It is a common observation that improvement continues throughout the ascent, at 12 minutes per meter. Presumably the resolution of the bubble is more rapid at this ascent rate than its expansion, due to Boyle's Law". If this is true, then divers attempting IWR according to the USN Method could conceivably suffer recurrence of symptoms immediately following ascent to the next shallower stage. The validity of this argument has yet to be verified.

Hyperbaric Oxygen

All of the published IWR methods advocate breathing an oxygen partial pressure of 1.9 atm for extended periods. Such high levels permit increased saturation of dissolved oxygen in the blood and tissues, which may help provide badly needed oxygen to areas of restricted circulation or tissue hypoxia. At such concentrations and durations, however, the risks of acute CNS oxygen toxicity are a serious consideration. Oxygen partial pressures of 1.2-1.6 atm have been suggested as the upper limit for technical diving operations. The published IWR methods have endorsed exposure to higher oxygen partial pressures because of the therapeutic advantages, and because a diver performing IWR is apt to be at rest (reducing the likelihood of an acute oxygen toxicity seizure). In at least one case (Case #7 above), the depth of in-water oxygen treatment was limited to a maximum of 20 feet (oxygen partial pressure of 1.65 atm) in an effort to avert oxygen toxicity problems. Because the consequences of convulsions resulting from acute oxygen toxicity are particularly serious underwater, all three published methods of IWR strongly recommend that a tender diver be continuously present, and that oxygen be administered via a full face mask. Although not prescribed in any of the in-water recompression methods, most recent publications discussing the use of oxygen as a decompression gas advise that the long periods of breathing pure oxygen be "buffered" by 5-minute air breaks every 20 minutes. The risk of additional nitrogen loading from these brief periods is more than offset by the reduced risk of acute oxygen toxicity problems.

Standard recompression chamber treatments commonly incorporate breathing 100% oxygen at a simulated depth of 60 feet (2.8 atm), however this should not be attempted during IWR due to changes in human metabolism when immersed in water, and to the grave consequences of an oxygen toxicity-induced convulsion underwater.

In the Absence of Oxygen

Perhaps one of the most critical conditions affecting the decision to perform in-water recompression is the availability of 100% oxygen, especially in a system capable of delivering it to a diver underwater. Although the risk of acute oxygen toxicity symptoms is certainly a cause for concern, the added advantages to effective decompression/recompression are tremendous. However, there will be cases of DCS which occur in situations where 100% oxygen is unavailable. Surely, in light of the theoretical disadvantages of attempting IWR using only air, such a practice would seem absurd. Indeed, all of the cases for which IWR left the divers in worse shape than when they began (e.g. Case #3 and #10), involved air as the only breathing mixture. Furthermore, the diver in case #8 did not improve after air-only IWR, and may have exacerbated his condition during his failed attempts. Nevertheless, the vast majority of the reported "successful" attempts of IWR (including Case #2, #4, #5, #6, and #11 above) were conducted using only air. Several early publications proposed methods of air-only IWR (e.g. Davis, 1962), however none are presently recognized as practical alternatives to oxygen IWR.

In two of the above cases of air-only IWR (#4 and #5), the afflicted divers followed the advice of their decompression computers in determining an air recompression/decompression profile, with apparent success. However, as pointed out by Overlock (1989), use of computers for this purpose "was never intended by the designer/manufacturer, nor would it be recommended". The reason this practice is not advisable is that the algorithms utilized by such devices for determining decompression profiles do not account for the complexities introduced by the presence of intravascular bubbles, which can dramatically affect decompression dynamics (Yount, 1988).

Edmonds et al. (1981, p. 173) sum up air IWR as follows: "In the absence of a recompression chamber, [air IWR] may be the only treatment available to prevent death or severe disability. Despite considerable criticism from authorities distant from the site, this traditional therapy is recognized by most experienced and practical divers to often be of life saving value".

Our suggestion (and an underlying message of this article), is that technical divers, who are already familiar with the use of 100% oxygen underwater as a decompression gas, should add to their equipment inventory the necessary items (such as a full face mask and large supplies of extra oxygen) to perform proper IWR procedures. Having done this, these divers avoid facing the decision to perform the risky gamble of air IWR.

Conclusions

It should be clarified at this point that the main purpose of this article is to bring forth the issue of IWR as an alternative response to DCS, and to summarize available information on the subject. We do not necessarily endorse IWR; however we see an increasing need by technical divers to become aware of the information available on this topic. Several disturbing facts have prompted us to bring this issue to light. First, based on available reports, it is clear that many people are attempting IWR without even knowing that published procedures are available. Furthermore, most reported attempts were conducted using only air. Although the practice seems to have led to a surprising number of successful cases, the advantages of using oxygen for IWR are tremendous, and cannot be denied. Thirdly, and perhaps of greatest concern, few of the individuals who successfully attempted IWR sought subsequent examination by a trained diving physician.

We feel compelled to strongly emphasize the importance of seeking a thorough medical examination after any situation where DCS symptoms have been detected. Regardless of how successful an attempted IWR procedure may be, the affected divers should arrange for transport to the nearest recompression facility as soon as possible to undergo examination by a trained hyperbaric medical specialist. The practice of IWR should never be viewed as an alternative to proper treatment in a recompression chamber. Rather, it should be viewed as a means to arrest and possibly eliminate a progressing or otherwise serious case of DCS. In most cases, in-water recompression should be used as an immediate measure to arrest or reverse serious symptoms while arrangements are being made to evacuate the victim to the nearest operating chamber facility. Without doubt, a person suffering from DCS is better-off within the warm, dry, controlled environment of a chamber, under proper medical supervision, than he or she is hanging on a rope underwater.

The information contained in this article is directed at the growing numbers of "technical" divers, who are conducting dives which expose them to elevated risk of sustaining serious DCS symptoms. These sorts of divers tend to be more experienced and better prepared and equipped to handle many of the procedures outlined by published IWR methods. As put forth by Menduno (1993, p. 58), "In-water oxygen therapy appears to be a promising, though perhaps transitional, solution to the problem of field treatment for technical divers. Though the concept will take some work to properly implement on a widespread scale, the technical community does not suffer from the same limitations as its mass market counterpart." By "transitional", Menduno was no doubt referring to the possibility that lightweight, portable recompression chambers may soon become standard technical diving equipment, and may be available on a much broader basis in the future. Selby (1993) describes one such chamber design which can be compactly stored and quickly assembled in field emergency situations. Edmonds (1993, p. 49), however, cautions that: "When hyperbaric chambers are used in remote localities, often with inadequate equipment and insufficiently trained personnel, there is an appreciable danger from 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 any case, the present high cost of portable recompression chambers will prevent their widespread availability anytime soon. Furthermore, there will always be DCS incidents in situations where no recompression chambers are available nearby.

Our intention is to illustrate that the issue of IWR is far from clearly resolved. We have little doubt that staunch opponents to the practice of IWR will angrily object to even discussing the issue, on the grounds that it might lead improperly trained individuals to make a bad situation worse. But we adhere to the idea that the dissemination of information to those who may need it is of utmost importance, especially when lives may be at stake. It is indeed tragic when a person suffering a relatively minor ailment resulting from DCS attempts IWR incorrectly and leaves the water permanently paralyzed or dead. However, it is perhaps equally tragic when a DCS victim ends up suffering from permanent disabilities because of a long delay in transport to a recompression facility, when the damage might have been reduced or eliminated had IWR been administered in a timely manner. We believe that the time has come to address this issue seriously, openly, and with as much scrutiny as possible. Only through further controlled experimentation and careful analysis of reported IWR attempts will this controversial issue progress towards resolution.

In an effort to document larger numbers of IWR cases, we have begun to collect data on this topic and intend to establish a database of reported IWR attempts. If any readers have ever attempted IWR, or know of anyone who has, we would be greatly indebted if copies of this form could be filled out and mailed to Richard L. Pyle, Ichthyology, B.P. Bishop Museum, P.O. Box 19000-A, 1525 Bernice St., Honolulu, HI 96817; or sent by FAX to (808) 841-8968.

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Appendix A. The "Australian Method" of Emergency In-Water Recompression.

Notes:
1. This technique may be useful in treating cases of decompression sickness in localities remote from recompression facilities. It may also be of use while suitable transport to such a centre is being arranged.
2. In planning, it should be realised 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.
3. Wet suit [or dry suit] for thermal protection.
4. Shot with at least 10 metres of rope (a seat or harness may be rigged to the shot).
5. Some form of communication system between patient, attendant and surface.

Method:
1. The patient is lowered on the shot rope to 9 metres, 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.
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.

Table Aust 9 (RAN 82), short oxygen table

DEPTH..................ELAPSED TIME...................RATE OF ASCENT
(metres)..........Mild...............Serious
9................0030-0100.........0100-0130
8................0042-0112.........0112-0142
7................0054-0124.........0124-0154......12 minutes
6................0106-0136.........0136-0206......per metre
5................0118-0148.........0148-0218......(4 min/ft)
4................0130-0200.........0200-0218
3................0142-0212.........0212-0242
2................0154-0224.........0224-0254
1................0206-0236.........0236-0306....From Edmonds et al. (1981), p.558.

Appendix B. The U.S. Navy Method of Emergency In-Water Recompression

If the command has 100% oxygen-rebreathers available and individuals at the dive site trained in their use, the following in-water recompression procedure may be used instead of Table 1A:
1. Put the stricken diver on the rebreather and have him purge the apparatus at least three times with oxygen.
2. Descend to a depth of 30 feet with a stand-by diver.
3. Remain at 30 feet, at rest, for 60 minutes for Type I symptoms and 90 minutes for Type II symptoms. Ascend to 20 feet after 90 minutes even if symptoms are still present.
4. Decompress to the surface by taking 60 minutes stops at 20 feet and 10 feet.
5. After surfacing, continue breathing 100% oxygen for an additional three hours.
From the U.S. Navy Diving Manual, Vol. One, Section 8.11.2, D.
NOTE: Gilliam (1993) adds that "This method can be easily adapted to full facemask diving systems or surface supplied oxygen. However, it requires a substantial amount of oxygen to be available, both for the in-water treatment and subsequent surface breathing period."

Appendix C. The "Hawaiian Method" of Emergency In-Water Recompression.
Notes:
This decompression sickness treatment table was designed for use by Hawaii's diving fishermen when afflicted with decompression sickness while diving and when more than 30 minutes away from a regular recompression treatment facility. In such an event, treatment must be initiated as soon as the signs or symptoms of decompression sickness are recognized. The urgent nature of the treatment must be recognized and acted upon immediately, inasmuch as nervous tissue of the brain or spinal cord can only be completely revived within the first 7 to 8 minutes after its oxygen supply has been stopped by the intravascular bubble emboli of decompression sickness. (Although its use by technical divers is generally discouraged, this method is presented here for the purpose of providing information to readers of these proceedings. Readers are strongly advised to obtain a copy of Farm et al. (1986) for further details concerning this treatment. Some suggested modifications to allow for more general applicability of this method and some additional comments have been added in italics.)

Equipment Required
1. An adequate supply of oxygen on board boat, i.e., a 120 cu ft capacity or greater bottle, an oxygen-clean hose at least 40-ft long plus fittings, and an oxygen-clean scuba regulator and mouth piece (NOTE: Use of full face mask with demand regulator is very strongly encouraged for administering oxygen underwater during these treatments)
2. A length of line marked to 30 ft from the waterline with seat attached upon which the victim can sit during decompression (the seat should be weighted so as to make victim and seat negatively bouyant)
3. Extra air tanks for victim and attending diver (minimum of two)
4. Anchor rope or sounding float line marked at 165 ft
5. Depth gauge and watch for use by attending diver
6. Wet suit jacket (or other adequate thermal protection) for use by victim with appropriate

weights

Method

Upon recognizing symptoms or signs of decompression sickness, immediately --

1. Stop the engines (of the boat, if the boat is already moving)
2. Throw over anchor line and let out 165 feet or to bottom
3. Rig one full air tank for victim and another for attendant diver
4. Put victim in water with one attendant diver (or two if required) to take victim down anchor line (Extreme caution should be excercised in choice of attendant diver - the risk of DCI occurring in the attendant diver as a result of the IWR attempt should be very seriously considered)
5. Descend to depth of relief plus 30 fsw (not to exceed 165 fsw)
6. Keep victim at that depth for 10 minutes
7. Attending diver and victim start slow ascent with initial rate of 30 ft/minute with stops every minute for assessment of patient's condition
8. Ascent from maximum depth to oxygen breathing depth should not take less than 10 minutes. Suggested rates of ascents from 165 fsw are: 30 ft/minute x 2 minutes; 15 ft/minute x 2 minutes; 10 ft/minutes x 3 minutes; 5 ft/minutes x 3 minutes
9. If patient starts to experience recurrence of any signs or symptoms, return to 10-ft deeper stop for 5 minutes, then resume ascent
10. During deep air breathing period, crew in boat rigs oxygen breathing equipment with regulator (or preferably, full face-mask with demand regulator) attached to hose and line with seat at 30 fsw
11. Upon reaching 30 fsw victim switches to oxygen breathing
12. Victim breathes oxygen at 30 fsw for a minimum of 1 hour
13. If victim had initial symptoms of pain only, and if signs and symptoms are relieved after 1 hour of breathing oxygen, start slow ascent. If victim had signs and symptoms of CNS disease, keep victim at 30 fsw on oxygen for one or two additional 30-minute periods. When victim is completely relieved (or emergency transport arrives, or oxygen supply is exhausted), start slow ascent to surface while breathing oxygen (or air if oxygen supply is exhausted)
14. If the in-water recompression is not effective and the supply of oxygen is apparently inadequate, emergency transport to the on-shore recompression chamber should be arranged (Technical divers are strongly encouraged to begin making arrangements for emergency transport to a recompression facility as soon as DCI symptoms become evident). Recompression on oxygen at 30 fsw should be continued until the oxygen supply is exhausted or transport arrives.
15. Even if victim is asymptomatic when reaching surface, have victim breathe oxygen in boat on surface until supply is exhausted. Consult with diving medical officer upon return to shore.