The Case for In-Water Recompression

Just when you thought it wasn't safe to go back into the water...

The issue of IWR is far from clearly resolved. It is indeed tragic when a person suffering a relatively minor ailment resulting from DCI attempts IWR incorrectly and leaves the water permanently paralyzed or dead. However, it is perhaps equally tragic when a DCI 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.

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Many aspects of technical diving involve systems and procedures which have not 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 f/40 m for bottom times which result in extensive decompression obligations and increased decompression illness (DCI) risk. Although technical diving involves equipment and procedures designed to reduce this risk, technical divers need to be prepared to deal with DCI.

The answer to the question of how best to treat an afflicted diver beyond the administration of oxygen is not universally agreed upon. Perhaps the most controversial method is that of In-Water Recompression (IWR): treating divers suffering from DCI by placing them back underwater after the onset of DCI 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 DCI should *never*, under *any circumstances*, be placed back in the water. Most diving instruction manuals condemn IWR, and the Divers Alert Network's Underwater Diving Accident & Oxygen First Aid Manual states that *"In-water recompression should never be attempted."*

On the other hand, IWR for treatment of DCI is a reality in many fields of diving professionals. Abalone divers in Australia and diving fishermen in Hawaii have relied on IWR for the treatment of DCI 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 DCI. What's more is that the use of 100% oxygen for *decompression* is a standard operational procedure in technical diving which technical divers are generally prepared to handle.

At the root of the controversy surrounding In-Water Recompression 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, and the possibility of worsening the afflicted diver's condition is substantial.

Perhaps the most obvious concern is the risk of drowning. Depending on the severity of the DCI symptoms, the afflicted diver may not be able to keep a regulator securely in his or her mouth. Another complicating factor is that communications are extremely limited underwater. Therefore, monitoring and evaluating the condition of the afflicted diver can be very difficult.

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

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.

Hypothermia is also a major cause for concern. Successful IWR may require several hours of down-time, and even in tropical waters with full thermal diving suits, exposure to cold results in the constriction of peripheral circulatory vessels and decreased perfusion, reducing the efficiency of nitrogen elimination. Other underwater environmental factors—such as strong currents or the proximity of certain kinds of marine life (such as jellyfish or sharks)—can decrease the efficacy of IWR.

Another often overlooked disadvantage of immersion of a diver with neurological DCI symptoms is that the "weightless" nature of being underwater can make it difficult for the diver 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 deter-

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Case #1. Hawaii —
Four fishermen divers were working in pairs at a site about 165 f/51 m to 180 f/55 m. 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 US Navy recompression chamber and headed for the dock some 30 minutes away. 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 f/9 m to 40 f/12 m. The boat crew returned after two 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)

Case #2. Sussex, England —
Twelve experienced divers conducted an 18-minute dive on a wreck at about 215 f/66 m. 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 DCI 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 DCI 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

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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 DCI symptoms, they would, in all likelihood, have survived the incident had they not returned to the water.

Case#3. Hawaii —
After ascending from his second 10-minute dive to 190 f/58 m, 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 f/26 m where, after 3 minutes, the symptoms disappeared. After a total of 8 minutes at 80 f/26 m, he slowly ascended over a period of 50 minutes to 15 f/4.6 m (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.

Case #4. Central Pacific —
A diver had partially completed his decompression following 15 minutes at 200 f/61 m, when he suddenly became aware of the presence of a very large and somewhat "inquisitive" Tiger Shark. Initially, the diver maintained his composure, fearing DCI 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 f/12 m, the diver hauled himself over the bow of the 17-foot Boston Whaler (without removing his gear). Anticipating the onset of DCI, 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.

mine with certainty whether or not symptoms have disappeared, are improving, are remaining constant, or are getting worse.

In contradistinction to the above concerns, 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 DCI 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. 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.

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. 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.

IWR in Practice

Three different methods of IWR have been published.

Australian Method.

In this practice, surface-supplied oxygen is delivered via a full face mask to the diver at a depth of 30 f/9 m. The prescribed time a treated diver spends at 30 f/9 m varies from 30-90 minutes depending on the severity of the symptoms, and the ascent rate is set at a steady 1 meter per 12 minutes (~1 f/4 min).

US Navy Method.

This procedure is to be used when 100% oxygen rebreathers are available. It involves breathing 100% oxygen at a depth of 30 f/9 m for 60 minutes in so-called "Type I" (pain only) cases or 90 minutes in "Type II" (neurological symptoms) cases, followed by an additional 60 minutes of oxygen each at 20 f/6 m and 10 f/3 m.

Hawaiian Method.

This is a modification of the Australian Method which incorporates a 10-minute descent while breathing air to a depth 30 f/9 m greater than the depth at which symptoms disappear, not to exceed a maximum depth of 165 f/50 m. Following this brief "air-spike," the diver then ascends at a decreasing rate of ascent back to 30 f/9 m, 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 was developed in response to the experiences of diving fishermen in Hawaii.

All three methods share the requirement of large quantities of oxygen delivered to the diver via a full face mask at 30 f/9 m 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 527 of these cases, involving diving fishermen in Hawaii, shows that in 87.7% of the cases, there was complete resolution of symptoms. In 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 2.7% of the cases 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 surveyed 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.

At present, we are aware of about 20 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 #2), and one resulted in an apparent aggravation of the conditions (*i.e.* turning a sore shoulder into permanent quadriplegia—see Case #8). 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. Several professional divers have privately confided 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.

Evaluation of Case Histories

In determining the relative value of IWR as a response to DCI, it is useful to carefully examine case histories. DCI 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 DCI victim's condition was better or worse after attempted IWR is not always clear.

The Efficacy of IWR

From the cases described, it should be evident that IWR has almost certainly been of benefit to some DCI 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 #2 and #8) clearly led to deterioration of the condition of a DCI 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 DCI symptoms are often relieved, sometimes substantially, when the victim breathes 100% oxygen at the surface (the presently accepted and recommended response to DCI). Indeed, if symptoms do resolve with surface-oxygen, and recompression treatment facilities are relatively close at hand, then the additional risks incurred with re-immersion seem unwarranted. The two deceased divers discussed in Case #2 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 #7 and #11), then recompression is clearly necessary, and IWR perhaps should be attempted.

Determining Circumstances Appropriate for IWR

A wide variety of variables must be taken into account in identifying those circumstances under which IWR should be implemented. Although the decision to perform IWR should be made quickly, it should *not be made in haste.*

DCI often carries with it a certain stigma. Under some circumstances, a diver suffering from the onset of DCI symptoms may be reluctant to reveal his 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, 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 DCI in US Navy divers, it was found that 91.4% of the cases treated within 15 minutes were successful, whereas the success rate when treatment was delayed 12-24 hours was 85.7%. A similar study on DCI cases among sport divers showed similar results. Of 394 examined cases, 56% of divers with mild DCI symptoms achieved complete relief when treated within six hours, whereas only 30% were completely relieved when treatment was delayed 24 hours or more.

Also of significance 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 DCI symptoms are also important factors. Whether or not mild DCI 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 (as was demonstrated in Case #8). The death of the two divers in Case #2 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. #1 and #9) 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 #10 may have survived had he performed IWR along with his companions.

The immediacy of recompression may be particularly advantageous if DCI symptoms develop soon after surfacing from a deep dive. Under such circumstances, the condition of the DCI 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 might significantly influence the feasibility of IWR. Many technical dives are conducted in relatively cold water, and the risk of hypothermia and decreased nitrogen elimination rates create additional complications. However, 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.

Hazardous marine life is also of concern. Divers omitted required decompression in Cases #4 and #6 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, the availability of large quantities of 100% oxygen and the equipment needed to deliver it safely to a diver 30 f/9 m underwater are also very important factors when considering IWR.

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 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 US 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 DCI bubbles are further reduced in size. In addition to restoring circulation, the extra "overpressure" may facilitate bubble resolution. 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. Figure 1 shows the relationship between theoretical bubble size and depth of recompression. As is clear from this graph, there is a substantial "diminishing of returns" in terms of bubble size reduction as one descends deeper. The added risks of nitrogen loading and nitrogen narcosis increase with depth, further reducing the overall benefit of deeper recompression. A depth of 165 f/50 m was chosen by the USN and with the Hawaiian Method as the maximum at which benefit from recompression was significant. Descent to a depth of 30 f/9 m, 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 f/50 m 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 f/9 m of recompression than is gained in the next 135 f/41 m, whereas the reduction in bubble diameter is slightly greater during the subsequent 135 f/41 m than the initial 30 f/9 m. Whether or not bubble diameter or bubble volume is more critical to the manifestation of DCI symptoms is uncertain.

The fundamental question, in an IWR situation, is whether or not the additional recompression confers physiological advantages sufficiently in excess of the disadvan-

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Case #5. Australia –

After spending 18 minutes at a depth of 220 f/68 m, 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 f/6 m, where she breathed 100% oxygen for 30 minutes. She then ascended to 10 f/3 m, where she completed an additional 30

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minutes of breathing oxygen. Upon surfacing, she was taken to a nearby recompression chamber facility, breathing oxygen during the 30 minutes required for transport. Arriving at the facility, she noticed no obvious symptoms of DCI, but was diagnosed with mild "Type II" DCI and treated several times in the chamber. She suffered no apparent residual effects.

Although no DCI 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 was employed. Recompression depth was limited to a maximum of 20 f/10 m due to concerns of oxygen toxicity at greater depths. The victim was monitored continuously while breathing oxygen underwater by at least two tending divers.

tages associated with breathing air at depth. Obviously, this depends on the immediate diving history of the afflicted diver. The practice of subjecting DCI victims to a 165 f/50 m "spike" during chamber treatments has recently begun to fall out of favor among hyperbaric medical specialists. This philosophy may also be applied to IWR treatment procedures. The possibility of substituting enriched air nitrox (EAN) or high-oxygen Heliox during the "spike" must also be examined. 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 (#11), EAN was used during IWR, with apparently successful results. Using Heliox for IWR is probably unfeasible unless closed-circuit rebreathers are available at the site.

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 #10), there is no risk of aggravating the DCI 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.

Yet, the Hawaiian Method "air spike" may confer important advantages under certain circumstances, as seen in Cases #5 and #6. 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.

The USN Method 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 f/6 m and 10 f/3 m. Although at first this difference may seem trivial, it might, in fact, have important physiological ramifications. It has been commonly observed that, using the ascent rate prescribed in the Australian Method, improvements continue throughout the entire ascent. This suggests that the rate of bubble resolution exceeds the rate of bubble expansion (due to Boyle's Law) during the ascent. Divers following the ascent pattern prescribed in the USN Method could conceivably suffer recurrence of symptoms immediately following ascent to the next shallower stage.

Hyperbaric Oxygen

All of the published IWR methods advocate breathing an oxygen partial pressure of 1.9 atm for extended periods. 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 (#5), the depth of in-water oxygen treatment was limited to a maximum of 20 f/6 m (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 almost certainly 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 f/18 m (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

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., Cases #1 and #8), involved air as the only

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Case #6. Northern Australia —
After a second dive to 100 f/31 m, 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 26 f/8 m, where he breathed 100% oxygen for two hours, then decompressed according to the Australian Method. 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 26 f/8 m can have positive effects on DCI symptoms even after much time has elapsed. It also underscores 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.

Case #7. Solomon Islands —
Fifteen minutes after a 20-minute dive to 120 f/37 m, and 8 minutes of decompression, a diver developed severe neurological DCI 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 three hours of surface-breathing oxygen. She was returned to the water, where she followed the Australian Method. Her condition was much improved after the first 15 minutes, and after an hour she was asymptomatic, with no recurring symptoms.

Case #8. Caribbean —
A young diver experienced pain-only symptoms of DCI 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.

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Case #9. Hawaii —

Shortly after a third dive to 120 f/37 m-160 f/49 m, 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 f/11 m-40 f/12 m. When the symptoms did not regress, the victim was pulled deeper by the tender. At 50 f/15 m, 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 f/8 m for a period of time, and then finished his second tank at 15 f/5 m. Except for feeling "a little tired" that evening, he regained full strength in his arms and legs and remained asymptomatic.

Case #10. Central Pacific —

In this previously unpublished case, four aquarium fish collectors ascended rapidly from their second 200 f/61 m dive of the day, aborting essentially all decompression. All immediately began experiencing nausea and varying degrees of neurological DCI symptoms. Three of the divers returned to a depth of about 50 f/15 m, 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 DCI symptoms. The worst of these was the diver who did not attempt IWR: 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 f/9 m-40 f/12 m, until nightfall forced them out of the water. That night, all four took turns breathing 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.

breathing mixture. Furthermore, the diver in Case #6 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 Cases #1, #3, #4, and #9) were conducted using only air. However, none of the air-only methods are presently recognized as practical alternatives to oxygen IWR.

In one of the air-only IWR cases (#3), the afflicted diver followed the advice of his decompression computer in determining an air recompression/decompression profile, with apparent success. However, the computer was not designed for this purpose. 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.

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 that 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. 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. Moreover, 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 by a trained hyperbaric specialist after *any* situation where DCI 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. 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 DCI. Without doubt, a person suffering from DCI 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 issue of IWR is far from clearly resolved. It is indeed tragic when a person suffering a relatively minor ailment resulting from DCI attempts IWR incorrectly and leaves the water permanently paralyzed or dead. However, it is perhaps equally tragic when a DCI 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.

Richard Pyle has worked at the Bishop Museum's Ichthyology collection since 1986, and is pursuing his Ph.D. David Youngblood is a physician of occupational and hyperbaric medicine, and has written extensively on diving and hyperbaric medicine for 25 years.

The authors are collecting case studies in order to establish a database of reported IWR attempts. If any readers have ever attempted IWR, or know of anyone who has, please contact Richard L. Pyle, Ichthyology, B.P. Bishop Museum, P.O. Box 19000-A, 1525 Bernice St., Honolulu, HI 96817; fax (808) 841-8968. A complete list of notes and references from this article is available upon request from Richard Pyle.

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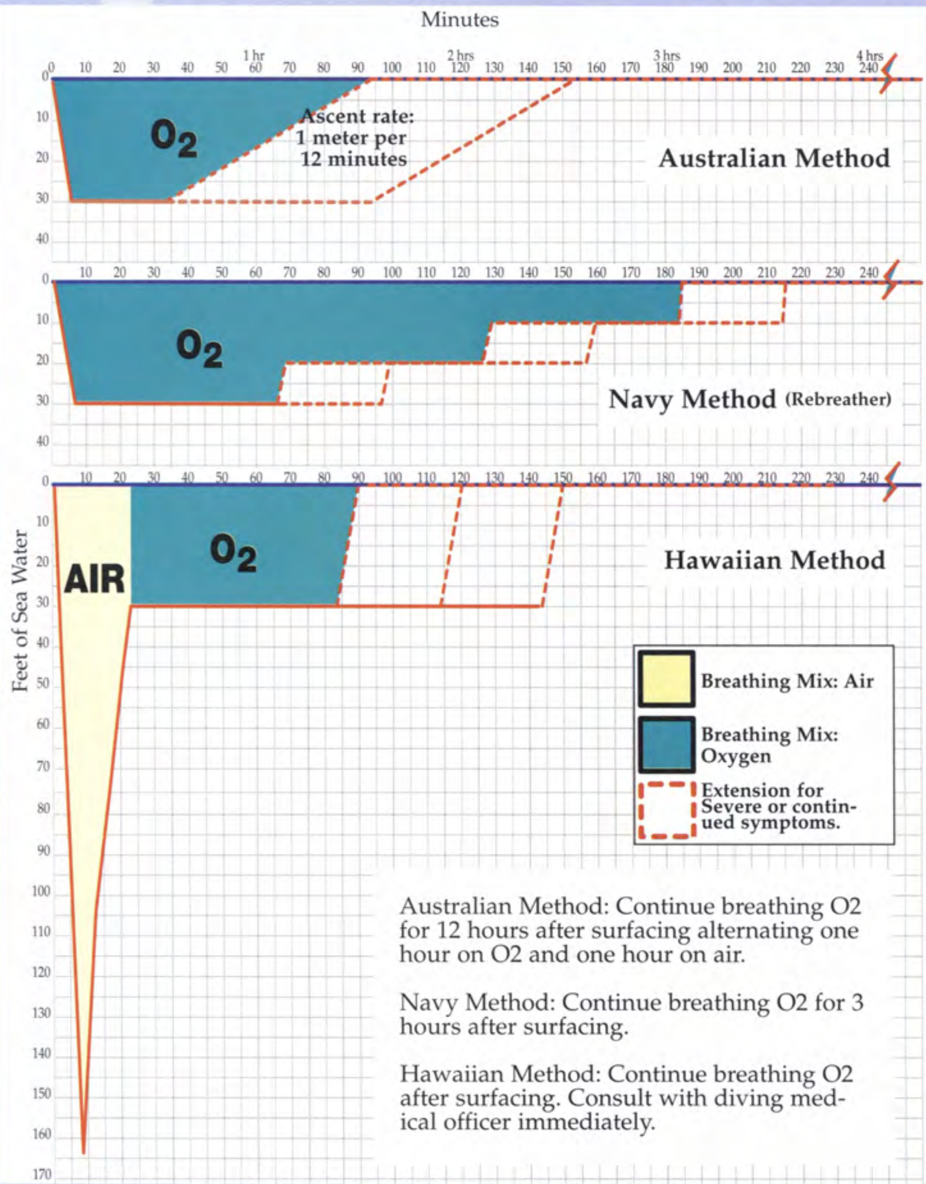
Case Studies

Case#11. Northeastern United States —

After spending 25 minutes at a maximum depth of 147 f/45 m, 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 f/9 m decompression stop. He completed an additional 30 minutes at 10 f/3 m 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, and descended to 100 f/31 m for a period of 10 minutes. He ascended to 20 f/6 m over a 10-minute period, and remained there for 68 minutes. He spent an additional 5 minutes at 10 f/3 m, 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.

In Water Recompression Procedures



Australian Method

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 center is being arranged.

In planning, it should be realized that the therapy may take up to three 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 30 f/9 m, 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 m 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 alternately given one hour on oxygen, one hour off, for a further 12 hours.

From Edmonds *et al.* (1981), p.558.

Hawaiian Method

This decompression sickness treatment table was designed for use when more than 30 minutes away from a regular recompression treatment facility.

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 seven to eight 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. Additional comments and suggested modifications to allow for more general applicability of this method are in italics.)

Equipment Required

1. An adequate supply of oxygen on board, 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 mouthpiece (*NOTE: Use of full face mask with demand regulator is strongly recommended for administering oxygen underwater during these treatments due to the risk of convulsion).*
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 buoyant).
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 (*if the boat is already moving*).
2. Throw over anchor line and let out 165 ft, 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 exercised 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 f/9 m (not to exceed 165 f/51 m).
6. Keep victim at that depth for 10 minutes.
7. Attending diver and victim start slow ascent with initial rate of 30 f/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 f/51 m 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 f/9 m.
11. Upon reaching 30 f/9 m, victim switches to oxygen breathing.
12. Victim breathes oxygen at 30 f/9 m for a minimum of 1 hour.
13. If victim had initial symptoms of pain only, and if signs and symptoms are relieved after one hour of breathing oxygen, start slow ascent. If victim had signs and symptoms of CNS disease, keep victim at 30 f/9 m 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 onshore 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 f/9 m 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.

U.S. Navy Method

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:

Method

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 f/9 m with a stand-by diver.
3. Remain at 30 f/9 m, at rest, for 60 minutes for Type I symptoms and 90 minutes for Type II symptoms. Ascend to 20 f/6 m after 90 minutes even if symptoms are still present.
4. Decompress to the surface by taking 60 minute stops at 20 f/6 m and 10 f/3 m.
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: "This method can be easily adapted to full face mask 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."