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KEEPING UP WITH THE TIMES: APPLICATIONS OF TECHNICAL DIVING PRACTICES FOR IN-WATER RECOMPRESSION

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Abstract

With the proliferation of so-called “technical” diving practices among recreational divers, has come an increased potential for Decompression Illness (DCI), and consequent increased interest in the topic of in-water recompression (IWR). Many of the reasons often cited for not conducting IWR (inability to deliver oxygen to a diver underwater, risk of oxygen-induced convulsions, complexities of staged in-water decompression procedures, insufficient logistical support, thermal concerns, etc.) are either negated, or are of less concern to trained technical divers, who must deal with such issues on a routine basis. This combination of increased potential need for, and increased ability to manage IWR by technical divers, make them ideal candidates for performing IWR under appropriate circumstances. Existing published methods of IWR might be improved upon in light of common technical diving practices, and a new method of conducting IWR specifically targeted at the technical diving community is proposed. Although the questions of whether IWR is a valid response to DCI, and if so, what specific methods are optimal represent the bulk of discussion surrounding the topic of IWR, more discussion (and perhaps standardization) is required for the most complex aspect of the IWR process; that is, how to decide whether a particular situation warrants the use of IWR.

Introduction

Perhaps the only aspect concerning the topic of in-water recompression (IWR; defined herein as any attempt to treat or relieve suspected symptoms of decompression illness [DCI] by returning an afflicted diver to the water – as distinguished from cases of “interrupted” or “omitted” decompression, where a diver returns to the water in order to complete omitted decompression prior to the onset of symptoms) that has escaped controversy, is the fact that the topic itself is highly controversial. This magnitude of dispute is not so surprising, considering that IWR involves a practice supported neither by conventional decompression theory nor clinical research data, which includes the placement of a person stricken with a very poorly-understood and potentially debilitating malady into a relatively hostile and uncontrolled environment. Only a few articles within academic publications include elaborated discussion of IWR, and most of those have originated in either Australia or Hawaii (1-6). A handful of other published articles (e.g., 7-10) include some brief discussion of IWR; but most references to IWR in primary and reference literature pertaining to general treatment of DCI has been limited to at best a paragraph or two (e.g., 11-13).

Over the past decade, an increasing number of non-commercial civilian divers have conducted dives involving alternative breathing mixtures (e.g., enriched air nitrox, pure oxygen, heliox, trimix), on profiles involving substantial decompression obligations. Collectively referred to as "technical" diving, this expanding aspect of recreational diving has sparked the creation of several training agencies, annual international meetings, and the publication of several books, dedicated periodicals, and numerous popular and semi-popular articles. The divers engaged in these technical diving practices often find themselves at greater risk of incurring DCI due to the relatively extreme nature of their dive profiles and largely experimental decompression procedures. Therefore, many of these divers have gained an increased awareness of the need to be prepared to deal with the sudden onset of DCI (14). Consequently, this has led to an expanded interest in the topic of IWR among technical divers, resulting in presentations on the topic at annual meetings and a series of articles discussing IWR in the popular literature (15-18).

As pointed out by Pyle and Youngblood (19, 20), at the root of the controversy surrounding the practice of IWR is a basic conflict between theory and practice. The list of theoretical reasons why IWR has historically been discouraged is long, and includes the risks of additional nitrogen loading (when air or enriched air nitrox is breathed), risk of oxygen-induced convulsions (when pure oxygen is breathed), risk of drowning, insufficient supervision, risk to tending divers, thermal considerations, adverse environmental conditions (e.g., strong currents, rough seas), potentially adverse marine life, and reduced capacity for the afflicted diver and treatment supervisor to assess the nature of symptom progression during treatment. There are two theoretical considerations supporting IWR. First, there is the obvious advantage on the effect of *immediate* recompression on bubble growth; and second there is the advantage of increased inspired oxygen partial pressure (when pure oxygen is breathed), which could in some cases help counteract the effects of tissue hypoxia that may result from DCI-induced vascular obstruction. In stark contrast to the apparently overwhelming theoretical disadvantages of IWR, however, is the equally overwhelming apparent success rate among actual attempts at IWR (1, 4, 19, 20, this article).

The objectives of this article are threefold: first, to review the emerging practices of technical diving in the context of IWR; second, to examine existing published methods of IWR and propose a new method targeted at technical divers that represents a conglomeration of existing IWR methods with technical diving practices; and third, to discuss possible future directions that progress on refining IWR procedures might take.

Technical Diving Practices - Overview

In addition to being generally more at risk of experiencing DCI (due to more extreme dive profiles), technical divers are also perhaps among the most qualified and best suited for attempting IWR. This is a result primarily of generally increased awareness of diving physics and physiology (particularly DCI manifestations and oxygen toxicity issues), and perhaps more importantly, familiarization with factors related to IWR including breathing oxygen-rich mixtures underwater, staged decompression management, extended dive durations, and extensive thermal protection. Moreover, technical divers often conduct their operations with dedicated support personnel trained and prepared for dealing with unexpected emergencies.

Oxygen decompression

A common component of many technical diving operations is the practice of breathing pure oxygen for decompression at 20 ft (6 m) depth (21). This is among the most significant components of technical diving with respect to IWR, because all published IWR procedures involve breathing pure oxygen underwater. Because many technical divers routinely breathe pure oxygen for their normal decompression, they are not only trained for doing so (for the most part), but are also already equipped with appropriately cleaned and serviced cylinders and regulators (or even surface-supplied oxygen in some cases) for administering oxygen underwater. Moreover, there is a tendency for many technical dive operations to stock quantities of oxygen on-site that are considerably in excess of what is required for the planned dive, thereby reducing or eliminating the oft-cited criticism of IWR that sufficient quantities of oxygen are seldom available. One important disadvantage of routine in-water oxygen decompression by technical divers in the context of IWR is that, following long decompression dives involving in-water oxygen decompression, divers have been exposed to a much larger cumulative "dose" of oxygen, thereby possibly enhancing susceptibility to oxygen-induced convulsion should IWR be subsequently attempted.

Enriched air nitrox

The most ubiquitous of technical diving practices is the use of enriched-air nitrox (EAN). Although the most widespread use of this breathing mixture is for relatively shallow, non-decompression diving, various concoctions of EAN are almost universally an integral component of more extreme decompression diving, in the form of a decompression breathing mixture. Oftentimes a mixture containing 80% oxygen / 20% nitrogen (EAN-80) is used instead of pure oxygen for the final stages of decompression. Such a mixture might be worth considering as a breathing gas for IWR; the primary advantages being reduced potential for oxygen-induced convulsion and/or increased recompression depth , and the primary disadvantage being the presence of nitrogen causing a reduced off-gassing gradient across alveolar membranes (but still less nitrogen than breathing air at the surface). Other EAN mixtures available on-site in quantities during technical diving operations (e.g., EAN-50, EAN-40, EAN-36, etc.) might be useful as breathing gases during depth "spikes" associated with some methods of IWR. In any case, EAN can be considered a superior alternative to air as a breathing mixture for divers suffering DCI symptoms when no pure oxygen is available, regardless of whether IWR is attempted.

Helium

When conducting relatively deep (>165 ft / 50 m) diving operations, technical divers often employ helium among their breathing gas mixtures; either in the form of heliox (rare) or trimix (helium-nitrogen-oxygen mixtures; more common). This may have direct or indirect consequence on performing IWR in several different ways. For example, DCI symptom manifestation may be different following helium dives compared with air or other nitrogen-based dives (e.g., with regard to propensity towards neurological versus pain-only symptoms, or characterization of symptom onset), which may affect the relative importance of the immediacy of recompression. Also, there may be possible effects on the cost/benefit considerations of including a deep "spike" during IWR following a deep dive involving helium (i.e., the disadvantages of a "spike" while breathing EAN or air may be reduced if the primary constituent of excess dissolved gas in the diver's body is helium). Furthermore, there is some indication that treatment using helium-based breathing mixtures has advantages over nitrogen-based breathing mixtures (22), although the role of this with respect to IWR is unclear.

Rebreathers

Although still relatively uncommon within the civilian diving community, closed circuit rebreathers are gaining broader popularity, especially among technical divers (23-27). As these devices, which offer greatly increased gas efficiency, become more and more prevalent, their role in the practice of IWR may expand. The primary disadvantage shared by all rebreathers is increased complexity and expanded range of failure modes (e.g., flooding the CO_2 absorbent canister), and hence greater need for specific training.

<u>Oxygen rebreathers.</u> The most basic kind of closed-circuit rebreather is the oxygen rebreather. Widely used in military operations around the world, these devices deliver pure oxygen to a diver via a closed-circuit breathing loop that includes a canister containing chemical CO_2 absorbent material. Oxygen utilization is based on diver metabolism, and very little gas is wasted. Hence, a very small supply of oxygen can sustain a diver for long periods of time. In some ways, pure oxygen rebreathers represent an ideal tool for use in the Australian method of IWR, because they greatly extend the duration a diver can remain underwater with a limited supply of oxygen. However, like all rebreathers, they can be dangerous in the hands of untrained users, and thus would only be appropriate as an IWR tool for divers already trained in their use. Furthermore, because of the restrictive depth limits of breathing pure oxygen underwater, oxygen rebreathers remain a useful tool primarily for military operations, and are uncommon among recreational technical divers.

<u>Semi-closed rebreathers.</u> Semi-closed rebreathers are so-named because not all of the breathing gas is recycled. An oxygen-rich supply gas is added to the breathing loop at a constant or variable rate (depending on the specific type of unit), and excess gas is vented from the loop. Far and away the most common of rebreather types among recreational divers, semi-closed rebreathers may be of use in the practice of IWR for their ability to greatly extent the functional use of a given supply of oxygen (although not as much as with pure oxygen rebreathers). Although generally designed to utilize an EAN supply gas mixture, substitution of pure oxygen as the supply gas would allow extended durations with a limited quantity of oxygen. However, although the use of oxygen as a supply gas would eliminate the concern of hypoxia typically inherent to semi-closed rebreathers, other complexities common to all kinds of rebreathers (e.g., risk of flooding CO_2 absorbent, specialized training) still apply.

<u>Fully-closed mixed-gas rebreathers.</u> The most sophisticated (but somewhat less common) kind of rebreathers within the technical diving community are fully-closed mixed-gas rebreathers. Offering the 'best of both worlds' (i.e., maximal oxygen utilization efficiency of pure oxygen rebreathers combined with extended depth capabilities of semi-closed rebreathers), these kinds of rebreathers possibly represent the ideal tool for conducting the Hawaiian method of IWR (or any other method involving a depth 'spike'). In generally, fully-closed mixed-gas rebreathers incorporate electronic

control systems, which maintain a constant partial pressure of oxygen within the breathing loop. This means that the units can be set to provide 100% oxygen in shallow water, and add only enough 'diluent' gas (e.g., nitrogen or helium) to maintained the desired oxygen partial pressure. Hence, the non-oxygen component of the breathing mixture is held to an absolute minimum at all depths. Alas, as with the other kinds of rebreathers, a great deal of specialized training is required for proper use of these devices; so-much so that they would be useful as a tool for IWR only to those individuals already properly trained in their operation. Nevertheless, the sorts of civilian divers who become trained for and use fully-closed mixed-gas rebreathers often have done so in order to dive to relatively great depths, or dive in very remote locations (where gas supplies are limiting), and thus may find themselves in a situation to conduct IWR.

Other technical equipment

All published methods of IWR prescribe the use of full-face masks (FFMs) in order to safeguard against the consequences of suffering from oxygen-induced convulsions underwater. To divers unfamiliar in the use of full face masks (of which there are many designs), FFMs may represent an additional hazard or source of stress in an already stressful situation (i.e., a situation in which the need for IWR is warranted). However, many members of the technical diving community have embraced the use of FFM's for diving, often to allow use of electronic through-water communication systems (another kind of technical dive equipment that may be of great value in an IWR situation); and hence are more prepared to use this kind of equipment. Yet another aspect of technical diving equipment of relevance to IWR is that of thermal protection. The risk of hypothermia in a diver engaged in IWR is often cited as a reason why IWR should not be attempted. Technical divers, however, are generally prepared for long-duration dives, including extended decompression times. Consequently, these divers tend to be familiar wit proper thermal protection equipment and practices (including drysuits and associated thermal underwear). However, even the best of thermal protection cannot necessarily be relied upon to keep the diver adequately warm in extremely cold situations (6).

Logistical support

Over and above the value of typical technical diving equipment and practices in the context of IWR, technical dives tend to be conducted with far more controlled and disciplined logistical support than most average recreational dives. Moreover, support personnel are often specifically trained and prepared for dealing with unexpected emergency situations, and therefore would likely be capable of managing an IWR effort.

Technical IWR Methodology

Existing methods

At least three formal methods of IWR have been published: the so-called "Australian Method", which is used by abalone divers in Australia (1); the U.S. Navy method (29); and the so-called "Hawaiian Method" (4), which is used by diving fishermen in Hawaii. The Australian method involves continuous breathing of pure oxygen at a depth of 30 ft (9 m) for a period of time ranging from 30 to 90 minutes, depending on severity of symptoms. Ascent is conducted while continuing to breathe oxygen at a slow and steady 1 ft/4 min (1 m/12 min). Upon surfacing, oxygen is breathed for 1-hour periods interspersed with 1-hour periods of breathing air for the following 12 hours. The U.S. Navy method is similar, but the ascent is conducted as two 60-minute staged stops at 20 ft (6 m) and 10 ft (3 m), followed by continuous oxygen breathing for 3 hours after surfacing. The Hawaiian method is similar to the Australian method, but differs primarily in prescribing a depth "spike", descending while breathing air to a depth 30 ft (9 m) deeper than the depth at which symptoms resolve for 10 minutes, then returning to 30 ft (9 m) to commence breathing oxygen for an extended period of time.

Of the three methods, the Australian is most often cited, followed by the Hawaiian. The U.S. Navy method is seldom referenced for civilian use. Most authors who discuss IWR recommend the Australian method instead of the Hawaiian method, usually citing the risk of additional nitrogen loading during the air spike of the Hawaiian method as being too great to warrant the perceived benefit of increased ambient pressure exposure. Indeed, even among authors who discuss IWR, the vast majority condemn the practice of using air as a breathing mixture. The source of this condemnation appears to stem from the commonly-held believe among hyperbaric specialists that breathing air during IWR attempts tends to worsen symptoms more often than it improves them (11, 30). However, the empirical foundation of this widespread believe has been called into question (31). Published survey data of diving fishermen in Hawaii (4) indicate an apparently very high rate of success (in terms of symptom elimination or improvement) when using air as a breathing mixture for IWR (Figure 1).

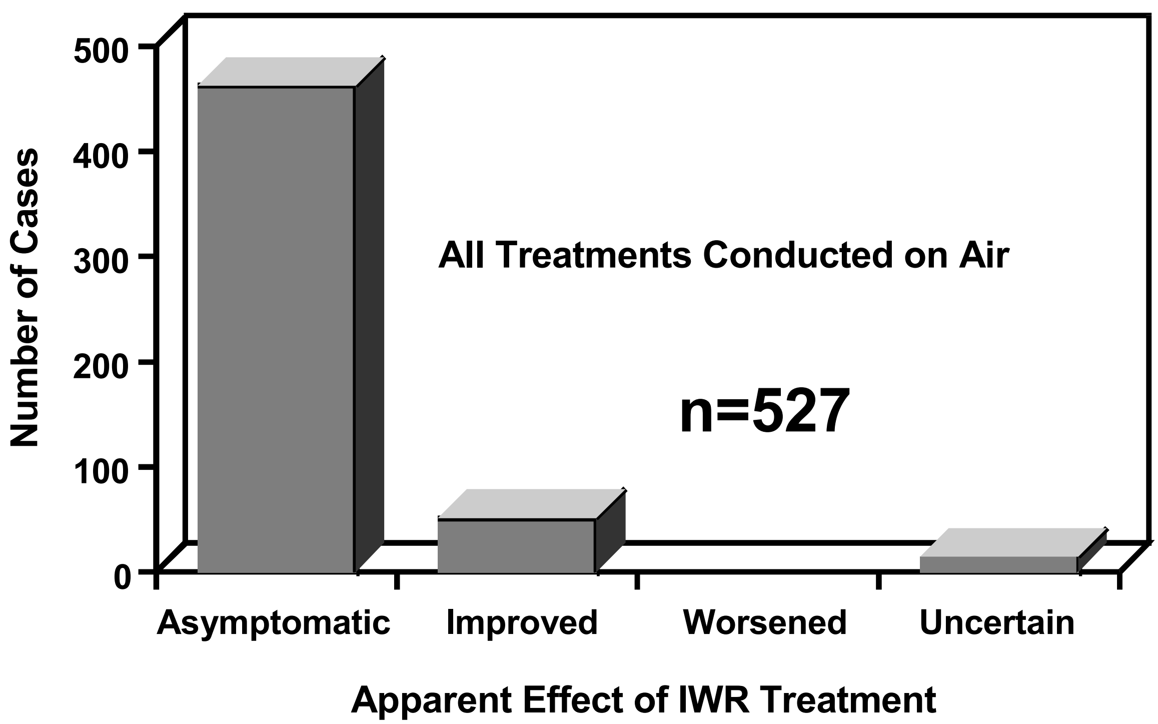
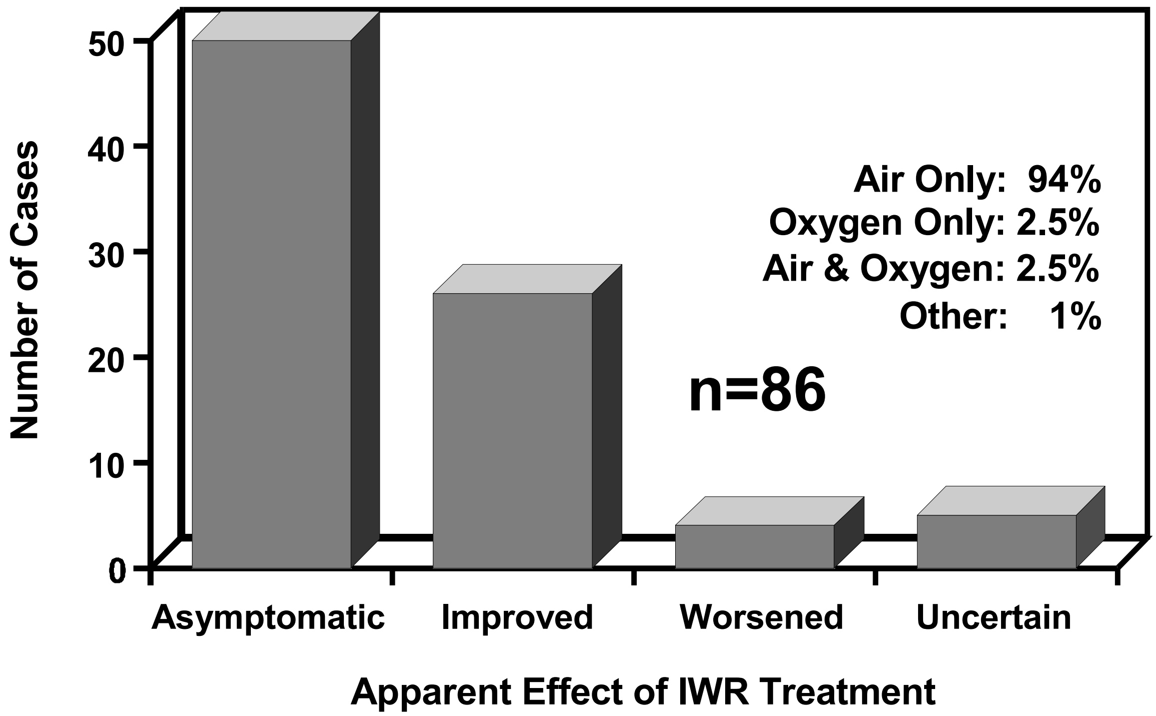


Figure 1. Success rates of IWR attempts among diving fishermen in Hawaii (4). "Asymptomatic" indicates diver felt no apparent residual DCI symptoms following IWR attempt; "Improved" indicates clear reduction of symptom severity to the point where subsequent treatment in a chamber was not sought; "Worsened" indicates exacerbation of DCI symptoms; and "Uncertain" indicates ambiguous outcome.

Because these survey data were obtained retroactively, and relied entirely on the recollection of the



divers involved, these findings have been called into question. However, a similar survey of IWR cases for which detailed accounts have been published and cases with specific records of events (almost all of which involve air as the only breathing gas) reveals a similar trend (Figure 2).

Figure 2. Success rates of IWR attempts among published or otherwise specifically documented cases of IWR, worldwide. Effect categories identical to those in Figure 1.

The somewhat less pronounced results indicating proportionally more "improved" and fewer "Asymptomatic" cases of the second set might be a reflection of bias in the data collection source. Most of the published cases came to the attention of hyperbaric specialists only because the diver sought further treatment or consultation at a hyperbaric treatment facility subsequent to the IWR attempt. For example, whereas 16% of these cases involved divers who subsequently sought additional treatment at a facility, less than 3% of the cases presented in Figure 1 sought such treatment. Therefore, the number of IWR attempts involving elimination of detectable symptoms is likely proportionally underreported for the latter data set.

These observations should not be construed as support for the practice of air-only IWR attempts. The advantages of breathing pure oxygen (whether underwater, on the surface, or in a chamber) are clear and unambiguous, both in terms of physiological theory and empirical observation. However, at the very least the data presented in the preceding figures challenge the notion that "If a victim has mild signs and symptoms of decompression sickness, the usual result [of an IWR attempt] is a much more seriously injured diver. If the initial symptoms are serious, the result is usually disastrous." (11).

So, if not founded in empirical experience, what is the source of general objection to the air "spike" of the Hawaiian IWR method? The most often-cited risk is that of additional nitrogen absorption. This seemingly indisputable contention is rooted in the conventional wisdom of decompression theory that DCI and its manifestations can (for the most part) be accurately modeled with hypothetical compartments representing levels of dissolved gas tensions throughout the body. As any hyperbaric specialist will admit, however, such models do not account for the entire DCI story. Modern approaches to DCI management acknowledge the roles played by other factors, primarily among them the physics governing gas-phase bubbles within aqueous solutions, and the biochemical (particularly immunological) responses of the body to the presence of disruptive intravascular. Thus, with decompression theory still relatively in need of further elaboration at fundamental levels, rejection of the "spike" on purely theoretical grounds seems unwarranted, and consideration of this practice is perhaps suggested by empirical experience.

Another aspect of published IWR methodology in need of scrutiny is the extent to which treated divers are exposed to elevated partial pressures of oxygen. Breathing pure oxygen at a depth of 9 m results in an inspired oxygen partial pressure of nearly 2 atm/bar. While this level is routine for dry hyperbaric chambers, it is somewhat excessive within the context of "safe" limits adopted by technical divers (1.6 atm/bar maximum; 1.4 atm/bar operational). To mitigate the effects of an oxygen-induced convulsion underwater, all published methods of IWR mandate the use of a full face mask by the afflicted diver. While it is certainly true that FFMs drastically reduce the probability of drowning during a convulsion, it is also true that their availability on-site (even during technical diving operations) is generally lacking, and the effect on untrained users may be amplification of stress levels. The fact of the matter is, IWR will be (and indeed already has been) conducted using oxygen underwater at the stated depth of 30 ft (9 m), without the benefit of FFM equipment.

Proposed method of IWR for technical divers

In response to these considerations, as well as personal observations of actual IWR efforts, I have developed my own method of IWR for use during technical diving operations in geographically remote localities. The specific methodology is summarized in the Appendix to this article.

This method differs from other published IWR methods in several respects. First of all, it includes a 10-minute period breathing 100% oxygen at the surface prior to re-entry into the water. This period allows for assessment of conditions as to whether IWR is appropriate, and provides a brief test to indicate whether surface oxygen alone will be sufficient to resolve symptoms. If IWR is to be performed, the diver descends to a depth of 25 ft (7.5 m) breathing 100% oxygen. This is shallower than the 30 ft (9 m) depth recommended by other IWR methods, with the intent of reducing the maximum inspired oxygen partial pressure from 1.9 atm/bar to just over 1.7 atm/bar. The advantage of this is reduced probability of oxygen-induced convulsion (especially important when a full face mask is not available), and the disadvantage is a reduction in ambient pressure. Because in many cases symptoms are relieved at depths of only 10 ft (3 m), the 25-ft (7.5-m) oxygen depth seems a more reasonable compromise between costs and benefits of recompression versus oxygen toxicity.

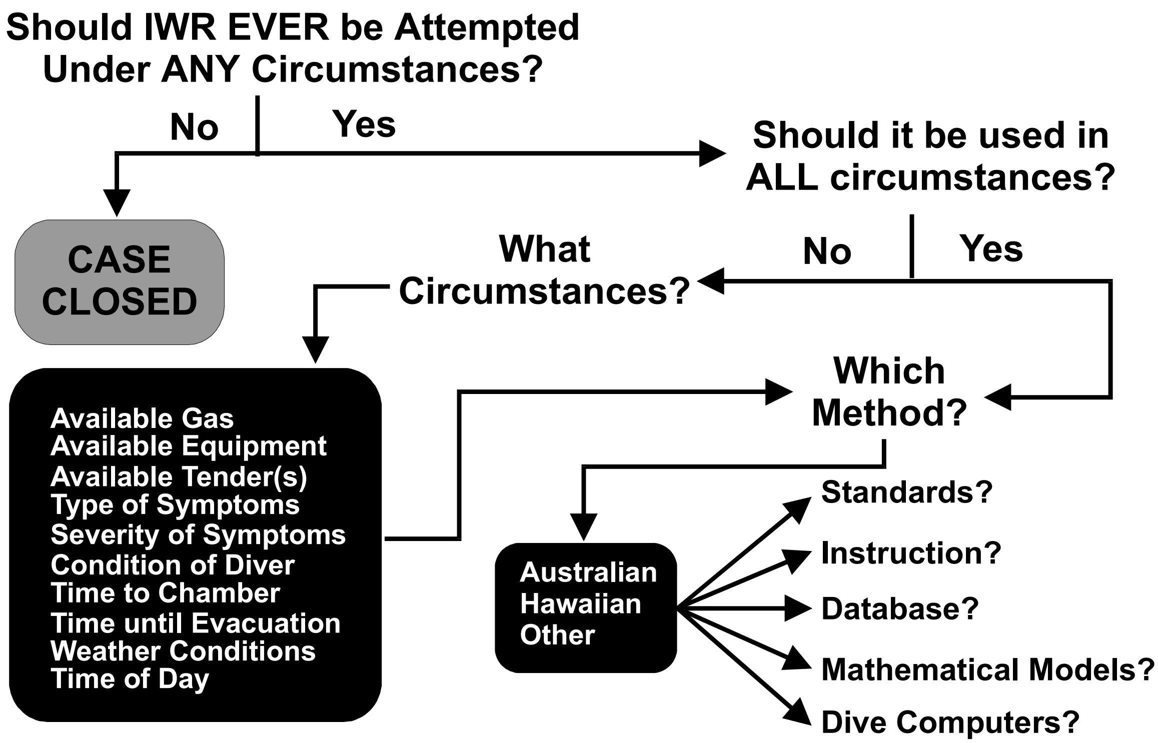
Like the Hawaiian Method of IWR, this method includes an optional deep spike while breathing air or (preferably) EAN. However, unlike the Hawaiian method, the spike is not conducted until after 10 minutes of breathing oxygen at 25 ft (7.5 m); and then, only if symptoms have not been substantially reduced. The purpose of delaying the spike is to allow time to assess the need for it. If 10 minutes of breathing oxygen at 25 ft (7.5 m) is sufficient to resolve symptoms, then the potential risks of a deeper spike might best be avoided altogether. On the other hand, if symptoms persist after 10 minutes at 25 ft (7.5 m), then the need for additional compression seems indicated and a spike is performed. The Hawaiian Method prescribes descending to a depth 30 ft (9 m) greater than the depth at which symptoms resolve. One potential problem with this approach is that symptom resolution may not be instantaneous, and therefore excessive depth may be achieved before making the decision to cease descent. The proposed new method breaks the spike up into 25-ft (7.5 m) increments, with two-minute assessment periods at each increment. If symptoms resolve after 2 minutes at a given spike depth increment, depth is no longer increased, and the remaining 8 minutes of the 10-minute spike duration are conducted at the current depth. If symptoms persist even after 2 minutes at a depth of 125 ft (38 m), spike depth is no longer increased, and the remaining 8 minutes of the spike duration are performed at 125 ft (38 m). After a total of 10 minutes at the maximum spike depth, the diver returns to 25 ft (7.5 m) following a slow ascent rate, and returns to breathing 100% oxygen. The primary reason for the divergence in specific spike methodology from what is described in the Hawaiian method is to reduce the probability of excessive spike depth. Also, it should be emphasized that a spike should not be performed if insufficient quantities of oxygen are not available to follow the spike up with an extended period breathing oxygen at 25 ft (7.5 m).

Regardless of whether a spike is performed, the period of breathing 100% oxygen underwater further differs from previous methods with the addition of 5-minute air or EAN breaks every 20 minutes. The technical diving community has borrowed this practice from hyperbaric treatment facilities in an effort to reduce probability of oxygen-induced convulsions. Presumably, the breaks were not included in previous IWR methods due to fear of additional nitrogen loading. However, given the apparent wide-spread success of air-only IWR, along with the fact that the concern for additional nitrogen loading does not seem to offset the value of the non-oxygen breaks during treatments in a chamber, the air breaks seem justified for IWR; and may be even more justified in view of the greatly increased dangers of suffering an oxygen-induced convulsion underwater.

At best, the new method of IWR described herein is a gross over-simplification of an optimal approach to treating DCI victims underwater. The fundamental problem with any standardized method of IWR is the difficulty of accounting for the wide variety of variables that can impact the decision to perform IWR. Even if all the factors could be taken into account, in many cases it is far from clear how those factors should affect IWR methodology. For example, are serious neurological symptoms more indicative of a need to perform IWR (to thwart permanent neurological damage before hypoxia leads to cell death); or are they more indicative of a need to *not* perform IWR (due to excessive risks of drowning, etc.)? This is only one of many factors that probably should affect the decision to perform IWR, but the way in which they should affect the decision is not clearly understood. Finally, the proposed new method is *not* intended as a replacement for any existing IWR method, but rather as an alternative to be considered by trained technical divers in appropriate circumstances.

Future Directions

The most important step in resolving the IWR controversy (i.e., the need to discuss the related issues from an open and objective perspective) has already been taken in the form of this workshop. The task at hand can be roughly summarized in the chart presented in Figure 3. The first question to



decide is whether IWR should be attempted in any circumstances whatsoever. If not, then we can all go home – the controversy has been resolved. Following the assumption that the answer is not so simple, the next question involves whether IWR should be performed in all circumstances where DCI symptoms are presented. If so, there only remains the question of specific methodology. Again, assuming the answer is not so simple, the topic in need of most attention is the elucidation of circumstances in which IWR should, or should not be performed.

Figure 3. Flow chart representing questions of IWR that need to be resolved.

The IWR decision process will always be a complex one. The first step is to decide what the relevant factors are. Some of the more obvious ones are listed in Figure 3, but there are undoubtedly many others. The next step is to determine what role each factor should play in the decision making process. Unfortunately, neither theoretical nor empirical approaches to resolving these factors will provide the single best answer.

Once a clearer understanding of the associated factors and their roles in IWR has been gained, the next step is a resolution on IWR methodology. Is there one optimal method for all circumstances, or should several specific methods be defined, with each applied in specific circumstances? Or, should one dynamic method be devised, which changes according to the status of various specific factors on a case-by-case basis? To make progress towards some answers, empirical and theoretical approaches must be taken in the context of effective emergency management techniques.

Finally, what are the ultimate future directions to take with regard to IWR? Published standards would represent a very important step in the right direction, but would not end the issue entirely. Given the complex nature of IWR procedures and victim condition evaluation, perhaps a training course in the practice and administration of IWR could be developed and certifications offered by appropriate diving agencies. Perhaps the most important step (and one that should be undertaken sooner rather than later) is the establishment of a centralized database documenting IWR cases. In the very long-term future, if patterns emerge with enough consistency, mathematical models of IWR could be developed and possibly even incorporated into dive computers.

The road to resolving IWR issues is a very long one, and it is apparent that we have only just begun our progress along its path.

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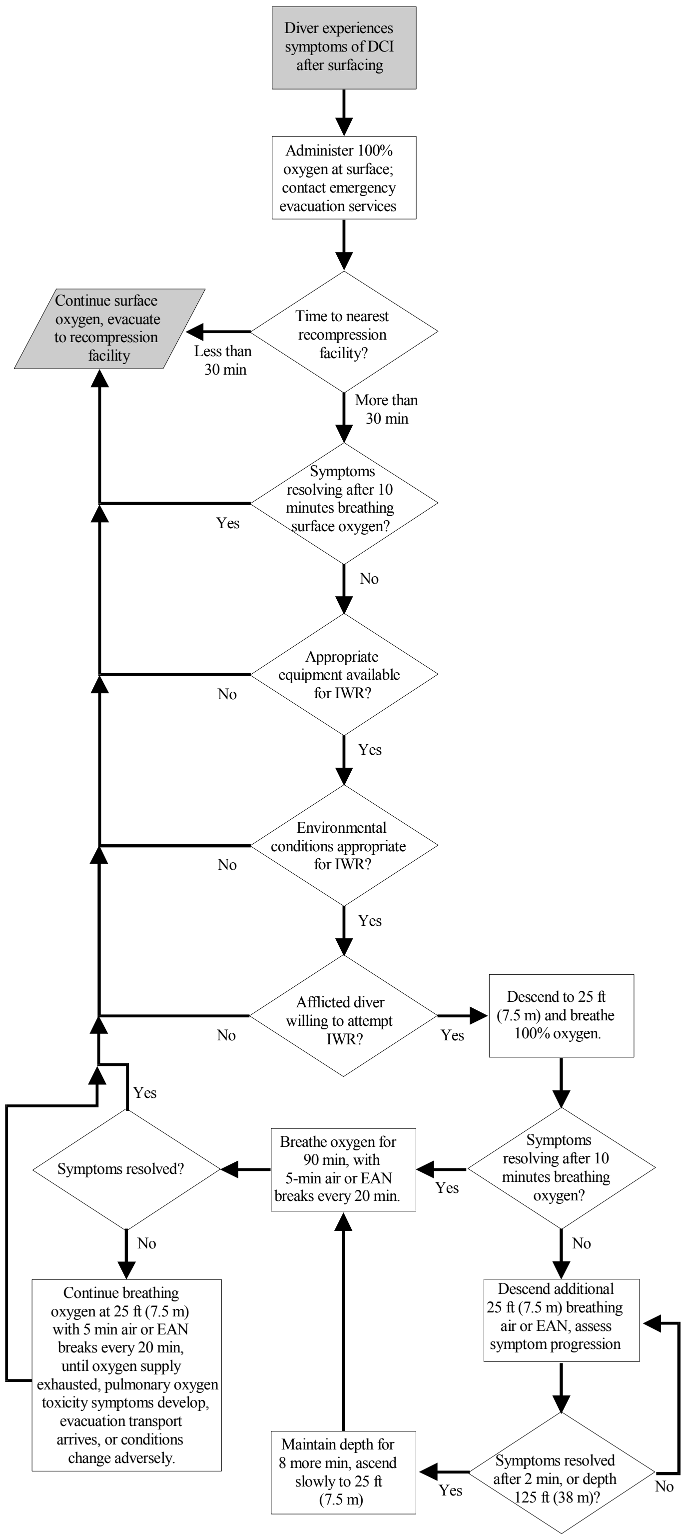
Appendix – Pyle IWR Method.

Required Equipment



1. An adequate supply of oxygen that can be delivered to a diver underwater, either in the form of an appropriately serviced scuba cylinder, surface-supplied apparatus, or rebreather device (the latter for appropriately trained divers *only*!)
2. An adequate supply of air, EAN, or other diluted oxygen mixture that can be delivered to a diver underwater, either in the form of an appropriately serviced scuba cylinder, surface-supplied apparatus, or rebreather device (the latter for appropriately trained divers *only*!)
3. Weighted descent or decompression line marked at 10-ft (3-m) intervals, extending to a depth of 130 ft (40 m) or the maximum available depth, whichever is shallower.
4. Some means of communicating basic information between the diver and the surface support.

Recommended Equipment

1. A full face mask or diving helmet to be worn by the afflicted diver.
2. Means to physically attach afflicted diver to decompression line.

Method

Immediately upon recognizing potential symptoms of DCI:

1. Administer 100% oxygen to diver while at surface for 10 minutes, assess the progression of symptoms, and evaluate conditions (time to nearest recompression facility, diver disposition, oxygen supply, availability of tender diver, weather conditions, time of day, etc.), contact emergency evacuation services, and decide whether IWR is warranted.

2. If IWR is warranted and symptoms are not resolving within 10 minutes of commencement of surface oxygen, place afflicted diver at a depth of 25 ft (7.5 m) on weighted decompression line, breathing 100% oxygen for 10 minutes, under close observation of a tender diver who can maintain communication with surface support.
3. If symptoms are resolving after 10 minutes of breathing 100% oxygen at 25 ft (7.5 m), maintain depth and continue breathing oxygen for a period of 90 minutes, interspersed with 5-minute periods breathing air or EAN every 20 minutes.
4. If symptoms persist or continue to progress after the initial 10 minutes at 25 ft (7.5 m), change breathing gas to air or appropriate EAN, descend to a depth of 50 ft (15 m) and assess symptom progression for 2 minutes. If symptoms are resolving, maintain depth for 8 additional minutes, then ascend at a rate of 5 ft/min (1.5 m/min) to 25 ft (7.5 m) and perform step 3.
5. If symptoms persist or continue to progress after 2 minutes at 50 feet, descend to 75 feet and repeat step 4. Continue to repeat step 4 at 25-ft (7.5-m) depth increments until symptoms resolve, or a depth of 125 ft (38 m) is reached. After 10 minutes at maximum "spike" depth return to a depth of 25 ft (7.5 m) at a rate of 10 ft/min (3 m/min) below 75 ft (22.5 m), and 5 ft/min (1.5 m/min) above 75 ft (22.5 m), and perform step 3.
6. After 90 minutes of 100% oxygen with air or EAN breaks, if symptoms have resolved, ascend to surface at a rate of 1 ft/min (0.3 m/min) and continue breathing oxygen at surface until emergency evacuation transport arrives, diver suffers pulmonary oxygen toxicity symptoms, or 3 hours.
7. If symptoms persist or continue to progress after 90 minutes of 100% oxygen with air or EAN breaks, maintain depth and continue 20-min oxygen / 5 min air or EAN cycle until oxygen supply is exhausted, emergency evacuation transport arrives, diver suffers pulmonary oxygen toxicity symptoms, environmental or diver conditions change adversely, or symptoms resolve, then ascend at a rate of 1 ft/min (0.3 m/min).