CHAPTER 40 CHAPTER

Emergency Management of Stricken Divers in Remote Areas

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Emergency Management of Stricken Divers in Remote Areas

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BACKGROUND

The definitive care for decompression sickness (DCS) has always been 100% oxygen combined with pressure. The majority of oxygen is carried on the hemoglobin molecule. At sea level, the alveolar gas equation predicts that during air breathing,

$paO_2 = \{(P_{atm} - P_{H20}) \times FiO_2) - (PaCO_2 / R)\}$
$paO_2 = \{((760 \text{ mm} - 47) \times .21) - (40 / 0.8)\}$
$paO_2 = \{(713 \times .21) - 50\}$
$paO_2 = \sim 100$ mmHg (driving force)

However, under pressure breathing 100% O_2 at 60 fsw and without significant CO_2 retention, the paO_2 is

$paO_2 = \{((2128 - 47) \times 1.0) - 50\}$
$paO_2 = \{2081 - 50\}$
$paO_2 = 2031$ mmHg (driving force)

Key:
paO_2 = Alveolar partial pressure of oxygen
P_{atm} = Atmospheric pressure at sea level
P_{H20} = Water vapor pressure at 37 degrees C
$PaCO_2$ = Arterial partial pressure of carbon dioxide
FiO_2 = Fractional concentration of inspired oxygen in breathing gas mixture
R = respiratory quotient

The above equations demonstrate that the partial pressure of oxygen in the alveoli and blood is significantly increased using 100% oxygen at elevated ambient pressure. This driving force of oxygen allows enhanced diffusion into the body's tissues even in the face of microvascular obstruction and reduced perfusion.

The purpose of this chapter is to introduce physicians to the history of in-water recompression (IWR) and the details of various methods for treating victims of DCS in the water. We also describe the capabilities and limitations of IWR and ensure the reader understands there are multiple logistical issues that need to be considered prior to attempting IWR. Finally, we describe current best practices as recommended by an industry consensus.

The goal of recompression therapy, in any form, is to reduce the size and number of bubbles by pressure and to facilitate the off-gassing of inert gases (e.g., nitrogen, helium). The treatment for DCS works in two ways. First, the absolute size of the bubble(s) is decreased by the direct mechanical effects of compression. Second, the maximization of oxygen within the surrounding tissues and the minimization of inert gases displaced by the oxygen create a gradient which enhances inert gas diffusion out of the bubble(s), eventually leading to bubble dissolution. Gases extracted from bubbles are dissolved in solution, transported to the lungs, and eventually off-loaded in the alveoli and removed during exhalation.

Immediate controlling actions for DCS are significant and can aide in resolution of symptoms. If recompression can be made almost immediately available at or near the diving site, the chances of a full recovery are more likely to be maximized.[7] The choice of management depends upon a great many factors such as weather, time of onset of symptoms, time until treatment can be accomplished in a recompression chamber, water temperature, and severity of the symptoms. Time as an independent variable is dependent upon severity of symptoms and can range from the need to treat almost immediately (< 30 min in the case of profuse intravascular bubbling) or up to 2 hours after (in the case of other emergent symptoms). An analysis of this situation produces only three viable options if a traditional (hospital-based) recompression chamber is unavailable in adequate time:

1. Treat the affected diver with oxygen at the surface
2. Treat the affected diver with oxygen in a portable recompression chamber
3. Treat the affected diver with oxygen in the water

IWR is not a new consideration. IWR predates the recompression chamber itself. In the nineteenth century when a diver was in pain on the surface post-dive, the diver would reenter the water and "redo" decompression stops. The main benefit of IWR is that it can be initiated rapidly, which provides immediacy of care. Similar to a recompression chamber, IWR increases the pressure, which may resolve the symptomatic bubbles before more serious problems occur.

Myriad tables/profiles exist currently because their potential risks are thought to be outweighed by the potential benefit. Control of the victim once in the water is considerably less than in a recompression chamber. Finally, the logistics for many of these methods is considerable and requires significant practice to conduct properly.

The Australian IWR Table (Figure 1)[14] was developed by the Royal Australian Navy in the 1960s in response to their need for treatment in remote locations far away from recompression chambers. The treatment was similar to the shallow portion of the table developed for recompression chamber use. Oxygen is breathed for the entire duration of the treatment without any air breaks and is followed by alternating periods of oxygen and air breathing on the surface. The maximum operating depth is 30 feet seawater (fsw) or 9.1 meters of seawater (msw) for between 30–90 minutes with an ascent rate of 1 fsw every 4 minutes.

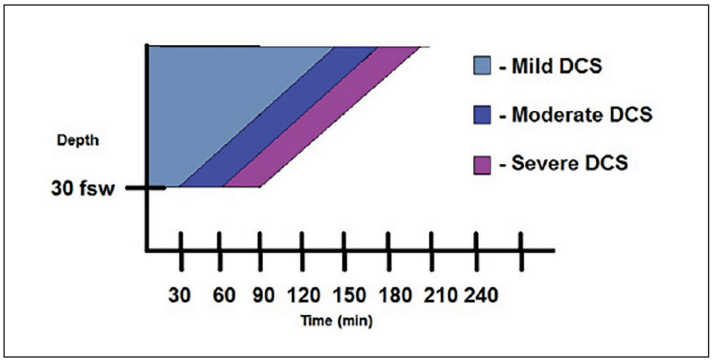


Figure 1. Australian IWR Table.

The Clipperton IWR Tables (2 variants – depending upon equipment availability) [2] were developed for use on a scientific mission to Clipperton Atoll, which is 1,300 km from the Mexican southwest coast. On the first variant, oxygen is breathed the entire portion of the treatment at 30 fsw without any air breaks for 70 minutes. Ascent rate is ~3 fsw/min. For the second table (Figure 2) used in Clipperton, initial descent is to 100 fsw using a rebreather and ascends gradually (~3 fsw/min) to 30 fsw maintaining 1.4 pO_2 on the deeper portion (~20 min). The rebreather is then purged, and pure oxygen (as close to possible) is then breathed at 30 fsw without any air breaks for 70 minutes. Ascent rate is ~3 fsw/min. Substantial oxygen prebreathe and postbreathe is required.

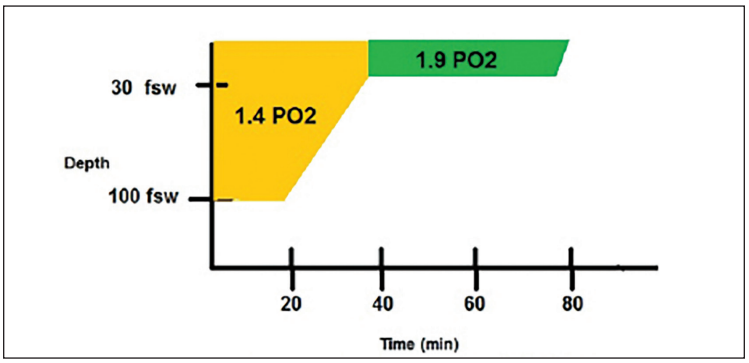


Figure 2. Clipperton (a) IWR Table.

The Hawaiian IWR table was first described by Farm et al.[9] while studying the diving of Hawaii's diving fishermen. These individuals were commonly known to have horrible DCS.[1] The initial portion of the treatment involves descent on air to the depth of relief plus 30 fsw or a maximum of 165 fsw for 10 minutes. The ascent from initial treatment depth to 30 fsw occurs over the course of 10 minutes. The diver then completes a long-duration treatment breathing oxygen at 30 fsw. The Hawaiian IWR Table with Pyle modifications (Figure 3)[16] is the shortest version of the Pyle Hawaiian Table. Longer versions include allowing for a 10-minute decision point to descend to different depths of relief but still starts at and spends a majority of time at 25 fsw. For unresolved symptoms at decision point, divers switch to air or nitrox and descend 25 feet and self-evaluate after 2 minutes. For further unresolved symptoms divers can

descend to up to 125 fsw maximum depth of relief with varying ascent times from deeper depths back to 25 fsw in 25 fsw depth increments. Air or nitrox breaks are performed every 20 min for 5 minutes. Following the oxygen time the diver ascends at 3 fsw/min.

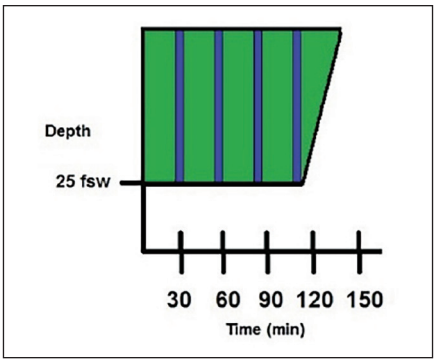


Figure 3. Pyle IWR Table (shortest).

The U.S. Navy developed 2 IWR treatment tables (Figure 4). The table used depends on the symptoms diagnosed by a diving medical officer. The first table is 60 minutes at 30 fsw, and the second table is 90 minutes at 30 fsw. Upon completion of time at 30 fsw, both tables have a stepped ascent to 20 fsw and 10 fsw all while breathing oxygen. No air breaks are considered for this table. The ascent rate is 2 fsw/min. Surface oxygen is required upon completion.

Finally, in 2013, a major training agency, the International Association of Nitrox and Technical Divers (IANTD), developed the first international program to teach IWR. They have certified almost 200 practitioners in the use of IWR as of May 2016. The recommended table (Figure 5) focused on an initial treatment depth of 30 fsw for 10 minutes using pure oxygen followed by an ascent to 25 fsw. It incorporated air breaks and had a 1 fsw/min ascent rate.

IWR has been a viable method of treating affected divers for over a century in one form or another. All of the previous suggested tables exposed the victim to partial pressures of oxygen in excess of 1.6 ATA pO_2 for long durations with complexity

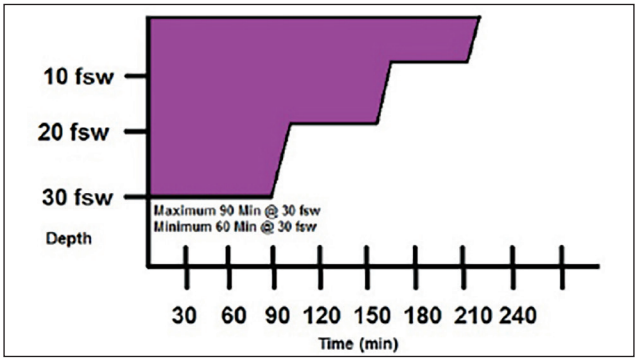


Figure 4. U.S. Navy IWR Table.

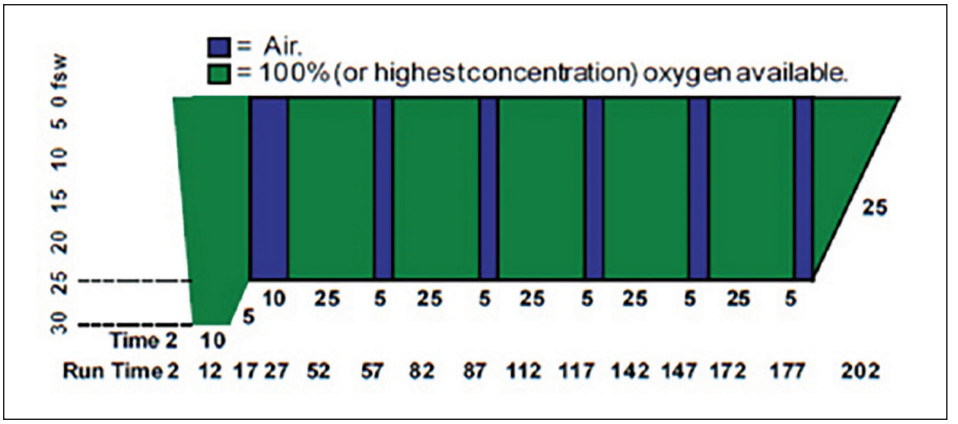


Figure 5. IANTD IWR Table.

and other logistical concerns. Excessively high pO_2 represents a significant risk. Some compromise was needed because IWR has been shown anecdotally to help divers overcome decompression sickness (DCS). In-water management of DCS may significantly reduce the severity of symptoms and improve the likelihood of permanent resolution of symptoms in follow-up professional medical care.

CONSENSUS STATEMENTS

On April 28–29, 2014, in San Diego, California, Richard Sadler, MD, FACS, CDR; Joseph Dituri USN (ret), MS; Simon Mitchell, MB, ChB, DipOccMed, PhD, FANZCA; Craig Jenni, JD; Richard Moon, MD, CM, MSc, FRCP(C), FACP, FCCP; and Richard Pyle, PhD, met to discuss the topic of IWR with the intent of polling industry-leading physicians and divers in the use and practice of IWR. The following is a consensus statement and list of guidelines that came from the invited speakers and input of dive industry professionals.[17]

This consensus statement is a set of recommendations and general guidelines developed using available evidence and expert opinion in areas where high-quality clinical data is limited or does not exist. These guidelines were developed systematically and resulted in specific recommendations that assist the practitioner and diver in making decisions. These recommendations may be adopted, modified, or rejected according to needs and constraints and are not intended to replace local institutional policies. They are not to be considered a standard or "best practice" for emergency response of DCS. Their use cannot guarantee any specific outcome. These guidelines are subject to revision as warranted by the evolution of medical knowledge, technology, and practice. They represent basic recommendations that are supported by a synthesis and analysis of the current literature, expert opinion, and open forum commentary combined with any existing data.

These statements represent the opinion, beliefs, and best judgments of the aforementioned subject-matter experts. As such, they have not been subjected to the same level of formal scientific review as some medical standards. Each person, institution, or practice should decide individually whether to implement the principles in this statement based on a careful evaluation of risk versus benefit and on the sound judgment of the participants involved in the situation at that time.

1. The definitive emergency response of DCS continues to be a combination of pressure and oxygen in high concentrations.
2. Oxygen and pressure are preferred over surface oxygen alone in the emergency response of DCS.
3. It is determined that IWR is a viable methodology for first aid (an intermediate step) prior to definitive emergency response of DCS.
4. Immediacy of emergency response with oxygen and pressure may be fundamental to affect optimal outcomes in selected symptomatic divers.[13]
5. The intrinsic advantage of immediacy in IWR surpasses the potential risks for appropriately selected symptomatic divers.
6. IWR has potential for improving outcomes in those divers with symptoms that have rapid onset and a poor prognosis.
7. IWR is rarely a complete and sole emergency response for DCS. All symptomatic divers of DCS shall, if they opt for IWR, be evaluated by a physician knowledgeable in diving and hyperbaric medicine as soon as possible following IWR.

New consensus recommendations for implementation of IWR:

1. During IWR the diver must be accompanied by a tender.
2. The effectiveness of IWR will be lessened if the diver becomes cold. Maintenance of optimal thermal comfort is therefore important.
3. Indications: While acknowledging the potential benefits of IWR, the potential risks of IWR limit its applications to those divers with symptoms associated with poor outcomes.
4. The breathing mixture should be as close as possible to 100% oxygen (with the goal of achieving a pO_2 of 1.6 atm/bar); mixtures containing less than a minimum FiO_2 of 0.80 (80% inspired oxygen concentration) should not be used for IWR.
5. Emergency response depth should not exceed 20 ft (6 m), even if the breathing mixture contains less than 100% oxygen.
6. Emergency response time should extend 60 minutes after the resolution of symptoms; the total emergency response time must NOT exceed 120 minutes at depth. Figure 6 (pictured at the end of this chapter) is a visual depiction of the treatment table.
7. Periods of breathing air ("air breaks") are not required due to additional complexity.
8. The planned ascent rate should be 1 fsw (0.3 msw)/min if possible.
9. The emergency response protocol should be terminated at any time if deemed necessary by either the tender or diver/symptomatic diver.

10. In the event of an emergency (such as loss of consciousness in the treated diver), a rapid ascent should be made to the surface. If the diver is convulsing and the mouthpiece is retained, (e.g., during use of a retaining strap or if a full-face mask is used) ascent should be delayed until the seizure has stopped. If the mouthpiece is not retained, an ascent should be made immediately, even if the convulsion continues.
11. If symptoms return during ascent from the planned IWR, the diver may return to 20 fsw (6 msw) if the total time at 20 fsw (6 msw) has not yet exceeded 120 minutes.
12. After exiting the water following IWR, the symptomatic diver must not reenter the water even if symptoms recur.
13. Mild activity (i.e., gentle finning movement) is acceptable and encouraged during IWR.
14. For severe DCS (e.g., paralysis), judgment will be required to weigh the benefits of quicker IWR with short delay to evacuation versus immediate evacuation to a hyperbaric facility that may be many hours away. Consultation with an offsite diving medical expert is recommended.

Note: Consideration should be given to combining the last 5 fsw 1-minute stops due to logistics and wave action if needed.

CONTRAINDICATIONS TO IWR

The following is a list of noted absolute contraindications to IWR. All of these conditions have in common a condition that poses a potential uncontrollable risk to the diver.

Absolute Contraindications

1. Isolated hearing loss and vertigo (a sense of spinning) are both potential symptoms of DCS that can lead to permanent injury and technically belong in the most serious category of decompression sickness. However, when they occur in isolation – that is, with no other symptoms of DCS – it is possible that they have been caused by ear barotrauma rather than DCS. If this is the case, then IWR is contraindicated. Isolated hearing loss and vertigo must be differentially diagnosed to ensure no ear barotrauma is present.
2. Airway compromise: Inability to perceive and clear secretions (stupor), active coughing of blood (hemoptysis) or frothy sputum of any sort, collapsed lung (pneumothorax), and "chokes" with paroxysmal coughing all represent risks to a clear airway, which is critical to safe diving. Similarly, emesis represents a potentially unsecure airway, and a victim should not be replaced in the water if such conditions exist.
3. Cardiac arrest: Resuscitation and stabilization always take priority. Successful resuscitation in no way reverses this contraindication, since relapse and instability are common.
4. Extreme anxiety: The risk of barotrauma from an underwater panic attack is prohibitive. The idea of "sedation" or other pharmacologic aid in this

setting is never appropriate and should never be considered. Only a trained Diving Medicine Physician is allowed to medicate a patient/diver.

5. Moderate or severe hypothermia: By definition, moderate hypothermia (core temperature 83°F–90°F)[18] produces uncoordinated muscle movement. This would make it impossible for the diver to safely manage his or her dive gear underwater. Additionally, it is unlikely that the body temperature can be raised while in water. Any potential benefit from IWR would be offset at the point of hypothermia due to the reduction in circulation to the extremities. Finally, at the onset of hypothermia the chattering of teeth would decrease the ability of a tender to accurately detect CNS oxygen toxicity.
6. Altered mental status or altered consciousness: A mental state which would prevent autonomous or volitional control of diving equipment. This could also include weakness or any other symptom of such severity that it would prevent safe diving practices (e.g., equipment use).
7. Severe tachypnea: A respiratory rate of > 24/minute.
8. Loss of consciousness (LOC): Occurring within 15 minutes of surfacing. LOC in this setting strongly implies AGE/CAGE ([cerebral] arterial gas embolism).

   Many dive sites do not have adequate facilities to check for shock or hemodynamic instability. Because these are clear contraindications, a physician must ensure these are checked or obvious to the casual observer not to be present prior to IWR.
9. Shock: A rare presentation of severe DCS where there is a massive capillary leak with loss of intravascular volume. This can be quickly fatal, and the diver is too unstable to consider IWR. Inadequate organ perfusion and low blood pressure will only get worse with the inability to give fluids while doing IWR. Intravenous fluid resuscitation is obligatory.
10. Hemodynamic instability or CPR: A victim with hemodynamic instability is a potential liability for management in water as well as any victim who has had CPR.

Relative Contraindications

1. Vertigo: Even when caused by DCS, vertigo is a potentially debilitating symptom which is usually accompanied by nausea and vomiting and may make IWR hazardous. Differential diagnosis must be performed to ensure the dizziness is not caused by middle-ear barotrauma.
2. Logistical issues: Myriad logistical issues are relative contraindications to IWR such as water temperature, wave action, insufficient oxygen, lack of trained individuals, hazardous marine life, adequate distance to a chamber, and correct equipment, to name a few.
3. Mild symptoms or more serious symptoms and signs that resolve or nearly resolve and remain improved on surface oxygen: An evaluation of benefit-to-risk ratio may not support IWR. These cases should still be monitored for deterioration and discussed urgently with an appropriate expert

authority. It is likely they will require evacuation to a hyperbaric medicine unit for evaluation and treatment.

The diver may only be recompressed in water if there are no overt signs of pulmonary compromise such as pneumothorax or hemoptysis, and he or she is fully conscious and cooperative.

Logistical Considerations for Performing IWR

The following is a group of practical and logistical considerations for equipment. Preemergency response informed consent of all potential IWR participants should ideally be obtained. In order to facilitate this, a webinar or video online should be used where IWR is explained and a standard waiver is signed. Trained IWR divers should practice IWR regularly in order to maintain proficiency.

Absolute control of a symptomatic diver must be ensured, and the diver should be tethered. The symptomatic diver's depth should be controlled by the use of a stable reference line. Some form of positive contact with the symptomatic diver is mandatory. Some examples of positive control include the symptomatic diver being connected to the down line with a separate line, the symptomatic diver being tethered to the accompanying diver with a line, or the use of a quick release (snap) shackle in either of those first two examples is reasonable. Additionally, the surface support team and tender should be prepared for a sudden deterioration of the diver/symptomatic diver. Finally, if reasonably foreseeable adverse conditions cannot be mitigated, the IWR protocol should be terminated.

Some form of device to ensure the diver's airway breathing source remains in place should be used. A regulator retention (gag) strap (RRS) is strongly recommended to hold the regulator in place in the unlikely event of an oxygen seizure. The use of a full-face mask (FFM) is recommended for trained users. Significant caution is advised for the untrained user. The consensus recommendation of a maximum oxygen partial pressure of 1.6 ATA minimizes but does not remove the risk of seizure. The consequences of aspiration underwater are potentially life-threatening.

FFM is the traditional "best practice" for IWR. Advantages include the airway being maximally protected from ambient water in the event of a seizure, allowance for communication, and additional thermal protection. Disadvantages of a FFM include lack of training in most cases, imperfect fit or discomfort, difficulty in clearing water or vomitus (creating an additional risk of aspiration), the necessity in most cases to remove the full mask to change gas supplies (unless a gas switching block is used), and being costly (approximately USD$500–USD$750).

RRS consists of a strap around the head/neck attached to the second stage regulator and a rubberized flexible flange around the mouth, preventing loss of regulator and creating a barrier to water in the event of seizure. Advantages of RRS include lesser costs than a FFM (< USD$100) and requirement of minimal training. Disadvantages of an RRS include it is not as protective of the airway as a FFM, and properly designed devices are not widely available.

All previous IWR protocols require or strongly advocate the use of a FFM, primarily to mitigate the consequences of a hyperoxia-induced seizure underwater. These previous protocols also incorporate breathing 100% (or close to it) oxygen at depths in excess of 6 msw (20 fsw), where the inspired oxygen partial pressure is in excess of 1.6 ATA. As advantageous as a FFM may be in the event of a seizure underwater (for reducing the probability of drowning), as discussed earlier, the use of

a FFM also imposes some difficulty (and risk) for divers who are not trained in their use.[4]

In the context of these recommendations, a maximum depth of 20 fsw (6 msw) is advocated for IWR (a depth at which near-100% oxygen is commonly breathed by technical divers for decompression). At 20 fsw (6 msw) the incidence of hyperoxia-induced seizure is extremely low, and the potential net benefits of using a FFM depend on the degree of training and familiarity the afflicted diver already has with this equipment prior to attempting IWR. Therefore, a RRS is recommended in cases where the symptomatic diver is not already trained in the proper use of a FFM or when a FFM is not available.

Although more controversial than a FFM for this purpose, the RRS is arguably supported by data. Gempp et al. reported[10] 54 underwater loss-of-consciousness events in military divers leading to only 3 fatal drownings. In this series there were 26 cases of CNS oxygen toxicity with seizures, with an 11.5% major complication rate: 2 deaths (caught under a barge) and 1 nonfatal moderate water aspiration. The use of the Drager-style gag strap with strap and lip-sealing flange was used in all cases. Although this is an uncontrolled series, and notwithstanding the potential for other factors to influence outcome in the military setting, the unexpectedly high survival following these events suggests that gag straps are effective in most cases. Improvisation of gag straps by divers is not encouraged.

In the event sufficient oxygen is not available and all the other factors are met for selecting IWR, EMS should be activated and the victim prepared for evacuation. The affected diver can be immersed in water (head out of water) using the table and schedule discussed, breathing the highest percentage of oxygen available until 15 minutes prior to the arrival of reliable transportation or the end of the protocol. This idea, while not clinically proven, assists in redistribution of the fluid throughout the body[8] and has the potential to be a low-risk method to "increase" the volume of blood and improve the overall prognosis of a diver with DCS who has a delay in treatment.

As mentioned earlier, there are several IWR protocols, but there are no statistically valid trials favoring one over another. The answer to which one is better is "nobody knows." However, exceeding a maximum pO_2 of 1.6 ATA is strongly discouraged because it can lead to CNS oxygen toxicity in the water. The mechanism of CNS oxygen toxicity is not well understood. On a normal dive, the best protection against CNS oxygen toxicity is to keep below 1.6 ATA pO_2. Exceeding 1.6 ATA pO_2 is dangerous during normal sport diving activity. Be mindful the normal diver does not have a depth-limiting device which prevents accidental descent as well as a buddy whose express function is to monitor and assist in the event of a symptom of CNS oxygen toxicity. Contrary to a sport diver, the stricken diver is to do nothing during IWR except breathing and light motion to improve circulation. Exercise in excess of light motion may hasten the onset of CNS oxygen toxicity. Light movement to increase circulation is not recommended below 20 fsw. Light movement may assist in off-gassing 20 fsw and shallower. The stricken diver is also to be kept as warm as possible and well hydrated.

Prior to administration of oxygen, a safe oxygen environment must be established, removing possible sources of ignition as well as sources of fuel such as petroleum products, paper, or highly flammable objects. All oxygen tanks and sources should be secured, and only equipment designated "oxygen safe" should be used. Oxygen should be provided with either a demand valve/regulator or another means of providing 100% oxygen. If the victim is conscious, the rescuer should obtain permission before

administering oxygen. If the victim is unsure or doesn't want oxygen, the rescuer may advise the victim of the benefits of oxygen and that it could help. If the victim is unconscious, the rescuer should activate the EMS, administer oxygen, and perform an exam to determine possible causes.

As discussed, there should be some means of ensuring the stricken diver is not able to descend deeper than 20 fsw (6 msw) as well as a means of retrieval such as a line tied or clipped. A flat ocean floor would be best for this purpose; however, surge may be a factor if swells are high enough. Avoid excessive movement of the stricken diver (in the surge) as to cause any symptoms which could be confused with CNS oxygen toxicity. Alternatively, a line could be affixed to a boat with 20 feet of slack and a weighted bottom. The diver could then clip into the line and have a fixed position not affording the possibility of descending below 20 fsw (6 msw). Specific consideration should be given to slightly overweighing the stricken diver, provided the recommendations about tethering the diver to the line are adhered to. This will reduce the motion of the diver and, in the event of an oxygen seizure, assist the buddy diver in holding the victim at depth. If operating from a boat in a strong current, consideration should be given to drifting rather than having the boat anchored. Drifting eliminates any effect of the current which can complicate depth control and cause fatigue in the divers trying to maintain position.

The tethering or down line should be fixed to the boat so that there is an immediate connection that divers can follow between the surface support and treated diver. Avoid using an anchor line because it tends to move with wave action, which becomes fatiguing for divers trying to stay attached.

A community database of IWR incidents and outcomes is being maintained at http://www.ibum.org/iwr.html. The group of experts from the GAVI IWR symposium determined the most important information required during assessment of an injured diver and IWR is a timeline or chronology of events, along with key relevant data describing the symptomatic diver and circumstances of the incident. The following information should be captured:

1. Was victim referred for evaluation, hyperbaric emergency response, etc. (give details)
2. Outcome/degree of recovery
3. Type of thermal protection (mm of wet suit or dry suit/type)
4. Temperature of water (°F)
5. Did you have any complications with the IWR (detail them)
6. IWR protocol followed (percentage oxygen/depth/time at depth)
7. Surface oxygen use (yes/no) and duration
8. Time of symptom resolution (minutes after surfacing)
9. Order of symptom progression (list all Sx and when they started as well as pain level on a scale of 1–10
10. Time of onset of symptoms (how many minutes after surfacing was first Sx)
11. Dive profile
12. Gender
13. Race

This information will be added to a community database of IWR incidents; outcomes will be maintained by IBUM and available to the general public. This information will be shared freely with all interested parties.

CASE STUDY

IWR has been of benefit to some DCS victims in numerous circumstances. Only three recorded attempts at IWR clearly led to deterioration of the condition of a DCS victim. It is necessary to stipulate there is likely to be a bias against reporting any IWR study results because if successful the diver feels no need to report, and if a failure, divers may become embarrassed. There are hundreds of additional cases where IWR was of benefit that was, in some cases, significant.[19] While myriad anecdotal evidence/case studies exist for using IWR, perhaps none is more powerful or convincing as this case. Following the Gallant Aquatic Ventures International IWR Symposium where the above consensus statement was formed by industry-leading experts in hyperbarics, there was an apparent need to gather objective quality evidence concerning IWR. A group of concerned researchers worked through IRB and received approval to conduct a study.[5] The team wanted to ensure accurate depths for the in-water study, so they were working to place a platform at the exact depth in the water. The divers planned their dive and dove their plan. They planned for workload and wore computers to ensure the plan was matched. The dive team consisted of a physician who was UHMS trained and board certified in hyperbarics, a retired Navy Saturation Diving Officer and partial owner of IANTD who was also the principle investigator on the In-Water Recompression study and protocol and coauthored the IWR course and manual, as well as a local dive store owner and experienced cave instructor for IANTD who was also a trained IWR Instructor through IANTD.

The dive itself was unremarkable, except for a few "sawtooth" ascents (short cyclical ascents and descents), which were part of the dive plan. All decompression requirements as advised by the Sherwood dive computer were completed without incident. The team exited the water together. Approximately 15 minutes following final ascent to the surface, 1 of the divers experienced difficulty removing his drysuit and started rubbing his back and complained of back pain. Surface oxygen was administered, and a gross neurological assessment was performed including mental status, cranial nerves, strength, coordination and sensory. The victim seemed lucid, and there was no obvious loss of sensation nor any noticeable decrease in strength or coordination. The only symptom was radicular back pain which peaked at an 8 on a scale of 1 to 10. It was readily apparent that this back pain was not attributable to strain or mechanical injury, as it was worsening rapidly. During this time the local dive store owner/IWR Instructor geared up and set up logistics.

The dive site was approximately two hours from the nearest hyperbaric chamber. The rapid tempo of the pain was concerning. There were minimal logistical concerns for using IWR in the dive site. No sea state existed, nor was there an issue with hazardous marine life. Twenty-two minutes post dive, the victim reentered the water and descended to 10 feet with an experienced tender for in-water oxygen. An additional tender entered the water for full IWR using the IWR symposium recommendations as a guide. Twenty-seven minutes post dive, the 3-person team descended to 20 fsw (6 msw).

After less than 2 minutes at 20 fsw (6 msw) breathing oxygen, the pain had been completely relieved and there was complete resolution of all symptoms 31 minutes after surfacing. The remaining protocol was performed per the IWR consensus statement including an ascent rate of 1 foot per minute to the surface. There were no

residual symptoms, and the physician had a neurological assessment post dive as well as followed up with several other physicians knowledgeable in hyperbaric medicine. No additional treatment was required. The affected diver was administered a Doppler echocardiogram approximately 24 hours post dive and was noted as still having 1 bubble per 4 cardiac cycles. No abnormal heart defect such as a patent foramen ovale (PFO) was noted. Never before had such a well-informed group been faced with a situation such as this and reported this positive result.

OPPOSITION AND RISK ANALYSIS

As reported by Pyle and Youngblood (1995), some opponents to IWR declare that certain DCS symptoms can be relieved at the surface when the victim breathes pure oxygen.[16] As discussed earlier, this has limitations but is presently an accepted and recommended response to DCS. If symptoms do resolve with surface oxygen, and recompression treatment facilities are relatively close, then the additional risks incurred with reimmersion may not be warranted. However, in cases where chamber facilities are not available, or when symptoms persist in spite of surface oxygen, recompression may be necessary to relieve symptoms and prevent permanent damage, and IWR should be considered.[16]

There is no magic formula that will ensure safety or resolution of symptoms. The overriding theme of IWR is to pressurize the stricken diver, use oxygen to reduce or eliminate the size of the problematic bubbles, and improve the stricken diver's likelihood of full recovery. The placement of a person stricken with a very poorly understood and potentially debilitating malady into a relatively hostile and uncontrolled environment[15] may seem ill-advised. However, this emergent effort has prevented long-term injury and probably saved lives. As pointed out by Pyle and Youngblood, 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 following:

1. The risks of additional nitrogen loading (with air or enriched air nitrox)
2. The risk of oxygen-induced convulsions (with pure oxygen)
3. The risk of drowning
4. The need for and risk to tending divers
5. Thermal considerations
6. Adverse environmental conditions (e.g., rough seas, marine life, etc).
7. Reduced capacity for the afflicted diver and treatment supervisor to assess the nature of symptom progression during treatment

Many more risks exist and should be discussed prior to IWR.

There are two theoretical considerations supporting IWR. First, there is the obvious advantage of the effect of immediate recompression on bubble growth. A recent human study[3] showed that following a dive to 100 feet for 30 minutes, compression back to 1.6 ATA breathing oxygen reduced venous bubble formation substantially more than breathing oxygen at 1 ATA. Second, there is the advantage of increased inspired oxygen partial pressure (when pure oxygen is breathed), which can have a variety of positive effects on the pathophysiology of DCS (including amelioration of inflammatory events and correction of tissue hypoxia).

A more recent pilot study[5] investigated the efficacy of an IWR treatment on decompression stress measured by semiquantitative counts of venous gas emboli in the central venous circulation. This pilot study had promising results; however, further study is warranted to obtain conclusive results. There is a substantial body of anecdotal evidence of benefit when IWR has been used by divers in the field.

IWR USING AIR

IWR using air is considered less preferable than in-water recompression using oxygen. It must be remembered that the crucial drug used in the treatment of DCS is oxygen. However, it must also be remembered that the vast majority of documented successful IWR cases used air. The authors recommend not using the USN Diving Manual IWR Protocol (20.4.4).[20] The use of air at approximately 5 ATA (pO_2 = 1.0, same as surface O_2 at 100%) incurs inert gas loading with nitrogen at dangerous levels, negating any benefit. USN Air Treatment Table 1A should be avoided for IWR without oxygen for those reasons as well as the fact that the logistical needs are formidable, and it is unlikely that it could be done with the expectation of benefit, at the cost of great risk. At one time, divers were treated in recompression chambers using the U.S. Navy protocols breathing air instead of oxygen. The failure rate was high. It is unlikely that in-water recompression using air is more effective than those treatment tables. While these air tables still remain in the navy dive manual, they are not commonly used due to the lack of effectiveness of air treatments.

ROLE OF REBREATHERS IN OXYGEN ADMINISTRATION

Always consider the potential role of the rebreather for the administration of first aid following a DCS incident. A rebreather allows prolonged administration of 100% oxygen to the conscious victim. Rebreathers can increase duration of an AL 80 cylinder (2,265 liters) from 150 minutes in open circuit to as much as 2,900 minutes. This increase of more than 19 times can help with storage concerns for adequate oxygen reducing the overall footprint of emergency transport gas by approximately 90%. The stricken diver need not be certified or trained in rebreather operation as long as the victim is merely using it on the surface to extend the amount of surface oxygen provided. The rebreather must be set up by a qualified individual and closely monitored by a competent person on the surface. While rebreathers are recognized as a potential tool for administration of oxygen during IWR, their use in IWR by divers untrained in their use should only be attempted under expert supervision.

The volume of oxygen required to complete this management in water is about 6,000 liters. For those who choose this option, using a rebreathing apparatus would reduce consumption to about 300 liters, but the victim must be trained in the use of a rebreather prior to going in the water, and the rebreather must have sufficient carbon dioxide–scrubbing capacity remaining. This savings of 5,700 liters means the in-water management could be accomplished on a single rebreather cylinder as opposed to having another diver shuttle three or four bottles filled with oxygen to the stricken diver. If a rebreather is chosen, this amount will be decreased, but the carbon dioxide scrubber duration and the diver's ability to use the device must be considered.

MANAGEMENT OF NEUROLOGIC OXYGEN TOXICITY IN WATER

The stricken diver should be observed closely as the statistical probability of CNS oxygen toxicity increases when hyperoxic (< 1.6 bar pO_2) mixtures are used in the water. The symptoms of CNS oxygen toxicity are located in Chapter 3: Oxygen Toxicity and will not be mentioned herein for brevity.

The following suggestions can be used by a diver if oxygen toxicity symptoms (other than seizures) arise:

1. The diver being treated should report the symptoms to the accompanying safety diver immediately.
2. If possible, the victim's breathing gas should be changed to air.
3. The safety diver must watch the victim constantly and be ready to intervene (see below) immediately if a seizure occurs.
4. The relationship of premonitory symptoms to the onset of a seizure is variable and unpredictable, as is the efficacy of lowering the inspired pO_2 in preventing progression to a seizure. Given that a seizure in the water is a very dangerous event, the safest course of action when premonitory symptoms occur is to abandon IWR.
5. The safety diver and victim should surface over one to two minutes. The safety diver must be ready to intervene immediately should a convulsion occur.
6. Retrieve the diver from the water, place on oxygen, and consider evacuation for recompression in a hyperbaric chamber.

What to do when a seizure occurs follows:

7. If the diver is wearing a full-face mask or the regulator is retained in the mouth, the safety diver must make every attempt to hold the mask or regulator in place, and the diver should be kept at depth until the seizure is resolved.
8. The moment the seizure appears to abate, the diver should be brought directly to the surface and removed from the water as quickly as possible and an ABC (airway breathing, circulation) protocol instituted.
9. If the regulator is lost from the mouth, and the airway is obviously unprotected, the safety diver should not attempt to replace the regulator. Instead, the victim should be brought to the surface immediately, even if the seizure appears to be continuing. Remove from the water and initiate an ABC protocol.
10. Continue the administration of oxygen on the surface after ABC is complete, and the diver has been conscious for 15 minutes.[11]

Pulmonary oxygen toxicity is highly unlikely with this protocol, as the absolute exposures are too low. The previous dive profile may have a bearing on this, but in general the risk of neurologic toxicity limits the exposure. Some of the earliest symptoms is pain behind the breast bone and cough. Should paroxysmal coughing occur and become uncontrolled, the diver must surface.

There is a small but definite chance of pulmonary oxygen toxicity, especially if a long high exposure dive was the proximate cause. In this case, symptoms of chest discomfort or coughing would be present. Should this occur, 5-minute "air breaks" every 20 minutes may lessen or alleviate the symptoms. However, continuation of oxygen therapy is strongly encouraged, and air breaks should not be instituted without prior discussion with a diving medicine expert.

FOLLOW-UP CARE FOR A STRICKEN DIVER

Upon completion of the IWR protocol and safe return to the boat or remote shore, the stricken diver must be hydrated, be kept warm, and lay supine. Transport to the nearest hyperbaric facility for evaluation by a physician knowledgeable in hyperbaric medicine is required. The use of supplemental oxygen en route, if practical, is advisable. After three hours of surface oxygen, alternating one-hour periods with air is acceptable if symptoms have resolved. Cessation of diving activities is obligatory until evaluation by a physician trained in diving medicine.[6]

The stricken diver should be carefully monitored. The diver and all supporting documentation including dive profile, treatment profile and assessments, diver response, and any medical history as well as any interventions including first aid should be brought to the professional medical staff at the hyperbaric facility. Additionally, it is recommended that copies of all of the material stated above should be sent to the central database repository for IWR to gather data.

CONCLUSION

Divers who have DCS can present in many ways and may have a variable course. Caring for that diver entails diligence in the primary and subsequent evaluations, with awareness of the natural history of the disease. A well-executed plan for accurate diagnosis, aggressive hydration in the situational context, environmental management, and immediate use of oxygen will optimize the chances for better outcomes. Consider using IWR if the situation is warranted but know the contraindications. The placement of a person stricken with a poorly understood and potentially debilitating malady into a relatively hostile and uncontrolled environment[15] just may be the best thing you can do for him or her.

The decision to place a diver back in the water should be very carefully considered. The benefits of IWR should not be equated with recompression in a chamber at a medical treatment facility, and the risks may be substantially higher. With a chamber, additional resources are available to treat complications of DCS, and oxygen toxicity can be safely managed. In the case of IWR, the inherent isolation of the diver from other support requires serious consideration of risk versus benefit.

Though there are no data that would support definitive statements or guidelines, it is probably true to say that the milder forms of DCS do not justify exposure of the diver to the extra risk of IWR in order to achieve early recompression. At a workshop[12] convened to consider management of mild or marginal DCS in remote locations, it was agreed that such milder symptoms could be managed adequately without recompression. This is not to say that you would not recompress such a diver if a chamber was readily available, but the extra risks of IWR may not justified in such cases. Most importantly, the poorer prognosis of more severe symptoms recompressed after substantial delays would suggest that the benefits of immediacy of care offered by IWR may justify the risk in suitable divers. The injured diver must be able to participate in the recompression plan. This includes mental clarity

to properly evaluate his or her status, progress, and needs as well as communication with the tender and topside support. The diver must also be able to easily manage his or her airway and secretions.

It is the opinion of the authors and contributors that IWR has an extensive empirical evidence to justify its use in some circumstances. Properly equipped and trained teams caring for a diver with serious DCS should consider the victim's suitability for IWR. The recommendations herein are tools a physician can use to optimize the outcome of a diver with DCS when no chamber is readily available. Above all physicians should analyze the secondary consequences of all decisions. Finally they should know the risks the diver and person dealing with the DCS have assumed and try to do no more harm than good.

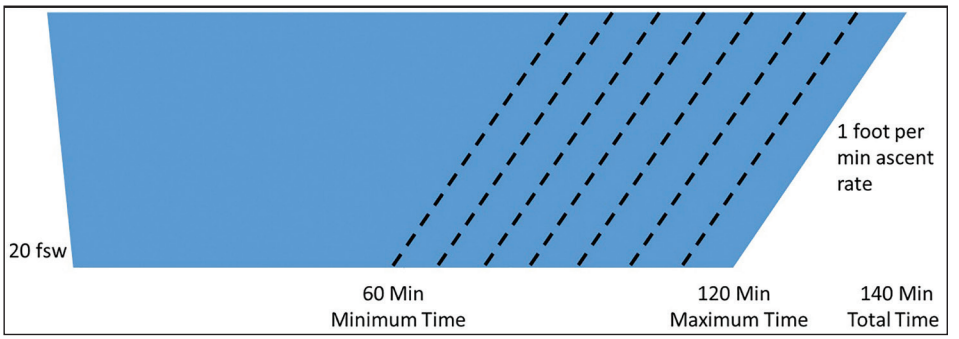


Figure 6. Graphical representation of consensus IWR table timeline that the authors feel is the newest and safer option for IWR.

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