THE EFFICACY OF USING A *HYPERLITE*™, HYPERBARIC STRETCHER FOR THE TREATMENT OF SERIOUS DECOMPRESSION ILLNESS: A CASE REPORT

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The risk of a scuba diver developing decompression illness (DCI) is viewed as an associated occupational hazard of compressed gas diving for the recreational, scientific, public safety and commercial diving industries. Each diving community has various techniques, procedures and approaches to help mitigate these risks in the diving populations they serve. If a diver is stricken by DCI or "the bends" and is not promptly and adequately treated, then that diver runs the risk of permanent medical or neurological deficit which could affect not only his/her future livelihood but also their quality of life. This paper explores the efficacy of the Hyperlite™, a portable "folding" hyperbaric stretcher, for field treatment of decompression illness. The deployment and use of this pressurization system is discussed in relation to an actual diving accident case where availability of a Hyperlite helped to mitigate and provide prompt therapeutic hyperbaric oxygen treatment (HBOT) to a diver suffering vestibular (inner ear) decompression sickness.

Introduction

In August of 2005, under the direction of the National Undersea Research Center at the University of North Carolina Wilmington (NURC/UNCW), a diving research expedition, supported with funding from NOAA's Office of Ocean Exploration (O.E.), was undertaken in the Thunder Bay National Marine Sanctuary (TBNMS; Figs. 1-3) as part of East Carolina University's (ECU) Diving and Water Safety Program. The expedition was aimed at documenting deep-water shipwrecks within the Sanctuary for NOAA.

TBNMS is located in the Northeastern corner of Michigan on Lake Huron and is home to more than 200 shipwrecks of which 50 have precise locations recorded. Thunder Bay became a national marine sanctuary in 2000, encompassing a 448-square-mile area of Lake Huron, and is now designated both as a national marine sanctuary and state underwater preserve.

The two week diving project focused primarily on two sites: an unidentified two-masted schooner located by Dr. Robert Ballard's Institute for Exploration in 2001 (tentatively identified as the *Corsican*) and the wooden passenger steamer *Pewabic*, which sank in 1865. Both wrecks rest in about 165 feet of water. Using mixed gas self-contained open circuit scuba diving techniques, the research diving team

created high resolution photomosaics of both sites, which served as baseline data for future documentation and monitoring.

Figure 1. Great Lakes Maritime Heritage Center - NOAA (Photo credit: D. Kesling)

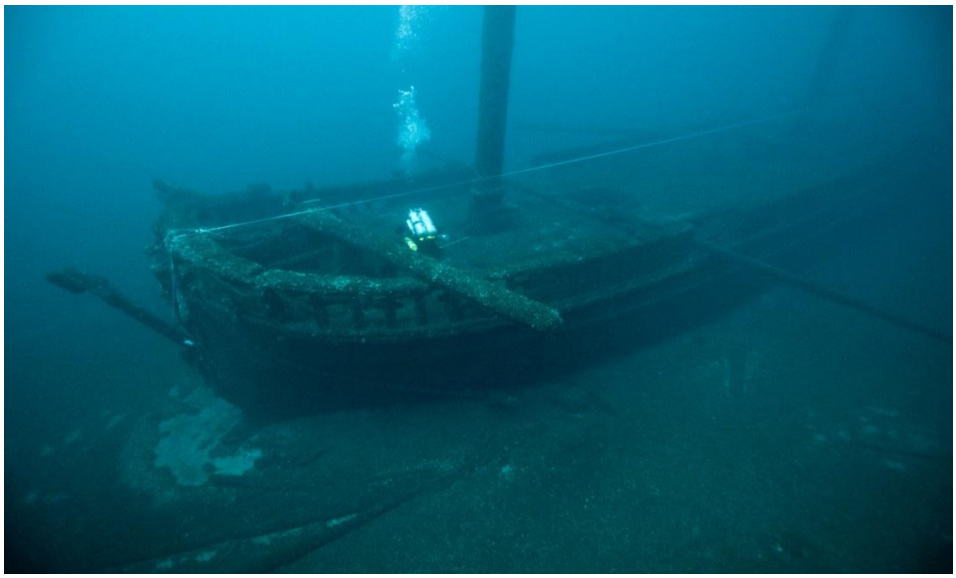

Figure 2. *Defiance* Shipwreck - TBNMS (Photo credit: D. Kesling)

During this field expedition, a diving incident occurred with one of the technical deep divers that required emergency, on-site hyperbaric oxygen therapy. Following diving protocols established by the NOAA Diving Program as outlined in the Report on NOAA's (2004) Diving Accident Management Program and Recommendations for Improvement, a recompression chamber was required within 30

minutes of the dive site for dives requiring decompression. To meet this mandate a *Hyperlite*™ Hyperbaric Stretcher (Fig. 4) was acquired by NURC/UNCW and allocated to the dive project. It had to be carried aboard the NOAA *R/V Huron Explorer*, a 12 m, ex-U.S. Coast Guard patrol vessel, in order to meet this 30-minute rule.

Figure 3. Diver 1 and unidentified shipwreck (Target 7) TBNMS (Photo credit: Joseph Hoyt /NOAA)

Figure 4. *Hyperlite*™ Hyperbaric Stretcher (Photo courtesy of SOS *Hyperlite*™; http://www.hyperlite.co.uk)

The SOS *Hyperlite*™ is a portable pressure vessel (or hyperbaric chamber) that provides immediate treatment for different medical conditions by supplying 100% oxygen to the patient above atmospheric

pressures during transport to a medical facility. The SOS *Hyperlite*™ Hyperbaric Stretcher and Treatment System (Fig. 5) significantly improves the chances of survival and full recovery, enhancing treatment and saving lives, even in the most extreme circumstances. Hyperbaric oxygenation is the treatment of choice for individuals suffering from decompression illness related maladies.

Figure 5. SOS *Hyperlite*™ Treatment System **(**Photo credit: Jitka Hyniova - NOAA Collection)

The SOS *Hyperlite*™ system can be assembled and operational within a matter of minutes to transport a patient to the nearest medical facility while breathing 100% oxygen under pressure. Alternatively, complete hyperbaric oxygen treatment (HBOT) can be performed at the accident site if necessary.

Background

The affected diver was a 46-year old male professional certified technical diving instructor. He had 10+ years of experience using mixed gas, open circuit, self-contained breathing apparatus at the time of the diving incident. With water temperatures averaging 42°F, full drysuits were utilized by all dive team members. Previous dives were conducted on 08/08, 08/10, 08/11 by Diver 1 (Table 1). All listed dives were incident-free without complications being reported post-dive.

Table 1. Diver 1 dive pre-incident profiles.

08/08	EANx 34	97 ffw (29.6m)	24 BT	31 TDT	100% 02 at 20 ffw (6m)
08/10	Trimix 22/36	161 ffw (49m)	24 BT	54 TDT	100% 02 at 20 ffw (6m)
08/11	Trimix 23/36	148 ffw (45.2m)	25 BT	52 TDT	100% 02 at 20 ffw (6m)

Emergency Assistance Plan

An emergency assistance plan (EAP) was developed for the TBNMS and approved by the NOAA Diving Center (NDC) for the regional dive location (NOAA, 2005). If an emergency situation were to arise offshore during the expedition, the Diving Supervisor would notify the Diver Medic (DMT) of the situation and take appropriate action to safely return the diver(s) to the R/V *Huron Explorer*. Once the

patient was stabilized on deck, the DMT would evaluate the patient and recommend an appropriate treatment regimen. With a medical standing order in place, the DMT would be allowed to act on certain treatment protocols without direct contact with medical control. The DMT would then contact the NURC/UNCW Diving Medical Advisor (DMA) for additional treatment recommendations and evacuation protocols when possible.

The initial treatment protocol steps (Fig. 6)

1. Perform a patient assessment and begin basic life support (BLS) if necessary;
2. Administer 100% oxygen via a positive pressure device or demand valve and check vital signs;
3. Conduct a five-minute neurological examination and/or a secondary assessment of injuries;
4. Apply direct pressure to bleeding wounds;
5. Stabilize the patient, monitor vital signs, conduct a more detailed neurological examination and prepare the patient for transfer to the onboard *Hyperlite*™ recompression chamber;
6. If the patient is weak or displays altered consciousness, try to start an IV with Normal Saline or Ringer's Lactate at a wide-open rate (500-1000 ml/hour); and,
7. Place patient in the *Hyperlite*™ hyperbaric stretcher or continue evacuation to the appropriate medical facility depending on nature of the illness, severity and established standing orders as outlined by the NURC/UNCW Diving Medical Advisor (DMA).

Figure 6. Mock-treatment with SOS *Hyperlite*™ (Photo credit: D. Kesling)

The Dive

Diver 1 made a 151 ffw (46 m) dive for 25 minutes with a 22/36/42 (O_2/He/N_2) mix (Fig. 7). He completed 31 minutes of deco with stops (Fig. 8) at: - Deep Stops 2 min - 104 ffw (31.7 m) & 77 ffw (23.5 m) (50 ffw/15.2 m - 1 min.); (40 ffw/12 m - 1 min); (30 ffw/9.1 m - 6 min); (20 ffw/6 m - 3 min); 100% O_2 (15 ffw/4.6 m - 16 min) surfacing on 100% O_2 on time according to plan. He entered the water at 10:52 and exited at 11:50. Following the dive, the diver returned to normal deck operations and served as dive supervisor for the next two dive rotations.

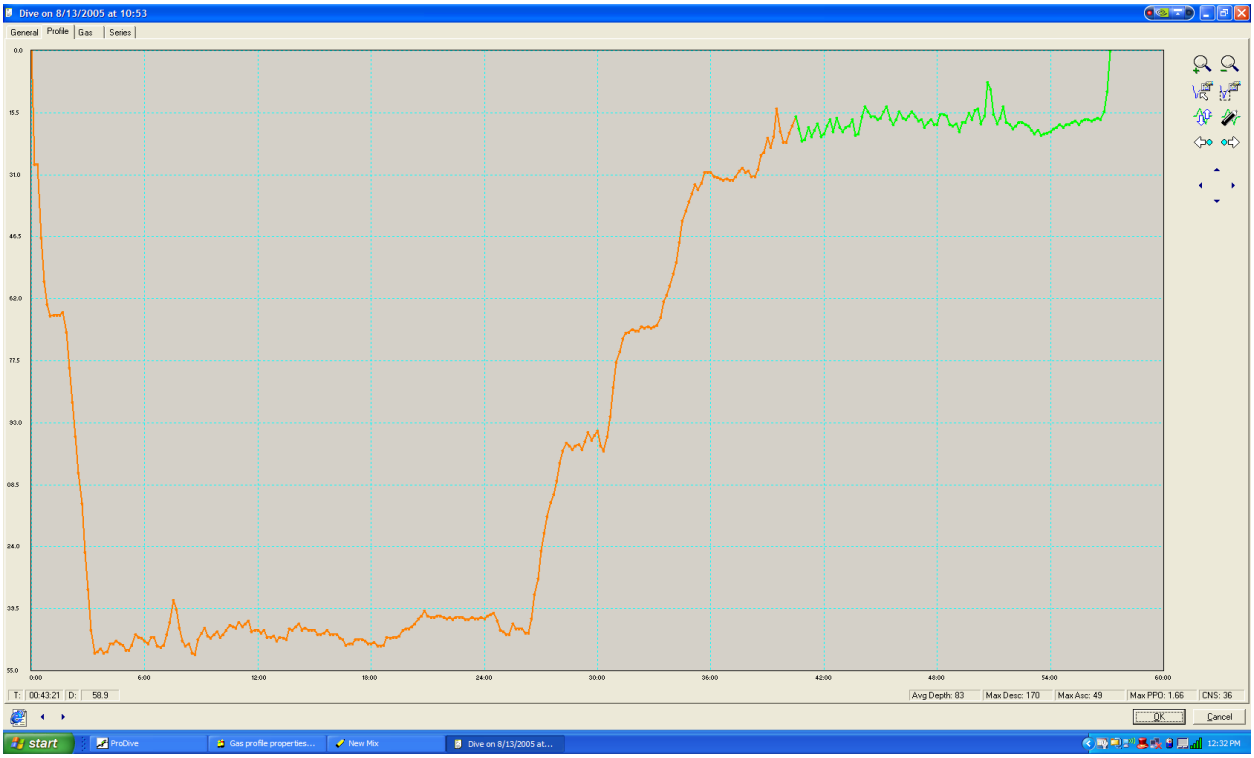

Figure 7. Diver 1 – Profile: VR3 Multiple mode/Multi-gas Dive Computer downloaded log (08/13/05)

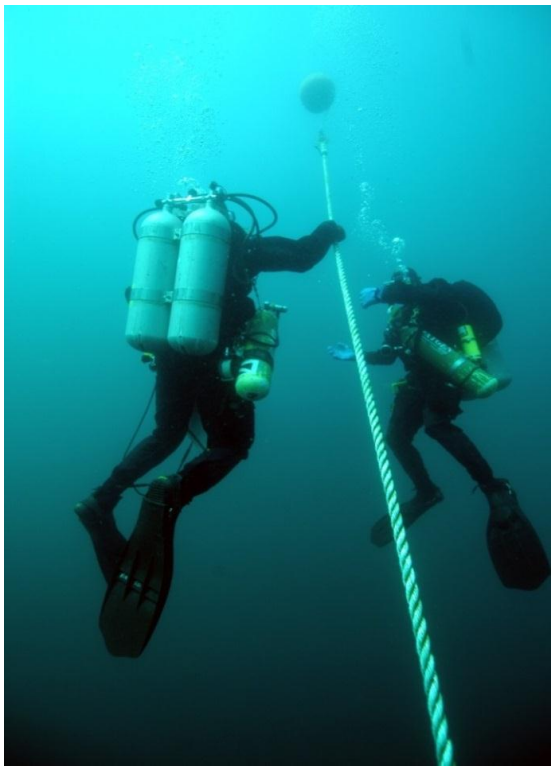

Figure 8. Staged decompression stop (Photo Credit: D. Kesling)

The Incident

At approximately 13:45, Diver 1 walked to the bow to check on the in-water ascending dive team but when he arrived was promptly struck by severe vertigo and nausea (Timeline of Events is presented in Table 2). He asked a fellow diver walking on deck to retrieve the oxygen kit and deliver it to him there on the bow. When it arrived, oxygen by demand valve was deployed and the stricken diver laid down while breathing 100% oxygen by double seal mask. Shortly after initial treatment began he became increasingly nauseous and commenced vomiting. In between bouts he continued to breathe 100% oxygen. A diver medical technician (DMT) arrived from the dive team at 13:50 and questioned the stricken diver to determine if there were other symptoms; Diver 1 reported there were none. He did report slight relief with 100% oxygen and the DMT decided that he should be placed in the *Hyperlite*™ Hyperbaric Stretcher. Given that a team of divers was still on the downline completing decompression, limited space on the vessel and the injured divers' progressing decompression illness, it was decided that treatment should start immediately after the divers were back onboard. While waiting for the rest of the dive team to surface the DMT instructed those remaining onboard to begin preparing the *Hyperlite*™ for treatment service. A brief neurological exam was conducted on the patient and no additional deficits found while vital signs were recorded by the attending DMT.

Inner Ear Decompression Sickness

Inner ear decompression sickness (IEDCS) is caused by the formation and growth of inert gas bubbles within micro vessels and otic fluids during ascent from a dive. This takes place when there is too rapid a drop in ambient pressure to a level lower than required to keep the gas in solution (Shupak et al., 2003). Signs and symptoms for IEDCS, or Vestibular DCS, include tinnitus, vertigo, nystagmus (rapid involuntary eye movements), hearing loss and associated nausea and vomiting. This is commonly called the "Staggers" because of the patient's unsteady, almost drunken gait (Ellerman, 2012). Staggers occur more often with heliox diving than air. The stricken divers' chief complaint was extreme dizziness and associated nausea and vomiting without any hearing loss complications.

Accident Management

Once all divers were back aboard the injured diver was placed in the *Hyperlite*™ at 14:35 and a U.S. Navy Treatment Table 6 (USN TT6) begun. The afflicted diver was returned to pressure at 2.8 ATA within approximately 45 minutes of initial presentation of the injury on deck. The mooring was dropped and the vessel began motoring slowly back to shore. Divers Alert Network (DAN) was notified of the treatment action and gave the attending DMT the location of the closest operational recompression chamber. While en route to shore DAN notified the local EMS for us. As the patient could tolerate it the vessel increased its cruising speed back to port. The patient reported slight additional relief at treatment depth but continued to vomit intermittently while inside the chamber. The patient tried to orally ingest as much water as possible. Some of this continued vertigo may have been induced by the vessels rolling action and/or the confinement within the small chamber. During the slide (ascent) from 60 ft/18 m to 30 ft/9.1 m, DAN was asked whether the DMT should extend treatment times at that depth as persistent symptoms were still present. The answer was *"No, continue treatment and get to the local hospital when finished* (pers.comm. Divers Alert Network). The R/V *Huron Explorer* reached the shore in approximately 90 min and the patient remained inside the chamber completing the entire USN TT6 on deck.

Hyperbaric Oxygen Therapy

Hyperbaric oxygen therapy (HBOT) was tested and developed by the U.S. military after World War I. Since the 1930s it has been safely used to help treat deep sea divers with decompression sickness.

Elevated atmospheric pressure in conjunction with intermittent 100% oxygen breathing combines to produce a number of beneficial effects that are poorly duplicated by breathing oxygen at sea level. Decompression illness bears out all the effects of Boyle's Law and of accelerated inert gas elimination, (Henry's Law) during oxygen breathing by creation of the oxygen window. HBOT involves breathing 100% oxygen in a sealed pressurized chamber. This oxygen concentration is five times higher than the ambient air normally breathed. The chamber is also pressurized to create 1.5 to 3 times our normal atmospheric pressure. These changes can improve blood circulation and its ability to deliver oxygen to the body and tissues.

Patient Transport

Once in the calm of the harbor the patient seemed to do much better. The weather was cool and overcast so there were no thermal concerns and a tarp was rigged over the *Hyperlite*™. Local EMS was standing by dockside when the vessel arrived and remained throughout treatment to receive the patient at its conclusion. At 19:45 he still reported some dizziness after reaching the surface and emerging from the chamber. He was transferred to the local EMS, examined, and taken by ambulance to the local area hospital at 20:05. The DMT rode along to help with any additional reporting of findings and to determine what the prognosis would be from the local ER doctor.

Follow-up and Medical Evaluation

A CAT Scan-Head, Chest X-ray and EKG were ordered, with a baseline medical examination performed by the ER doctor at 20:15. Intravenous fluids were administered to the patient. All findings for these three exams were normal. After initial evaluation the ER doctor concluded that this was not a case of DCS but merely an inner ear related positional/posture problem. The DMT suggested that the ER physician consult with Divers Alert Network (DAN) to discuss his working diagnosis. DAN referred him to Spectrum Health, a hyperbaric facility in Grand Rapids, Michigan, whose on-call physician informed the ER doctor at 21:00 that this was indeed a case of DCI needing prompt, follow-up HBO treatment. Ambulance transport was ordered and dispatched with the diver taken to Grand Rapids that evening at approximately 22:55. Intravenous fluids were administered to the patient to reverse his dehydration while en route to the chamber facility.

The patient was admitted to Spectrum Health in Grand Rapids and received three follow-up HBO treatments in an attempt to wash out any residual inert gas and aid in his full recovery, hence improving the prognosis of his inner ear DCI insult. He tolerated all the retreatments well and noticed slight improvement with each one.

Table 2. Timeline of Events

08.13.05 – Day 1
10:52 - Diver 1/Diver 2/Diver 3 start dive
11:50 - Diver 1/Diver 2/Diver3 on surface
13:45 - Diver 1 reports possible DCS event/starts 100 % oxygen breathing via demand valve
13:50 - Neurological examination/vitals taken by Diver Medic (DMT)
14:35 - Treatment started – Compression in *Hyperlite*™ to 60 fsw/18.2m (Treatment #1) USN TT6
19:45 - Treatment concluded. Still minor dizziness
19:55 - Diver 1 released to local EMS, transported to Alpena, Michigan regional hospital
20:05 - Arrival at Alpena Hospital, Alpena, Michigan
22:55 - Diver 1 departs for Grand Rapids, Michigan via ground ambulance evacuation

08.14.05 – Day 2
03:00 - Diver 1 arrives at Spectrum Health - Grand Rapids, Michigan

08:00 - Diver 1 reports that the HBO facility will run a USN T6 at 09:15. Little change occurred from the previous evening
09:00 - Start USN TT6 on Diver 1 (Treatment #2) in a mono-place chamber
15:00 - Diver 1 reports little change after treatment. "Feels 99%" but still afflicted by slight dizziness with nystagmus

08.15.05 – Day 3
Diver 1 will meet with the hyperbaric physician at 07:00
Diver 1 receives HBO treatment of (USN TT 5) on 100% O_2 - (Treatment #3)

08.16.05 – Day 4
Diver 1 receives HBO treatments of (USN TT 6) on 100% O_2 - (Treatment #4)

08.17.05 – Day 5
Hospital discharge

Post-incident review and dive operation continuance

The NOAA Diving Program (NDP) Manager was informed of the situation and subsequent on-site accident mitigation and reporting. After careful consideration, NOAA's Diving Safety Board (NDSB) approved continuation of dive operations at the Thunder Bay National Marine Sanctuary. A NURC/UNCW dive supervisor imposed a 20% safety factor to be programmed into VR3 dive computers for all divers and all further diving operations. This, in effect, produced the equivalence of the *Cold and Arduous Diving Rule* using the next greater depth table to calculate decompression obligations as prescribed by U.S. Navy Air Decompression Tables. At the start of the project it was felt that this rule would not be necessary as divers would be wearing adequate thermal protection under their drysuits and the diving activity would be relatively easy with no water currents or sea states to contend with. NDP gave no indication that an additional safety factor should be added during its review of the initial dive operations plan. However, in light of the recent decompression illness incident, the dive management team felt it prudent to impose this additional safety factor for in-water decompression diving on mixed gas. The recovering diver rejoined the operation and returned to a topside support role aboard the vessel for the remainder of the mission.

Lessons Learned

- It is important to have a pre-mission set-up and demonstration of the system with a mock casualty drill to familiarize the dive team with deployment and operation of the *Hyperlite*™ system in event of a diving accident (Fig. 6). In most cases this will require 3-4 individuals to complete chamber set-up and to initiate treatment.
- A 41 ft/12 m research vessel is probably the smallest craft of opportunity capable of accommodating deployment of the *Hyperlite*™ system on deck.
- Carry more gas supplies than are recommended by the manufacturer and U.S. Navy guidelines. The USN TT 6 required three times the volume of gases recommended as the minimum in the U.S. Navy Operations Manual. Recommended: Compressed air: 174 scf; Carried: 240 scf; Required: 320 scf. Recommended: 100% Oxygen: 210 scf; Carried: 250 scf; Required = 300 scf.
- Chamber supplies for a patient should be standing by and include: a towel, bottled drinking water, a urinal, an emesis bag and patient clothing-gown.
- Appropriate sun screen/shelter apparatus for overhead cover of the chamber unit. The manufacturer does not recommend use of the chamber in direct sunlight; chamber temperature and patient comfort can then become an issue.
- Initiate treatment promptly to improve therapeutic results of HBOT. Once initiated, complete the prescribed treatment tables for improved patient outcome unless transfer under pressure can be

accomplished to a multi-place chamber system. Consider treatment table extensions if the patient is well-hydrated.
- Develop a load list for deployment which includes all components of the *Hyperlite*™ system including compressed gas cylinders, two travel cases, operators console, medical supplies, patient stretcher and chamber clean-up kit.
- Be prepared for patients to refuse treatment against medical advice (AMA) because of the constraints/size of the *Hyperlite*™ system.

Post Treatment Outcome

Upon patient discharge, the attending hyperbaric physician at Spectrum Health set a minimum of six weeks for Diver 1 to return to active diving status and then only after a follow-up evaluation with a diving medical officer (DMO).

Recovery and Follow-up

On October 14, approximately eight weeks post-incident, the diver underwent a follow-up medical exam and return–to-diving evaluation at Duke University Medical Center with Richard Moon, MD as the attending physician for the examination and consultation. He ordered a series of tests that were performed at the F.G. Hall Hyperbaric Center, including:
- Audiological evaluation (dB hearing test). Findings: Mild to moderate high-frequency hearing loss (consistent with noise-induced hearing loss)
- Vestibular – ENG with caloric stimulation. Findings: ENG within normal limits without spontaneous or positional nystagmus
- Physical Examination: Normal
- Neurological Examination: Normal

Based on the physical and laboratory findings above by Dr. Moon, limited return to diving status recommendations were issued for Diver 1 for a period of twelve months with:
- Use of enriched oxygen breathing gases on the bottom phase and high O_2 mixtures/100% O_2 as appropriate during decompression;
- Decompression procedures should be as conservative as feasible and practical;
- There is no reason to avoid air saturation diving; and,
- Restriction in the use of helium in the diver's breathing gas.

Diver 1 resumed both air and nitrox diving, conducting approximately 150 dives with minimal in-water decompression using 100% oxygen at all 20 ft (6 m) and 15 ft (4.6 m) decompression stops. During this twelve-month period, the diver did not experience any reoccurrence of DCI symptoms. In August of 2006, one year post incident, Diver 1 contacted Dr. Moon for consideration of a full return to diving status with planned mixed gas dives to 150 - 170 ft (45.7 - 51.8 m). Dr. Moon approved the use of helium as a breathing gas but felt that diving without close chamber availability would not be in the diver's best interest. If an on-site chamber could not be arranged he recommended that a shore-based chamber be located within 30 minutes of the dive site. Based on these recommendations, a chamber system was allocated to all diving operations that used helium as a breathing gas requiring in-water decompression stops. Diver 1 is still an active scientific diver within an approved diving program.

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